APPLICATIONS OF WELDING TECHNOLOGY

Soundra Prashanth
Sanjeet Kumar

ALEXIS PRESS
JERSEY CITY, USA

APPLICATIONS OF WELDING TECHNOLOGY

APPLICATIONS OF WELDING TECHNOLOGY

Soundra Prashanth
Sanjeet Kumar

ALEXIS PRESS

ALEXIS PRESS

Published by: Alexis Press, LLC, Jersey City, USA
www.alexispress.us

First Published 2022

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication Data

Includes bibliographical references and index.

Applications of Welding Technology by *Soundra Prashanth, Sanjeet Kumar*

ISBN 978-1-64532-480-5

CONTENTS

CHAPTER 1

MONITORING AND CONTROL OF WELDING AND JOINING PROCESSES

Mr. Soundra Prashanth, Assistant Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: prashanth.sp@presidencyuniversity.in

ABSTRACT:
In particular, resistance spot welding and arc welding techniques are covered in-depth in this chapter's discussion of the various approaches available for monitoring assembly and joining processes. Using examples from the assembly of automotive bodies, it provides ways for monitoring assembly operations. Two different assembling procedures exist. Type I assemblies are made up of machined or molded pieces whose matting characteristics have already been completely defined by their separate manufacturing processes before being put together, such as when a peg is put into a hole. Type II assemblies are those in which some, all, or specific positions for some assembly features are established during assembly. The primary control factors, such as the fixturing and joining procedures, can be used to monitor an assembly process. Resistance welding is a highly common joining method used in the production of goods including cars, furniture, and appliances.

KEYWORDS:

Arc, Control, Current, Data, Flow, Process, Sensors, Variable, Welding.

INTRODUCTION

To create high-quality welds, many welding operations depend on a trained operator to monitor and manage the process. Weld placement, weld joint tracking, weld size control, and control of the weld pool are just a few of the nuanced duties that human operators handle quite easily. This delicate understanding of the process is lost when mechanized process control technology replaces human welders or operators in the welding process control role. However, the need for real-time process monitoring and control continues to be driven by the demands for more productivity and better quality, a greater emphasis on statistical process management, and a desire to remove the operator from the challenging welding environment[1]–[3].

Real-world use of automatic controls is severely hampered by the challenges of measuring and manipulating process variables in real-time. The variables that negatively affect the finished weldments' qualities can alter since welding operations are complex. At the point where a process is applied, the environment can be very hostile. High electric and magnetic fields, severe electromagnetic radiation, molten metal splatter, and fumes are frequently present. To gather physical data regarding the welding process, sensors must be utilized. Once the right sensor has been chosen, the process variables can be recorded and shown using a monitoring device. A process monitor can also be used to compare the sensor's output to predetermined parameter limits concerning these variables and sound an alarm when the measured value exceeds these limits.

Process control differs from process monitoring in that changes are made automatically during the welding process to fix a variable that has diverged from the target value. The fundamental ideas and practical uses of sensors, monitors, and controls in welding operations are covered in this chapter. The principles underlying process sensing, monitoring, and control are covered in the first section. The use of sensors, monitors, and process controls is then discussed in sections about friction welding, brazing, arc, resistance, laser, and electron beam processes.

Principles of monitoring and control

The four fundamental control elements can be used to define welding operations. The actual welding procedure, the controlled input parameters, unsettling input parameters, and process response parameters. The fundamental welding process, as shown, uses energy and mass inputs to create an output weld with the appropriate geometry and mechanical and microstructural properties.

Manipulated Input Variables

The process response variables are those that are immediately impacted by the altered input variables. As an illustration, more energy leads to greater penetration (see below). the altered input parameters might be predetermined before the welding operation begins or changed after it has begun. In resistance welding, preset variables can include welding current, duration, and force, and in gas metal arc welding, voltage and wire feed speed. Arc length, travel speed, electrode position, and angle are additional input variables that can be manually changed during welding for arc welding procedures.

Disturbing Input Variables

Unwanted or unavoidable changes in variables that affect the process yet are typically uncontrolled are referred to as unsettling input variables. Instabilities in sheet thickness, particularly in resistance spot welding, changes in weld joint size and location in arc welding, and changes in the joint gap in brazing are a few examples of unsettling input variables.

Process Response Variables

The welding process's byproducts, such as the real current, voltage, travel speed, and cooling rate, are what make up the process response variables. desirable weld characteristics, including soundness, microstructure, size, and shape. Since there are currently no sensors for the in-situ measurement of mechanical properties or weld microstructure, it is impossible to directly feel the majority of process reaction variables for conventional welding operations. Thus, indirect measurements of more useful control variables, such as temperature, weld profile, weld size, penetration, and radiation, are frequently carried out.

Sensing Devices

A sensor is essentially a transducer that transforms a property from one physical form to another, frequently into an electrical signal. Process sensors for welding translate physical phenomena from the input and process response variables into signals that can be used by monitoring or control equipment to learn about the welding process. It is frequently necessary to perform signal conditioning, amplification, and isolation before feeding sensor output into a monitor or controller.

Sensors might have a straightforward or intricate design. Simple sensors include thermocouples, which convert temperature into a voltage signal, and current shunts, which change the current running through the welding circuit into a proportionate voltage. Complex sensors are made up of numerous separate sensors that work together. The robotic arc welding system's machine vision sensor serves as one illustration. Including a video camera (a transducer that transforms light intensity into a video signal), a video signal digitizer, and a computer that extracts data from the video image, this sensor is a full subsystem. Machine vision sensors offer data on the location and geometry of weld joints as well as the size and shape of weld pools; these sensors are covered in more detail later in this chapter. Compared to other sensors, some sensors are better suited for use with particular welding processes due to their physical and operational properties.

For instance, direct measurements of the process variables are preferred to indirect measurements, hence it is preferable to use sensors that provide direct measurements. Sensing equipment that needs to be in direct contact with the process or weldment is less preferable than equipment that doesn't. Additionally, sensors that can be applied from the weld's face are preferable to those that need access to the weld's interior or back. Overall, it is highly desired to have sensors that can be used in numerous operations.An overview of the typical physical characteristics related to welding processes is provided together with the accompanying sensors and measured units. More information on these physical characteristics and associated sensing tools is provided below.

Time

Time, the quantifiable length of an event, is typically expressed in minutes or seconds. Arc welding can be divided into several events upslope time, downslope time, weld time, and overall arc time. The period during which the current constantly transitions from the starting current to the welding current is known as the upslope time. The weld time is the time between the upslope time's conclusion and the downslope time's start. The period known as the "downslope" is when the current is continuously changed from the welding current to the final current. The length of time that a welding arc is maintained is known as the total arc time. Other welding techniques, such as resistance welding, are similarly divided into discrete time-measurable periods. Time in resistance welding is frequently expressed as the quantity of alternating current cycles per second (Hz) at 60 hertz (Hz).

Temperature

For measuring temperature, a wide variety of transducers are available. These include optical sensors, resistive-temperature instruments, thermocouples, and thermistors. photon detectors, pyrometers, and thermal imaging devices. It is possible to use thermocouples, thermistors, and resistive temperature sensors only as contact sensors or as a component of more sophisticated noncontact sensors.Thermopiles, bolometers, and radiometers are a few examples of the latter, which measure radiant thermal energy. The temperature range between room temperature and is often measured by the temperature sensors most frequently used for welding applications[4]–[6].The research work already done in this particular field has to be discussed here, in this specific section.

DISCUSSION

Photon Detector and Thermal Imaging Camera

By producing a voltage proportionate to the density of the photon flux impinging on the sensor, photon detectors may estimate temperature. Thermographic cameras are infrared radiation sensitive. They are used to monitor temperature distributions more intricately and for temperature sensing.

Force

The idea behind force sensors is that a body would bend in direct proportion to the amount of applied force. Measuring the physical is an indirect way to determine the force deformation.

Load cell sensors

A structure (a cantilever beam, shear beam, diaphragm, proving ring, or column) that deforms in response to a force makes up the load cell sensor. An electrical signal corresponding to this deformation is produced by a network of strain gauges. The physical size restrictions of the sensor and the maximum force to be applied are the main factors that influence the choice of the structural element.

Other Force Sensors

The piezoelectric, linear variable differential transformer (LVDT), and capacitive force sensors are further force sensors.

Pressure

Pressure sensors track the distortion that results from applying pressure to a flexible material. Through the measurement of displacement, strain, or piezoelectric response, they transform this distortion into an electrical signal.

Displacement and Diaphragm

Bourdon tubes are used as the elastic element and LVDTs as the sensor in displacement-type pressure sensors. The oval cross-section of the C-shaped Bourdon tube tends to straighten as internal pressure is applied. The tube has a fixed one end and an unfixed other end. The LVDT converts the displacement of the free end into a voltage as pressure is applied to the Bourdon tube. Diaphragm-type pressure sensors use electrical resistance strain gauges as the sensors and either a clamped circular plate (diaphragm) or a hollow cylinder as the elastic element. The diaphragm deforms under increased pressure, changing the resistance of the strain gauges.

Piezoelectric-Type Pressure Sensor

A piezoelectric crystal serves both the elastic component and the sensor in piezoelectric-type pressure sensors. The crystal is contained in a thin, cylindrical shell. On one end, a sturdy support platform for the crystal serves as a pressure-transmitting diaphragm. An electrostatic charge is created as pressure is applied to the face of the crystal that is in contact with the diaphragm. The pressure, crystal size, and axis orientation are all factors that affect how much charge is present.

Flow Rate

Determining the amount of flow of a liquid or gas (such as cooling water or shielding gas) is the goal of flow rate measurement. There are times when a flow The signal is typically derived from some aspect of the flow, such as volume, heat transfer rate, or momentum flux, although the meter can also return this data directly.

Before the flow rate can be calculated, the flow meter signal must typically be corrected for pressure, temperature, or viscosity. Numerous physical principles can be used to measure flow. The majority, nevertheless, can be categorized as measurements of volume or mass flow rate.

Differential Pressure Flow Meters

The instruments that are most frequently used to measure flow volume are differential pressure flow meters. When the flow path is restricted, a corresponding fluid's pressure and speed are changing. Pressure gauges can be used to measure the pressure difference. The Venturi meter, flow nozzle meter, orifice meter, and elbow meter are examples of differential pressure flow meters.

Mechanical Flow Meters

The flow volume or rate triggers mechanical flow meters, which are positioned in the flow route. The most popular kind of mechanical flow meter is the turbine flow meter. A multibladed rotor suspended in the flow with its axis of rotation parallel to the flow direction makes up this meter. The blades are impacted by the flow, which causes them to rotate with angular velocity proportionate to the flow rate. Numerous speed-sensing methods can be used to measure the turbine's rotational speed.

Electric Current

Common current-sensing tools include the Rogowski coil, the Hall-effect current sensor, and the current shunt.

Current Shunt

A resistor with a tiny, precisely measured resistance value serves as the current shunt. The voltage output across the shunt is proportional to Ohm's law, which states the flow of the current. The current shunt has the benefit of being reasonably priced. The millivolt output from the shunt may need to be increased in some applications, though, to make it compatible with a monitoring or control device. The current shunt's electrical connection to the welding power circuit is a drawback. The voltage of the shunt is relative to the ground may damage the connected device or result in inaccurate readings if suitable signal conditioning and electrical isolation are not provided.

Hall-Effect Current Sensor

The Hall-effect current sensor is a piece of technology that measures the strength of the magnetic field generated by the flow of current to infer current. Simple clamping is used to encircle the conductor carrying the current via the probe. The Hall-effect gadget has the distinguishing advantage that no electrical contact with the power circuit is necessary. However, compared to the current shunt, the Hall-effect current sensor is substantially more expensive.

Rogowski Coil

In resistance welding, a Rogowski coil is a tool for measuring alternating current. It is made of wire that is tightly wound around a uniform belt that conducts no electricity. sectional view. The conductor carrying the current from the resistance weld is then encircled by the belt.

The coil's output voltage is inversely proportional to the current's rate of change. The root-mean-square (RMS) current, peak current, waveform, and the percentage of time the current was on during each half cycle during the weld are all outputs that may be obtained from several commercially available coil/integrator combinations. The Rogowski coil, like the Hall-effect sensor, does not disrupt the conducting circuit, making it a non-intrusive current measurement tool. Figure 1 displays a typical Rogowski coil and meter combo.

Figure 1 Rogowski-Type Current Sensing Coil and Meter Combination

Process Instrumentation

Instruments used in the welding process use one or more sensors to gather and display data on the variables involved in the welding process. several groups of It is possible to use instrumentation technology with welding procedures. These consist of process monitoring systems, data displays, data recorders, and data loggers. The signal from a sensor is converted into engineering units via data displays, which might be analog or digital meters or gauges that show the results. The majority of welding apparatuses come with one or more built-in data displays, such as those that show voltage, current, and wire feed rate.

Data Recorders and Loggers

Analog devices called data recorders allow the storing and showing of process data as a function of time. Strip chart recorders and oscilloscopes are data recorder illustrations. Unlike data recorders, which convert analog sensor signals into digital format before processing the information with digital computer technology, data loggers convert analog sensor signals into digital format.

Process Monitoring Systems

Welding process monitoring systems are computer-based tools with extensive data processing power as well as data storage and gathering capabilities. This ability to process data may involve statistical analysis, sophisticated signal filtering, and limited decision-making. A system for monitoring the welding process, for instance, can compare measured data to predetermined limitations. To notify the operator or stop the process, the monitor sounds an alarm when a threshold value is surpassed. Some monitors can gather and store data for many welds, enabling offline trend analysis of the welding process[7]–[9].

Process Control Systems

A process or piece of equipment is controlled by a controller or control system to deliver the intended result. Typically, controllers manage the process's order of steps.In the case of robotic or automatic equipment, motion; numerous schedules; variables; and other specialized control functions. They are utilized across the factory at every level. A supervisory controller may, at the highest level, oversee all aspects of an entire welding manufacturing line. A robotic controller controls the motion of a welding robot arm at a lower level.

The word "controller" can also refer to one of several welding system components. A resistance weld's current, force, and time may all be controlled by an open-loop controller at the most basic level. The closed-loop feedback control built into welding equipment to regulate welding variables like the current or wire feed speed may be considered a slightly higher level.Process control, as defined in this chapter, refers to the real-time regulation of one or more welding process control variables. The most comprehensive classification divides control systems into the two basic categories of open-loop and closed-loop control. Feedforward or feedback control are additional categories for closed-loop control.

Open-Loop Control

The process response variables cannot be measured by an open-loop system, and as a result, the process cannot be adjusted using these variables. to follow the desired result. Figure 2's block diagram serves as an example of an open-loop process control system.

A semi-automatic arc welding process wire feeder is an illustration of open-loop control. The welding equipment controller is tuned to the required wire feed speed. The controller can't detect that the process output may have varied from the desired value if any unsettling input affects the process. For instance, the controller is unable to detect whether a welding torch obstruction reduces the wire feed speed below the controller-set value. Open-loop control requires the elimination of process disturbances by pre-weld preparation, fitting and featuring, or equipment maintenance to govern a welding process effectively.

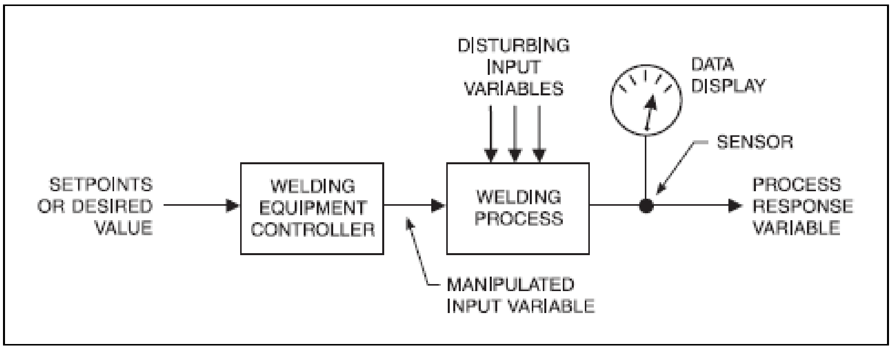


Figure 2 Open-Loop Control of the Welding Process.

Closed-Loop Control

The controller needs knowledge of the process inputs to keep the process output at the intended level despite the impact of disruptive inputs. current status of the procedure. The process control loop must be closed, in other words. Sensing, a process model, and control strategies are the three components that make up the implementation of a closed-loop control system. Sensing, the first of these components, has already been covered.During welding, a sensor that gives data on the process response variables is used to implement closed-loop feedback control. Figure 2 depicts this kind of setup. An illustration of feedback control is arc voltage control. As the desired arc voltage is attained, the height of the welding flame about the weldment is adjusted to change the arc length. The closed-loop system is referred to as a feedforward control if a sensor offers information about disturbances that are about to influence the process, such as those brought on by upsetting input variables. When welding with an arc or electron beam, joint tracking is an illustration of feedforward control. In this situation, the sensor issues corrective movement directions to maintain the correct joint alignment when it notices that the torch or beam's trajectory is veering away from the weld joint's centerline before the point of welding.

The controller can be created using traditional control techniques and empirical or analytical models when the input-output relationship of a process can be mathematically modeled or precisely defined by measuring the output response due to changes in input variables. Artificial intelligence approaches like fuzzy control may serve as the foundation for a controller if the process is complex and only a few input-output pairs of process data can be acquired. There are also hybrid control systems that mix conventional and artificial intelligence methods.

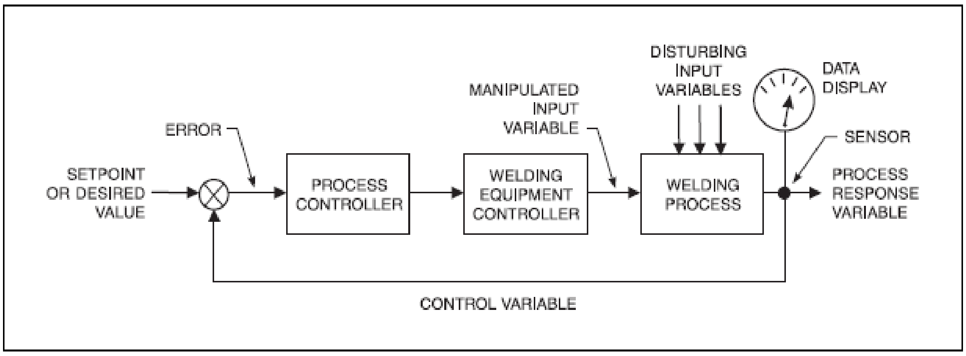


Figure 2 Closed-Loop Feedback Control of the Welding Process

According to formal control theory, adaptive control uses a controller that has the flexibility to alter how it behaves in response to functional shifts in the process it is controlling.Adaptive control is described as " process control that automatically determines changes in welding conditions and directs the equipment to take appropriate action" in the American National Standard Standard Welding Terms and Definitions, A3.0:2001. Consequently, adaptive control can be used with a variety of welding process control strategies because it is just closed-loop control.

Monitoring and Control systems

Process monitoring and control systems come in a wide variety of forms. The following approaches are all either commercially accessible, undergoing continuing investigation as a possible product, being developed as a commercial product, or being created by a specific manufacturer for use in their manufacturing. The monitoring and control systems discussed below are divided into groups based on the welding process. Arc welding, resistance welding, laser beam welding, electron beam welding, friction welding, and brazing are the procedures that are covered.

Control of Basic Process Variables

Even though all arc welding systems use some type of open-loop control, closed-loop control has become more popular, especially with extremely automated procedures. In this part, techniques that are often used are covered, including joint finding and joint tracking for robotic gas metal arc welding and arc length control for gas tungsten arc welding. Recent ideas like metal transfer mode control and weld shape control are also covered. For semi-automated, mechanized, and automatic arc welding operations, arc welding equipment is provided that offers closed-loop control of one or more process variables. With the aid of the proper sensors, it is possible to manage the welding current, voltage, shielding gas, and wire feed speed to set limitations on these variables' actual values. A block diagram of this kind of control is shown in Figure 2.

Additionally, closed-loop control of the welding speed, arc-on time, shielding gas flow rates, as well as the preheating and temperatures of the weldment, can be achieved using automated and mechanized welding equipment[10]–[12].

CONCLUSION

To ensure high-quality welds and joints, welding and joining processes must be monitored and controlled. Due to the intricate interactions between multiple process factors and the material being welded or joined, welding and joining operations can be difficult to regulate.

A thorough understanding of the process variables, such as the material being welded or joined, the welding or joining method, and the ambient conditions, is necessary for the effective monitoring and control of welding and joining operations. Utilizing the proper sensors and measurement equipment is also crucial for keeping track of crucial process variables like temperature, pressure, and weld quality.

Automated monitoring and control systems can greatly enhance the effectiveness and consistency of welding and joining processes, lowering the possibility of errors and boosting output. Human operators continue to be essential in making sure that the welding and joining operations are set up, monitored, and regulated correctly.

REFERENCES

[1] I. Balz *et al.*, "Process monitoring of ultrasonic metal welding of battery tabs using external sensor data," *J. Adv. Join. Process.*, 2020, doi: 10.1016/j.jajp.2020.100005.

[2] D. Mishra, R. B. Roy, S. Dutta, S. K. Pal, and D. Chakravarty, "A review on sensor based monitoring and control of friction stir welding process and a roadmap to Industry 4.0," *Journal of Manufacturing Processes*. 2018. doi: 10.1016/j.jmapro.2018.10.016.

[3] J. Zhao, H. Li, H. Choi, W. Cai, J. A. Abell, and X. Li, "Insertable thin film thermocouples for in situ transient temperature monitoring in ultrasonic metal welding of battery tabs," *J. Manuf. Process.*, 2013, doi: 10.1016/j.jmapro.2012.10.002.

[4] R. Shotri, K. Faes, and A. De, "Magnetic pulse welding of copper to steel tubes–Experimental investigation and process modelling," *J. Manuf. Process.*, 2020, doi: 10.1016/j.jmapro.2020.07.061.

[5] Y. M. Zhang, Y. P. Yang, W. Zhang, and S. J. Na, "Advanced Welding Manufacturing: A Brief Analysis and Review of Challenges and Solutions," *J. Manuf. Sci. Eng. Trans. ASME*, 2020, doi: 10.1115/1.4047947.

[6] J. Zeng, B. Cao, and R. Tian, "Quality monitoring for micro resistance spot welding with class-imbalanced data based on anomaly detection," *Appl. Sci.*, 2020, doi: 10.3390/APP10124204.

[7] H. Li *et al.*, "Transient temperature and heat flux measurement in ultrasonic joining of battery tabs using thin-film microsensors," *J. Manuf. Sci. Eng.*, 2013, doi: 10.1115/1.4024816.

[8] S. G. Rahul and A. Sharmila, "Fundamentals and review on material science, control theory and parametric inter-dependencies during friction stir welding of aluminium metal matrix composites," *World Journal of Engineering*. 2019. doi: 10.1108/WJE-03-2019-0093.

[9] T. Prater, "Friction stir welding of metal matrix composites for use in aerospace structures," *Acta Astronaut.*, 2014, doi: 10.1016/j.actaastro.2013.07.023.

[10] X. R. Li, Z. Shao, Y. M. Zhang, and L. Kvidahl, “Monitoring and control of penetration in GTAW and pipe welding,” *Weld. J.*, 2013.

[11] O. J. Bakker, C. Gibson, P. Wilson, N. Lohse, and A. A. Popov, “Linear friction weld process monitoring of fixture cassette deformations using empirical mode decomposition,” *Mech. Syst. Signal Process.*, 2015, doi: 10.1016/j.ymssp.2015.02.005.

[12] R. Hamzeh, L. Thomas, J. Polzer, X. W. Xu, and H. Heinzel, “A sensor based monitoring system for real-time quality control: Semi-automatic arc welding case study,” 2020. doi: 10.1016/j.promfg.2020.10.029.

CHAPTER 2

AN ANALYSIS OF RESIDUAL STRESS AND DISTORTION

Dr. Bolanthur Vittaldasa Prabhu, Professor,
Department of Mechanical Engineering, Presidency University, Bangalore, India,
Email Id: bvprabhu@presidencyuniversity.in

ABSTRACT:

In-plane welding distortion includes transverse shrinkage, longitudinal shrinkage, and rotational distortion. Out-of-plane welding distortion includes buckling, longitudinal bending (bowing), and angular change. There are various techniques for reducing welding distortion; some can be used while welding, while others work best after welding. It is essential to determine the distortion mode of a specific structure before choosing the best distortion mitigation strategy because some methods may lower one distortion mode while increasing another. The critical buckling stress of the plate must be raised, the welding residual stress must be decreased, or the residual stress after welding must be modified to ensure that the compressive longitudinal residual stress is less than the critical buckling stress of the plate. Usually, back-side heating, constraints, or presetting are used to reduce angular distortion. Bowing distortion, also known as camber distortion, is managed by either lowering the welding heat input or distributing the welding residual stress evenly across a structure's cross-section to reduce the bending moment.

KEYWORDS:

Distortion, Distribution, Fracture, Residual, Residual, Weld, When, Welds.

INTRODUCTION

Weld residual stress occurs in a variety of ways, and the distribution of each type is highly intricate. Stress is examined in this chapter in both single- and multiple-pass welds and investigates how different variables interact to change how much stress is present in welds. The methods used to forecast distortion are also covered here because distortion in weldments affects how well they will function. The numerous methods for reducing or controlling residual stress and distortion in welds are thoroughly discussed in the final section. The discussions offered in this chapter almost entirely focus on residual stress and distortion in welds made using arc welding methods, which are the subject of the majority of literature published on the issue. The residual stress in titanium 8Al-1Mo-1V alloy spot welded joints is discussed in very little detail. Weld residual stress occurs in a variety of ways, and the distribution of each type is highly intricate. This chapter addresses the different factors that interact to either raise or decrease the magnitude of stress in welds and gives an analysis of stress in single-pass and multiple-pass welds [1]–[3].

The methods used to forecast distortion are also covered here because distortion in weldments affects how well they will function. The numerous methods for reducing or controlling residual stress and distortion in welds are thoroughly discussed in the final section. The discussions offered in this chapter almost entirely focus on residual stress and distortion in welds made using arc welding methods, which are the subject of the majority of literature published on the issue. The residual stress in titanium 8Al-1Mo-1V alloy spot welded joints is discussed in very little detail.

Fundamentals

Most welding procedures involve localized heating of a weldment; as a result, the temperature distribution within the weldment is not constant, and structural and the welding moves along a joint, and metallurgical change happen. The temperatures of the weld metal and the heat-affected zone next to it are often much higher than those of the base metal that is unaffected. The surrounding weld metal and heat-affected zones start to experience stress as the weld pool solidifies and contracts. Since the weld metal is hot and relatively weak when it first solidifies, there is little tension on it. However, as the weld cools to room temperature, the tension in the weld area rises until it eventually approaches the base metal's yield point and the heat-affected zone. When a weld is created gradually, the already-solidified portions of the weld oppose the shrinkage of later weld bead portions. As a result, the firstly welded pieces are put under stress in a direction that is longitudinal to the weld, or down the length of the weld bead, Due to the preparation of the weld joint and the stiffening impact of underlying passes, butt joints allow for very minimal weld motion in the transverse direction. Transverse residual stress is also evident because the weld has shrunk. The shrinkage stress for fillet welds is tensile over the weld's face and length. Weldments may experience one of two significant impacts from residual stress. It may result in distortion, early failure, or both. When a heated weld region contracts unevenly, causing shrinkage in one area of a weld to apply eccentric pressures on the weld cross-section, distortion results. Elastically, the weldment contracts in response to this tension. This non-uniform tension results in discernible deformation. both a longitudinal and transverse contraction or shrinking. When the face of the weld shrinks more than the root, it may also appear as an angular change (rotation).

Transverse bending of the plates over the length of the weld is caused by angular change. illustrates these impacts.Similar to butt weld distortion, fillet weld distortion also occurs. The imbalanced nature of the tension present in these welds causes transverse and longitudinal shrinkage as well as angular distortion. Due to the frequent usage of fillet welds in conjunction with other welds in welded structures, the specific distortion that results could be highly complex. Various methods exist for controlling distortion. Most methods control the geometry of the welded junction either before or during the welding process. Among these methods are prepositioning the workpieces before welding such that the resulting weld distortion leaves them in the intended final geometry, and restraint of the workpieces to prevent distortion during welding. Another helpful strategy is to design and weld the joint so that the weld deposits are evenly distributed on both sides of the weld centerline.

Both distortion and residual stress can be influenced by the choice of the welding procedure to be utilized as well as the weld sequence. Because they cause buckling and brittle fractures at low applied stress levels, residual stress and distortion have an impact on the fracture behavior of materials. Buckling might happen at lower compressive stresses than would normally be expected when residual stress and the associated distortion are present. In weld zones with low-notch toughness, residual stress in tension may cause considerable local stress. Any low overall stress that is present may cause brittle cracks to start as a result of this local stress. Additionally, residual stress could be a factor in corrosion or fatigue failures.

Both thermal and mechanical methods can be used to decrease or eliminate residual stress. Thermal stress reduction involves heating the weldment to a temperature where the yield point of the metal is low enough for plastic flow to happen and therefore permit stress relaxation. The thermal stress relief process typically has an impact on the weldment's mechanical characteristics. Thermal stress relief, for instance, frequently improves the brittle fracture resistance of many steel weldments because residual tension in the weld is decreased and the heat-affected zones are tempered. This process increases the heat-affected zones' toughness. The microstructure or hardness of the weld or heat-affected zone is not considerably altered by mechanical stress-relief treatments, although they do lower residual stress.It is crucial to increase the dependability of welded metal constructions. Engineers must take into account discontinuities, residual stress and distortion, the mechanical characteristics of the weldment, the need for nondestructive testing, and the total cost of fabrication throughout the design phase. There are a variety of methods that can be used to reduce residual stress and deformation, including the following:

1. Deciding on the best welding sequence, processes, and fixturing
2. picking the best stress-relieving techniques
3. Making use of design considerations and materials to lessen the impacts of residual stress and distortion.

The research work already done in this particular field has to be discussed here, in this specific section.

DISCUSSION

Nature and Causes of Residual Stress

The tension that remains in a weldment after all external loads have been eliminated is referred to as residual stress. Several terms have been used to residual tension. These include reaction stress, locked-in stress, initial stress, internal stress, and intrinsic stress. Thermal stress, on the other hand, is the word typically used to describe the residual stress that develops when a structure experience a nonuniform temperature change.During the various stages of manufacturing, residual stress arises in metal structures for a variety of causes. Stress in structural elements like plates, bars, and sections may be produced during casting or mechanical action (such as rolling, forging, or bending). As a result of welding, brazing, and heat-cutting procedures, it can also happen during fabrication. Relative stress can be impacted by heat treatments that are used at different manufacturing stages. For instance, residual stress can be increased by quenching from an excessive temperature, whereas it can be decreased by stress-relieving heat treatments [4], [5].

Macroscopic And Microscopic Residual Stress

The areas of a metal structure where residual stress can be observed range widely, from substantial chunks of the structure to regions at the atomic level. In Figure 1, examples of macroscopic residual tension are shown. Thermal distortions and thermal stress are created in a structure when it is heated by solar radiation on one side, as shown in Figure 1(A).

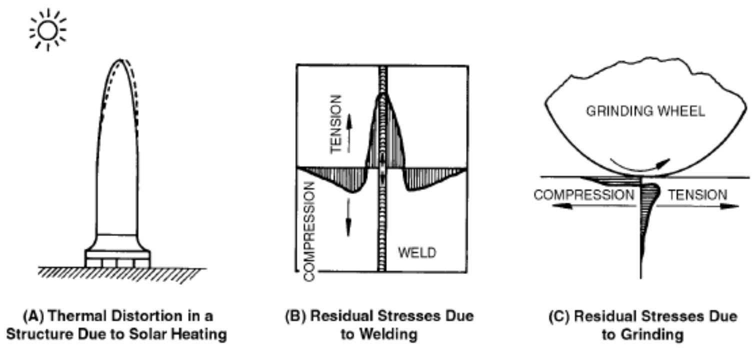


Figure 1 Macroscopic Residual Stresses on Various Scales: (A) Thermal Distortion Due to Solar Heating; (B) Residual Stress Due to Welding; and (C) Residual Stress Due to Grinding

Figure 1(B) shows how welding results in residual stress. It is clear from this figure that the stress is concentrated in the vicinity of the weld. The residual stress caused by grinding is seen in Figure 1(C). In this instance, the stress is concentrated in a narrow layer close to the surface. Microscopic residual stress can also exist. For instance, the martensitic alteration of steels results in residual stress.1 This process causes the metal to expand since it happens at a low temperature.

Formation of Residual Stress

The many forms of residual stress are divided into groups based on the factors that cause them, specifically structural mismatching and uneven distribution. of strains that are not elastic, such as thermal and plastic strains.

Residual Stress Resulting from Structural Mismatch

Figure 2 depicts a straightforward scenario where forcibly connecting bars of various lengths results in residual strains. The setup in Figure 2(A) is depicted. statue of liberty. Between the two parts of Bar Q, which is a little shorter than Bars P and P ′, there is an opening. Tensile residual stresses are created in Bar Q and compressive residual stresses are created in Bars P and P ′ when these two parts are forcibly joined as depicted in Figure 2(B). The absolute values of the stresses in Q are twice as great as those found in P and P ′ if the cross-sectional areas of P, P ′, and Q are equal. After the two parts of bar Q are forcibly joined, the overall system gets a little bit shorter.

An experimental setup resembling that in Figure 1 was utilized by Satoh, Matsui, and Machida2 to investigate the processes causing residual tensions to accumulate. The used experimental system is depicted in Figure 2. The movement of the round bar specimen displayed in the middle was constrained by the employment of two round bars. The rigid frame-mounted round bar specimen was put through a thermal cycle that mimicked the welding thermal cycle. An induction heater with a high frequency was used to initially heat the specimen. After that, the specimen was either naturally cooled by air or controlled by an argon gas stream. Thermal stresses that formed in the specimen were measured using a load cell that was attached to it. Thermocouples were used to measure the heat cycle.

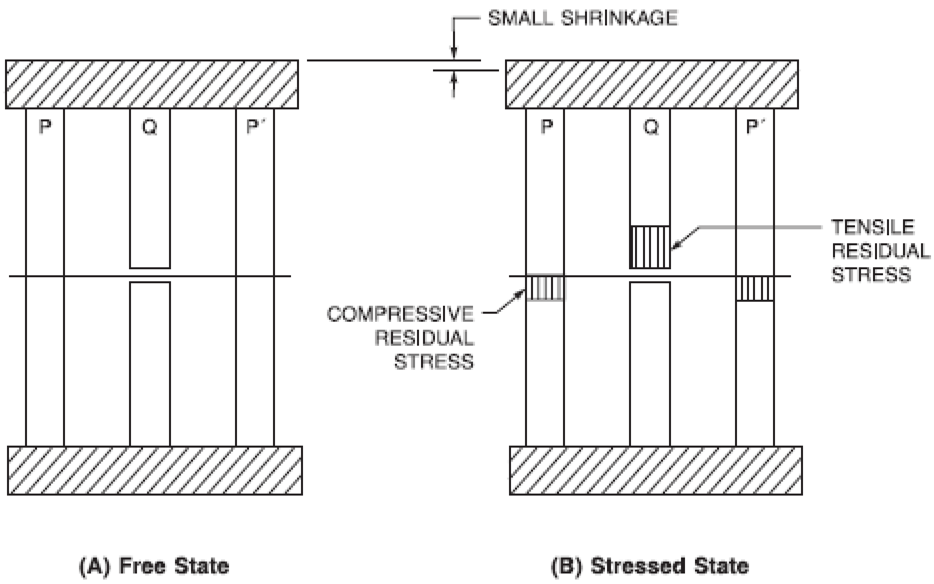


Figure 2 Residual Stress Produced When Bars of Different Lengths Are Forcibly Connected: (A) Free State and (B) Stressed State

Change In Weldments Subjected To Tensile Loading

The residual stress at a welded butt joint changes as a result of tensile loading, as shown in Figure 3. The longitudinal residual stress's lateral distribution in the as-welded condition is shown by Curve A. The distribution of stress is illustrated by Curve B when uniform tensile tension 1 is applied. The yield stress is reached at the vicinity of the weld, and the majority of the stress rise takes place in places further from the weld. The distribution of stress is represented by Curve C when the applied tensile stress rises to. The stress distribution throughout the weld becomes more uniform as the applied stress level rises (i.e., the residual stress's influence on the stress distribution declines). When the amount of applied stress is raised even higher, general yielding—where yielding happens over the entire cross-section occurs. Curve D displays the distribution of stress at general yielding.

The impact of residual stresses on the stress distribution vanishes after general yielding. The distribution of residual stress following the removal of the tensile stresses is the next factor to be taken into account. When tensile stress 1 is applied to the weld and subsequently released, Curve E shows the residual stress that is left over after unloading. When the tensile stress is imposed and then relaxed, Curve F depicts the residual stress distribution. The residual stress distribution after loading and unloading is less severe than the initial pattern of distribution, as indicated in Curve A, as shown by Curves E and F. The effect of welding residual stress on the overall distribution of stress throughout the welded joint reduces as the level of loading rises, resulting in a distribution of residual stress that is more or less uniform after unloading.The impacts of residual welding stress can be summed up as follows based on this analysis:

1. The performance impact of residual welding stress is the performance of welded structures under applied stress greater than the yield strength.
2. The effect of residual stress decreases as applied stress level increases
3. The effect of residual stress is negligible on the performance of welded structures under applied stress less than the yield strength.
4. The effect of residual stress tends to decrease after repeated loading.

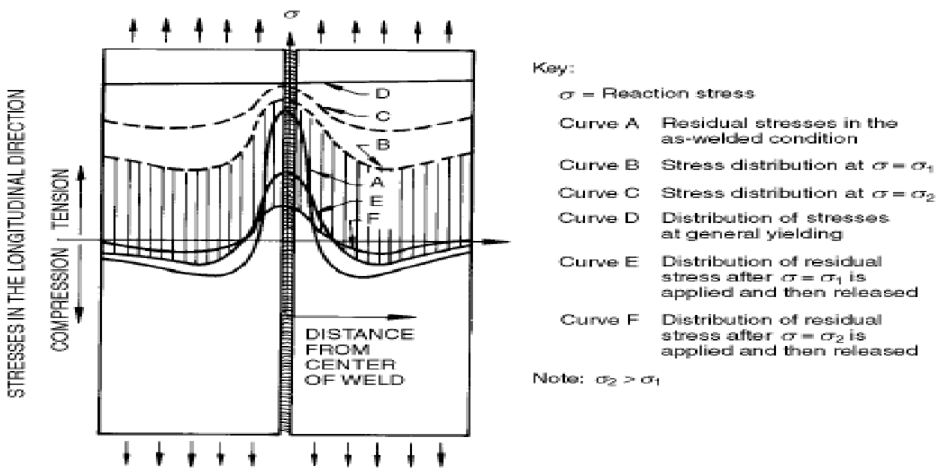


Figure 3 Effect of Uniform External Loads on Residual Stress Distribution in a Welded Butt Joint.

Brittle Fracture or Unstable Fracture Under Low Applied Stress

The effects of residual stress on brittle cracks in welded steel structures have been extensively studied. The experimental results obtained with notched specimens are different from the data gained from brittle cracks in ships and other structures. Actual fractures have happened at stress levels that are much lower than the material's yield strength. Even when the specimen has very acute cracks, the nominal fracture stress of a notched specimen is equal to the yield strength. Even though the applied stress magnitude was much below the material's yield stress in some test situations, a specimen had completely fractured.

The effects of a transverse sharp notch and residual stress on fracture strength, as well as the general fracture-strength tendencies of welded carbon-steel specimens at different temperatures. When a specimen lacks a distinct notch, fracture takes place at the material's maximum strength, as shown by Curve PQR. A fracture happens at the stress indicated by Curve PQST when a specimen has a sharp notch (but no residual stress). A high-energy (shear-type) fracture develops under high stress when the test temperature exceeds the fracture transition temperature, Tf. When the test temperature falls below Tf, the fracture seems low-energy (cleavage type), and the stress at fracture falls to a level that is almost equal to the yield strength. The following fracture types can happen when a notch is situated in regions with high residual tensile stress:

1. At temperatures higher than the fracture transition temperature, Tf, residual stress and fracture stress are equal in strength (Curve PQR). has no impact on fracture stress
2. A crack may begin at low stress but will not spread at temperatures lower than Tf but higher than the crack-arresting temperature.
3. Depending on the stress level during fracture initiation, one of the two phenomena listed below may manifest at temperatures lower than:

a. The fracture stops spreading after traveling a short distance if the stress is below the critical stress, VW;

b. The complete fracture will happen if the stress is greater than the critical stress, VW.

Fracture mechanics ideas have been used to analyze the impact of residual stress on unstable fractures. This analysis suggests that minor cracks that would typically be stable in the absence of residual load can transform into unstable fractures. The intensity of the stress at the tip of the discontinuity is not affected when a small subcritical fault is located in an area that is either free of compressive residual stress or contains it. The intensity of the stress surrounding the tip of the discontinuity would rise if the tip of the fault were to occur in a location with tensile residual tension because it would add to the applied stress. This increase in force could lead to the imperfection cracking and spreading until its tip is outside the area of residual stress. Depending on the crack's length and the level of stress at this time, it may either stop growing or continue to do so. As a result, residual stress is localized, and only the area of the residual stress field is impacted in terms of fracture performance [6].

Buckling under compressive Loading

When exposed to compressive loads, metal constructions like slender bars, beams, and thin plates can fail to owe to instability or buckling. bending, torsional, or axial loading. The buckling strength of a metal structure is decreased by residual compressive stress. The buckling strength is further reduced by initial distortions brought on by residual stress.

Columns under Compressive Loading

When columns are welded together, residual stress can dramatically lower their buckling strength, especially if the columns are formed of a universal mill plate. However, the effects felt by columns made from universal mill plates are comparable to those felt by hot-rolled columns of like size. Both residual compressive stress and residual tensile stress are extremely high at the intersections of the flanges and webs in universal mill plate columns as well as hot-rolled columns. the exterior portions of the flange of columns manufactured from oxygen-cut plates typically have residual tensile stress. Figure 4 illustrates how columns made from flame-cut plates and stress-relieved columns fare better against buckling than columns made from universal mill plates. In this instance, the residual stress from oxygen cutting the plate and the tension from afterward welding into the column section work together to balance each other out in terms of buckling strength. These columns' performance ought to be comparable to that of hot-rolled plates. Thus, a flame-cut plate rather than a universal mill plate is used in the majority of welded manufactured columns.

Measurement By Diffraction

Diffraction techniques can be used to measure the strain on lattice planes to determine the elastic stresses in metals. The elastic strains in a polycrystalline metal are visible in the crystal lattice of the individual metal grains when the metal is stressed. Interatomic strain absorbs externally applied load as well as internal tension when the metal is below its yield point. The interatomic spacings, which are a sign of strain, can be measured using diffraction techniques. By establishing the material's elastic restrictions and making the assumption that stress is proportional to strain, stress values are calculated from these elastic strains. For homogenous, nearly isotropic materials, such as the majority of metals of practical significance, this is a valid assumption.

Without machining or drilling, elastic tensions in the metal can be detected nondestructively. There are currently several X-ray and neutron-diffraction methods available. Film technologies were used in early measurement procedures, but the measurements were so slow and laborious that few useful results were attained.28 By 1975, X-ray residual stress measurements were almost entirely performed on standard scanning X-ray diffractometers. The development of equipment based on position-sensitive X-ray detectors and made expressly for measuring X-ray residual stress is more recent. These stress X-ray diffractometers offer non-destructive residual stress measurements that can be performed in the field, such as on gas pipelines or bridge weldments, in a matter of seconds or less.

These diffractometers can be used to measure residual stress on pin bearings with a diameter of less than 0.04 in. (1 mm) on both moving and static parts. Additionally, X-ray diffraction methods assess surface stresses 0.0001 in. to 0.002 in. (2 m to 50 m) into the surface, giving a way to resolve significant stress gradients with depth into the surface. Unfortunately, it is impossible to assess internal and subsurface stress without causing damage.The weldment must be carefully sectioned, and the surfaces to be measured must be electropolished, to determine internal stress with X-ray methods.

30 However, the shortcomings of film and traditional scanning X-ray diffractometers in terms of precision, accuracy, and speed have been overcome by these new stress X-ray diffractometers. When there are significant stress gradients, these X-ray techniques, used with stress diffractometers, are extremely accurate and offer the best stress resolution. Techniques for neutron diffraction can measure internal stress without damaging the weldment. Instead of being absorbed in a few hundred microinches (10 to 20 micrometres) like the relatively low-energy X-rays employed in diffraction, neutrons can pass through many inches of metal and can be diffracted from the internal volumes of a metal weldment to assess internal residual stresses. The neutron stress measurements have a volume resolution of 6 10-4 in.3 (10 mm3). However, only a few nuclear reactor facilities can perform neutron diffraction stress measurements.

Effects of Specimen Size and Weight on Residual Stress

When analyzing residual stress in a welded specimen, the specimen must be big enough to hold an amount of residual stress that matches the structure's real level of residual stress.

Effect of Specimen Length

Two series of welds were made by the submerged arc and shielded metal arc procedures in an examination intended to examine the impact of weld length on residual stress in unrestrained low-carbon steel welded butt joints. A summary of the welding circumstances is given. The sole variable in each series of welds was the length of the weld. Each specimen's width was sufficient to guarantee that full constraint was used. the pattern of longitudinal and transverse residual stress along welds created by a shielded metal arc and submerged arc welding methods. While there is substantial tensile stress in the weld's center areas, longitudinal residual stress must be zero at both ends of the welds. With an increase in weld length, the peak stress in the center increases. Figure 7.28, which plots the peak stress for each panel against the weld length, exemplifies this effect well. This graph shows that to achieve the greatest residual tensile stress in the longitudinal direction welds longer than 18 in. (457 mm) must be produced. For welds longer than 18 in. (457 mm), longitudinal residual stress becomes homogenous in the centre. Regarding the transverse residual stress, the stress was compressive near the extremities of the plates and tensile in the center. The highest tensile stress in the middle of the plate and the maximum stress in regions close to the ends of the plate were not significantly impacted by the weld length [7]–[9].

CONCLUSION

Residual strains are tensions that persist in a material even in the absence of external loads or thermal gradients (particularly in a welded component). Remaining tensions can occasionally cause a large amount of plastic deformation, which results in the warping and distortion of an object. There are several different types of weld residual stress, and each type's distribution is extremely complex. This chapter examines stress in single-pass and multiple-pass welds and looks at how various factors combine to alter the amount of stress in welds. Weldments' ability to perform well is affected by distortion, hence the techniques for predicting distortion are also included in this article. In the final section, various techniques for minimizing or regulating residual stress and distortion in welds are covered in great detail.

REFERENCES

[1] T. Mukherjee, W. Zhang, and T. DebRoy, "An improved prediction of residual stresses and distortion in additive manufacturing," *Comput. Mater. Sci.*, 2017, doi: 10.1016/j.commatsci.2016.10.003.

[2] L. Mugwagwa, I. Yadroitsev, and S. Matope, "Effect of process parameters on residual stresses, distortions, and porosity in selective laser melting of maraging steel 300," *Metals (Basel).*, 2019, doi: 10.3390/met9101042.

[3] R. Li *et al.*, "Effect of path strategy on residual stress and distortion in laser and cold metal transfer hybrid additive manufacturing," *Addit. Manuf.*, 2021, doi: 10.1016/j.addma.2021.102203.

[4] S. Thakur, G. Talla, and P. Verma, "Residual stress, distortion, and porosity analysis of LED heat sink printed by SLM process using machine learning," *Eng. Res. Express*, 2021, doi: 10.1088/2631-8695/ac3dc6.

[5] Y. P. Yang, "Recent Advances in Prediction of Weld Residual Stress and Distortion — Part 2," *Weld. J.*, 2021, doi: 10.29391/2021.100.016.

[6] A. Khoshroyan And A. R. Darvazi, "Effects of welding parameters and welding sequence on residual stress and distortion in Al6061-T6 aluminum alloy for T-shaped welded joint," *Trans. Nonferrous Met. Soc. China (English Ed.*, 2020, doi: 10.1016/S1003-6326(19)65181-2.

[7] J. Sivakumar, N. N. Korra, and P. Vasantharaja, "Computation of residual stresses, distortion, and thermogravimetric analysis of Inconel 625 weld joints," *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.*, 2021, doi: 10.1177/0954406220974058.

[8] X. Song *et al.*, "Advances in additive manufacturing process simulation: Residual stresses and distortion predictions in complex metallic components," *Mater. Des.*, 2020, doi: 10.1016/j.matdes.2020.108779.

[9] N. C. Levkulich, S. L. Semiatin, J. E. Gockel, J. R. Middendorf, A. T. DeWald, and N. W. Klingbeil, "The effect of process parameters on residual stress evolution and distortion in the laser powder bed fusion of Ti-6Al-4V," *Addit. Manuf.*, 2019, doi: 10.1016/j.addma.2019.05.015.

CHAPTER 3

EXPLORING THE APPLICATION OF DESIGNWELDING

Dr. Surendrakumar Malor, Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: coe@presidencyuniversity.in

ABSTRACT:
Laser technology is being used in more and more applications. These uses have primarily been in the production of automobiles and automobile parts. The applications in machine building have just recently begun to draw more attention, in part because of declining sales in the automobile industry, and a number of these applications have gone public. If used effectively, laser welding and cutting may typically offer reduced manufacturing costs and turnaround times. The integration of the laser's true potential into the product's structure must be overcome before further utilization. Only seldom are the benefits of laser welding in product design realized. But in many instances, this would be a crucial consideration that would support the laser investment. The creation of processes for welding product design is the topic of this study. Modulation has been promised with the systematic method, and with that, cost-effectiveness is attained. Since welding must meet the same fundamental requirements as automated and robotized welding, the process begins with common design guidelines. There are several ways to use lasers in product design, along with some common examples.

KEYWORDS:

Design, Fracture, Metals, May, Stress, Strength, Stresses, Welding.

INTRODUCTION

An assemblage of component pieces linked by welding is known as a weldment. It might be a piece of machinery, a bridge, a building frame, a car, a truck body, a trailer hitch, a piece of equipment, or a platform for offshore oil drilling. The main goals in the field of weldment design1 are to create an assembly that fulfills its intended functions, has the necessary reliability and safety, and can be manufactured, inspected, transported, and put into service for the least amount of money possible. The cost of design, materials, fabrication, erection, inspection, operation, repair, and product maintenance is included in the overall cost. Weldment designers need to be familiar with fundamental design concepts and principles. Assembling components, preparing and constructing welded joints, assessing welds for conformity with set acceptance standards, performing a nondestructive examination and mechanical testing, and cutting and shaping metals are just a few of the skills they must be familiar with. When assessing the potential implications these may have on the design of weldments, designers commonly draw on their knowledge in the following topics. Manufacturing businesses are aware of their technical issues, yet the beginning of development is frequently challenging or never begins. Smaller businesses frequently lack the resources and expertise necessary to develop innovative production techniques and products. This article provides some advice for the creation of welding products, design implementation, and welding product development for use in the workshop. Because usefulness and price are determined during the design process, creating products is a difficult undertaking [1]–[3].

To consider assembly and manufacturability factors, designers must be familiar with the various manufacturing processes as well as the concept of manufacturing-friendly design. The amount of welding used in a good welding construction is modest. Modulation, standardization, and welding alternatives have all been employed. This article proposes a "Design for Welding" paradigm that is manufacturing-friendly and examines the distinctive characteristics of welded structures from a design standpoint. Because the design is outsourced to a third party and manufacturing is handled by a variety of vendors, the design knowledge is decreased. These design subcontractors frequently lack the resources or expertise necessary to make the product more conducive to manufacturing. Additionally, designers frequently lack sufficient knowledge of manufacturing techniques and production methods that are manufacturing-friendly. Because the designers are used to doing things a certain way and have more time and knowledge to examine new manufacturing methods, their previous experience can also be a burden. The company frequently needs an outsider to point out things that need to change and grow. The bar for beginning development work is frequently high. An excellent illustration of a production technique offering fresh possibilities for product design is laser welding. These benefits can be significantly more advantageous than those that can be directly attained, such as high speed and low heat input.

Properties of Metals

Five broad categories can be used to categorize the characteristics of metals: mechanical, physical, corrosion, optical, nuclear, and so on. Each group's typical traits are listed. To emphasize the considerations that should be paid to the reported values of the attributes, these are further divided into two categories: structure-insensitive and structure-sensitive.4 In this chapter, only those characteristics that are pertinent to weldment design will be covered. These consist of the corrosion, physical, and mechanical characteristics. Regardless of variations in microstructure, the structure-insensitive characteristics of metals are constant from one piece of a metal to another of the same composition. This has been confirmed by information gathered through common engineering testing, and it is accurate for the majority of engineering uses. The chemical composition can frequently be used to determine or explain these qualities. Metals' structure-insensitive characteristics are frequently regarded as constants.

The structure-sensitive qualities are influenced by microstructural features, which may be slightly influenced by the metal's manufacturing and processing history, in addition to the chemical composition and crystallographic structure. Even the sample size can have an impact on the test findings for a property that is structure-sensitive. If the samples were handled and prepared differently, structure-sensitive attributes may change somewhat. Except the moduli of elasticity (see the section "Modulus of Elasticity" below), the most significant mechanical properties of metals in the field of weldment design are those that are structure-sensitive. The reported single values for these attributes should therefore only be taken into consideration under certain conditions. The mechanical characteristics of metal plates or bars with very large dimensions or unusual treatment conditions frequently differ greatly from the values reported for the specific metals. Additionally, according to standard quality acceptance tests in an American Society for Testing and Materials (ASTM) specification, a metal's mechanical properties do not ensure that the material represented by the test sample has the same properties throughout. For instance, the direction of the test (longitudinal, transverse, or through-thickness) on wrought metal may produce noticeably different strength and ductility values. Metals' physical and corrosion characteristics are typically thought of as being structure-insensitive. However, some of the numbers specified for these characteristics only apply to typical polycrystalline metals.

Mechanical Properties

Metals make ideal construction materials since they are often robust, hardy, and ductile. Rarely do nonmetallic materials have this particular set of characteristics. The majority of nonmetallic building materials, therefore, rely on the composite action with metals for their functionality. Metals can have their strength, hardness, and ductility altered via heat treatment or alloying.

Metals provide a wide range of mechanical properties and traits, both individually and in combination, that are very valuable. Due to its flexibility, designers can choose the ideal set of characteristics to guarantee the desired performance level. The amount of heat applied, the rate of cooling, the inclusion of filler metal, and the metallurgical makeup of the joint are some of the elements that have an impact on the mechanical properties of metals.10 Metals' mechanical characteristics are also impacted by the welding or brazing processes used to unite them.The process of choosing materials must also take the simplicity of production into account. It is best to choose base metals and welding supplies to make fabrication easier. Examining the governing properties of the metals and taking into account their combined impact on the design and service behavior of the weldment are required when deciding on the selection of materials. The research work already done in this particular field has to be discussed here, in this specific section.

DISCUSSION

Modulus of Elasticity

Young's Modulus, sometimes referred to as the modulus of elasticity, is an easy approach to determining a metal's capacity to resist stretching (strain) under force in the elastic range. This is the proportion of applied strain to generated stress. The following equation represents the constant modulus of elasticity in the elastic range:

$$E = \sigma / \varepsilon$$

E = Modulus of elasticity;

σ = Stress, pounds per square inch, psi (megapascal [MPa]),

ε = Strain, inch per inch (in./in.) (millimeter per millimeter [mm/mm])

The observed strain and computed stress produced during a typical tension test can be used to calculate Young's modulus. As a structure-insensitive property, the modulus of elasticity is unaffected by grain size, cleanliness, or heat treatment. The modulus of elasticity frequently stays constant even after significant alloy additions. When a piece of metal is forced to stretch elastically a predetermined distance, the modulus of elasticity can be used to calculate the amount of stress that is produced in the metal. By dividing the strain by the elastic modulus, the stress may be calculated. It's crucial to note that the modulus of elasticity reduces as the temperature rises and that the temperature-influenced variations varied depending on the metal.

Elastic Limit

The elastic limit is the point at which a metal no longer exhibits elastic behavior. This is the maximum stress that a part may withstand before deforming back to its original size after the load is lifted. When the member's elastic limit is surpassed, the deformation is permanent

[4]–[6]. A metal's elastic limit is structure-sensitive and strain rate-dependent.The elastic limit places restrictions on the design of various components. As a result, a number of limit-related attributes have been specified. These characteristics can be determined using the typical stress-strain diagram for a tension test. It shows a common diagram. Line A-A' represents the stress-strain curve's starting straight line. The metal's elastic modulus is indicated by the slope of this line. A point where the strain exceeds the amount indicated by the prior straight-line connection is reached as the line climbs. Due to potential differences in the curve's clarity and interpretation, it might be challenging to pinpoint the precise point at which the proportionality between stress and strain ceases. Figure 5.2's stress-strain curve has an elastic limit that is roughly 28 kips per square inch (psi) (190 MPa). This is the highest point at which the strain and stress remain exactly proportional.

After the load is removed, a metal that has been stretched below its elastic limit will recover. The additional strain, on the other hand, is plastic and causes permanent deformation when metal is stretched beyond its elastic limit. As an illustration, the tensile specimen shown in Figure 5.2 would elongate by 0.00125 in./in. (.00125 mm/mm) if it were loaded to 32 psi (220 MPa), as shown in S1. As soon as the stress was removed, the specimen displayed a persistent stretch of about 0.00015 in./in. (0.00015 mm/mm), symbolized by line B-B', rather than returning to its previous length.

Yield Strength

The stress level at which a metal demonstrates a specific deviance from the proportionality of stress and strain is known as the yield strength of the metal. An approach that works Illustrated is the method used to calculate a metal's yield strength. From a point on the abscissa, Line C-C' is drawn parallel to the elastic Line A-A', denoting an elongation of 0.2% (0.0020 in./in. [0.0020 mm/mm]). The stress-strain curve is intersected by line C-C' at S2, where the stress is about 38 (260 MPa).The yield strength of the metal under test is this stress. While offset yield strengths of 0.1% and 0.5% are occasionally utilized in the same way for different metals, offset yield strengths of 0.2% and 0.1% are more frequently used in engineering design.

Tensile Strength

The ultimate tensile strength (UTS) is defined as the ratio of the utmost load a tension test specimen can withstand to its initial cross-sectional area. The most typical value derived from the standard tension test is known as the UTS. However, a metal's true tensile strength, which is determined by dividing the breaking load by the final cross-sectional area, could be far higher than its stated tensile strength. Numerous factors affect the metals' tensile strength measurements. Tensile strength is a quality that depends on the structure. It is influenced by chemical makeup, microstructure, rolling direction, grain size, and strain history. The specimen's size, shape, and rate of loading can all have an impact on the outcome. These factors may cause the UTS of the heat-affected zone to differ from that of the base metal that was not affected.

Fatigue Strength

An essential component of the strength of metals and welded joints is how they behave under cyclic loads. Even at nominal tensile stresses below yield-point stress, the applied forces induce the tip of a crack to progress a very small amount, which leads to fatigue fractures. Stable crack growth is the name given to this occurrence. Up until the crack reaches a critical size, the rate of crack growth accelerates as the area in front of the crack shrinks. At this moment, unstable fracture growth starts, and then there is an abrupt, total failure. However, crack growth does not happen when the crack tip's net stress is compressive. High residual tensile stresses may cause a crack to occur, but the crack will release the local stress state. Therefore, if a compressive load is applied, the crack won't enlarge to a dangerous size. As more tension is applied repeatedly, the amount of stress that a metal can withstand before breaking down decreases. The greatest stress that may be tolerated for a specified number of cycles without failing is commonly referred to as fatigue strength. The corresponding fatigue strength decreases as the number of cycles rises. Accordingly, the phrase "fatigue life" refers to the number of stress cycles that a metal can withstand under specific circumstances. The fatigue strength of steel remains constant for a given stress level for more than two million cycles. It takes many millions of additional cycles to noticeably reduce fatigue strength. The greatest stress or stress range that a metal can withstand for an infinite number of cycles without experiencing fracture is, thus, the fatigue limit for practical applications. The endurance limit is a term used to describe such a restricting stress level.

Typically, polished round specimens examined in the air are used to determine the metal endurance limits published in engineering handbooks. These facts are accurate and helpful for designing things like spinning machine shafts and other uniform parts. However, given that weldments are characterized by sudden changes in cross-section, geometrical and metallurgical discontinuities, and residual stresses, all of which harm fatigue life, they might not be very important when designing weldments. Rotating equipment's weldments are especially prone to fatigue failure. When the pressurization is cyclic and the stress exceeds the fatigue strength and is concentrated at one location, pressure vessels can also fail due to fatigue. It is necessary to adhere to the applicable standard controlling the subject structure when designing welded built-up members and welded connections for constructions susceptible to fatigue loading. The designs of currently existing welded components should be considered as a guide in the absence of a specified standard. Localised stresses can be brought on by applied or residual stresses alone, or they can be brought on totally by external loading.

Although residual stresses are not cyclic, depending on their respective signs, they may add to or take away from applied stresses. Because of this, it may be desirable to create compressive residual stress, if at all possible, in key locations of a weldment where cyclic applied tensile stresses are anticipated. This can be achieved either by a welding sequence that manages the residual stresses created during welding or with a localized treatment that compresses the surface. It is necessary to view thermal stresses in the same manner as applied stresses. Thermal stresses are caused by a material's expansion and contraction as a result of heating and cooling. The metal expands when it is heated. Thermal compressive stresses are created when a material is constrained and not allowed to expand freely. In contrast, a cooled restrained portion produces a tensile tension. If the temperature gradients are high or if a stress raiser, such as a discontinuity or change in cross-section, concentrates the thermal stresses, thermal cycling may result in fatigue failure. In conclusion, designers of weldments need to have a full understanding of the metals' fatigue properties when applied to weldments. Fatigue is the most frequent reason for fracture in weldments that are susceptible to tension-range loading. The regular occurrence of stress raisers, which concentrate imposed cyclic stresses to levels exceeding the metal's fatigue limit for the current conditions, is one of the causes of this.

Ductility

The degree of plastic deformation that an unwelded or welded specimen experiences in a fracture-inducing mechanical test are regarded as a measurement of the metal or weld's ductility. Values representing ductility in different mechanical tests are only significant for the test specimen's relative size and geometry. They just provide relative values for comparing the ductilities of metals put through the same test settings, rather than measuring any basic property. A specimen's plasticity is just the deformation carried out during the yielding process. Regardless of the measurement technique, ductility is a quality that depends on the structure. Several of the testing conditions have an impact on it. The degree and position of plastic deformation before fracture is influenced by the size and shape of the specimen, ambient temperature, strain rate, microstructure, and surface circumstances.

Weldment design does not directly utilize the ductility values obtained from exact or complex tests. A significant deformation usually disqualifies the unit or item from service because structures are typically built to work at stresses below their yield strength. However, ductility values help indicate a metal's capacity to yield and relieve concentrated high stresses. They also shed light on the reserve of plasticity that can be used to guard against unexpected overloads that could cause a rapid fracture. However, because most constructions are sensitive to temperature as well as loading rate, ductility measurements do not always represent the amount of plastic deformation that will occur under all loading scenarios [7]–[9].

Fracture Toughness

A metal that passes the usual tension or slow-bend tests and is determined to be ductile may behave brittlely in a different test or under service conditions. Therefore, the only inference that can be made with a reasonable degree of certainty from the findings of tension or bend tests is that a metal with very limited ductility is unlikely to behave ductilely in any other kind of mechanical test used to induce fracture. A metal may or may not act ductile in other kinds of mechanical tests, even though it exhibits strong ductility in tensile or bend tests. In reality, ductile metals that pass the tensile and bend tests can fracture in use with little to no plastic deformation. The absence of distortion and other characteristics of such failures typically show that not much energy was needed to cause the fracture. Because of this widespread occurrence, metallurgists now refer to a metal's toughness as a separate attribute from ductility. The ability of a metal to resist fracture under circumstances that are unfavorable to energy absorption in the presence of a notch and to accommodate loads through plastic deformation in the presence of a notch is known as fracture toughness.

Many metals are ductile because they can absorb energy and deform plastically under the straightforward conditions of tension or bend tests; however, fewer of these metals show acceptable toughness when tested under high-stress concentration conditions. As (1) the rate of loading rises, (2) the applied stresses become multiaxial, and (3) the temperature of the metal is dropped, the toughness that a metal exhibits tend to diminish. Weldments in use could readily come into contact with one or more of these issues. As a result, concern over the weld metal's toughness and the heat-affected zones of the weld is justified. Design strength for ductile metals is typically based on a study to make sure that the applied stresses are below the design strength when they are used in the construction of engineering structures, including welds. Brittle failures are widely categorized as failures that happen at load levels below the design strength. These failures may be caused by critical-sized discontinuities or crack-like imperfections in the base metal or the weld that has a minor impact on the nominal stress distribution but are typically ignored in the design.

When structural grade steel is tested in uniaxial tension, it usually deforms ductile-ly before bursting under the ultimate stress. Any elongation in one direction must be accompanied by contraction in one or both of the other directions because the volume of metal must always stay constant. Due to the freedom to contract in the opposite direction, the uniaxial tension test specimen exhibits ductile behavior. The same material that displays ductile behavior in a straightforward tension test may fail in a brittle manner if the requisite lateral contraction is severely constricted or blocked and the longitudinal stresses are sufficiently high. The circumstances of constraint and stress concentrations in constructions where independent pieces are linked by welding are typically significantly different from those created by straightforward uniaxial tension. Significant material thickness might be a sufficient restraint to stop lateral contractions on its own. Therefore, if material dimensions are proportionately expanded to a significant extent, structural elements that have proven appropriate in lengthy usage and service may not necessarily have adequate ductile qualities.

The significance of discontinuities must be properly taken into account for a full fracture-safe analysis. Experience with particular designs, materials, and fabrication techniques has established a suitable association between Charpy V-notch test criteria for base and weld metals and acceptable service for various kinds of structures, including ships, bridges, and pressure vessels. Making sure a new design is sound and authentic is difficult. Analyses of fracture mechanics are used to protect against the impacts of typical weld discontinuities. Designers that use welded joints in their plans are in a difficult situation because it is common knowledge that welded junctions typically have some discontinuities. Although it is their goal, it is not practical to build joints that are completely devoid of discontinuities. Placing a realistic cap on those discontinuities that must exist is the practical strategy. Determining the types and degree of discontinuities that are permissible is hence the challenge.

The link between flaw size transverse to the stress field and fracture stress for a given base metal or weld joint is specifically defined by fracture mechanics tests, if applicable, even though traditional toughness testing methodologies cannot directly address this problem. As a result, these tests enable direct estimation of the sizes of allowable flaws for various geometrical designs and operational scenarios. The smallest critical crack-like defect size required for unstable crack propagation under tensile stress can be determined using fracture mechanics. It should be emphasized, however, that fractures may start at stress raisers that are regarded as acceptable discontinuities in members subject to cyclic loading, corrosion, or both. With each application of tensile stress, these little cracks could grow through steady crack extension until they reach the critical size. For such circumstances, knowledge of the fracture growth rate is crucial for establishing acceptance standards and ongoing inspection cycles.

Low-Temperature Behavior

Weldment designers must take into account the fact that pressure vessels and other welded products may occasionally be required to function at low temperatures (below 32°F [0°C]). the characteristics that metals display at very low temperatures. Cryogenic service, which involves the storage and use of liquefied industrial gases like oxygen and nitrogen, involves very low temperatures. A metal's fracture characteristics are significantly altered by cooling it, especially if it has a body-centered-cubic crystalline structure (like carbon steel). All metals and alloys experience changes in strength, ductility, and other qualities when the temperature drops. For example, the elasticity modulus increases. All metals and alloys generally have higher tensile and yield strengths as the temperature is reduced.

Elevated-Temperature Behavior

In addition to strength and ductility, other parameters, such as temperature (between 75°F [25°C] to 500°F [260°C]), may influence a metal's performance in service. Time becomes a consideration because metals experience the phenomena known as referred to as creep, which is "deformation over time at service temperature."16 In other words, even if the load is kept constant, the stressed part still deforms. With rising temperatures and heavier loads, a metal creeps at an accelerated rate. As a result, the period before a metal under load deforms excessively and cannot be used can range from many years at a slightly raised temperature to a short period at a temperature close to the melting point. Metals and alloys have very different creep rates. The metal will creep until it ruptures at high enough temperatures and stresses. The mechanics of metal deformation and failure under stress at high temperatures are referred to as creep rupture [10]–[12].

CONCLUSION

Design for Welding is a thorough method for creating welded parts and assemblies. Guarantee that welds have the correct shape, strength, ductility, and other desirable attributes, it entails the application of several principles, techniques, and processes. Weldment designers need to be familiar with fundamental design concepts and principles. They must be familiar with and have some experience in assembling parts, cooking food, and cutting and shaping metals. assessing welds for conformity with predetermined acceptance criteria, constructing welded joints, performing nondestructive investigation, and mechanical testing.2 When analyzing the implications that the following may have on the design of weldments, designers frequently use their understanding of these domains.

REFERENCES:

[1] C. Favi and F. Campi, "CAD-based design for welding (DFW) method," *Int. J. Interact. Des. Manuf.*, 2021, doi: 10.1007/s12008-020-00727-z.

[2] J. Madrid *et al.*, "Automated and interactive evaluation of welding producibility in an multidisciplinary design optimization environment for aircraft components," *Int. J. Interact. Des. Manuf.*, 2021, doi: 10.1007/s12008-021-00775-z.

[3] K. Lichtenthäler, C. Höltgen, F. Fiedler, and G. Bergweiler, "Automated design of welding jigs for body shops," *Konstruktion*, 2021.

[4] H. Li, J. Gao, Q. Li, A. Galloway, and A. Toumpis, "Effect of friction stir welding tool design on welding thermal efficiency," *Sci. Technol. Weld. Join.*, 2019, doi: 10.1080/13621718.2018.1495868.

[5] J. Madrid, S. Lorin, R. Söderberg, P. Hammersberg, K. Wärmefjord, and J. Lööf, "A virtual design of experiments method to evaluate the effect of design andwelding parameters on weld quality in aerospace applications," *Aerospace*, 2019, doi: 10.3390/AEROSPACE6060074.

[6] C. Favi, R. Garziera, and F. Campi, "A rule-based system to promote design for manufacturing and assembly in the development of welded structure: Method and tool proposition," *Appl. Sci.*, 2021, doi: 10.3390/app11052326.

[7] K. Treutler, S. Kamper, M. Leicher, T. Bick, and V. Wesling, "Multi-Material design in welding arc additive manufacturing," *Metals (Basel).*, 2019, doi: 10.3390/met9070809.

[8] P. C. Simamoto Júnior, V. Resende Novais, A. Rodrigues MacHado, C. J. Soares, and L. H. Araújo Raposo, "Effect of joint design and welding type on the flexural strength and weld penetration of Ti-6Al-4V alloy bars," *J. Prosthet. Dent.*, 2015, doi: 10.1016/j.prosdent.2014.10.010.

[9] E. Hoyos and M. C. Serna, “Basic tool design guidelines for friction stir welding of aluminum alloys,” *Metals (Basel).*, 2021, doi: 10.3390/met11122042.

[10] I. Mrkvica, K. Dihel, T. Szotkowski, J. Jurko, and A. Panda, “Jig Design for Welding of Wind Power Plant Component,” *Manuf. Technol.*, 2017, doi: 10.21062/ujep/x.2017/a/1213-2489/MT/17/2/237.

[11] O. F. Sánchez-Femat *et al.*, “Design and construction of a novel friction crushing welding machine,” *Soldag. e Insp.*, 2021, doi: 10.1590/0104-9224/si26.06.

[12] J. Madrid *et al.*, “A Welding Capability Assessment Method (WCAM) to support multidisciplinary design of aircraft structures,” *Int. J. Interact. Des. Manuf.*, 2018, doi: 10.1007/s12008-017-0429-5.

CHAPTER 4

AN ANALYSIS OF DESIGN CONSIDERATIONS FOR WELDING

Mr. Dileep Balaga, Assistant Professor
Department of Petroleum Engineering, Presidency University, Bangalore, India
Email Id: balagadileepkumar@presidencyuniversity.in

ABSTRACT:
The proper understanding of the anticipated loading conditions and required service life of the weldment is crucial for welding design. When designing a weldment, distortion, and residual stress are frequently crucial factors to take into account because considerable amounts of either one might determine whether the weldment is acceptable. The fundamentals of arc welding design are the main topic of this chapter. Physical attributes relate to the chemistry of the metal and include characteristics like melting temperature and electrical conductivity. Mechanical properties, such as tensile strength, describe how metal behaves under various loading circumstances. An essential component of the welding method and welder performance qualification testing is the welding position. Dimensional data, such as root opening, bevel angle, length and pitch of intermittent welds, and weld sizes in the case of fillet welds, may be included in welding symbols. Weld sizing is heavily influenced by safety considerations.

KEYWORDS:

Design, Joint, Metal, Position, Tensile, Stress, Welding, Weld.

INTRODUCTION

Weld and joint types, economics, weld sizing for various loading circumstances, symbols, quality and testing, residual stress and distortion, and heat flow are only a few of the topics covered under the idea of welding design in welding engineering. In addition to understanding the material being welded, how it was treated, and the weld filler metal being used, knowledge of all parts of the applicable welding code frequently plays a crucial role in welding design. The proper understanding of the anticipated loading conditions and required service life of the weldment is frequently crucial to welding design. For instance, the design criteria for a weldment subject to fatigue conditions will differ from those for a weldment subject to pure tensile or compressive pressure [1]–[3].

When designing a weldment, distortion, and residual stress are frequently crucial factors to take into account because considerable amounts of either one might determine whether the weldment is acceptable. Finally, before a weld enters service, the welding engineer must be cognizant of the various nondestructive inspection techniques. Although this chapter's discussion of welding design principles primarily focuses on arc welding, it's crucial to keep in mind that other welding processes involve similar issues. Understanding the fundamental mechanical and physical properties of metals is necessary for many of these topics. For instance, a metal having a higher coefficient of thermal expansion (COE) than one with a lower value may distort more when welded.

Higher tensile strength filler metals can be used to create smaller weld deposits than filler metals with lower tensile strengths. It is therefore helpful to first quickly go over the mechanical and physical characteristics of metals that are most crucial to the weld engineer. Physical attributes relate to the "chemistry" of the metal and include characteristics like melting temperature and electrical conductivity. Mechanical properties, such as tensile strength, describe how metal behaves under various loading circumstances.

Mechanical Properties

Yield Strength

A mechanical parameter known as yield strength is derived from the stress-strain curve of a tensile test and denotes the stress level at which a metal deviates by a certain amount from the elastic region of the curve to the plastic portion. Simply said, elastic strain is a strain that occurs when a metal bar is deflected (stretched) by weight and returns to its original shape after the load is withdrawn. If the deflection resulted in permanent deformation, it would have created a plastic strain, which would indicate that the metal's yield strength had been exceeded. the plastic distortion that results from exceeding the yield strength, which normally would be Yield strength, which is regarded as a structural failure, is frequently utilized as a design standard for structural fabrication. As a result, the yield strength of structural steel is a popular method of classification. For instance, the ASTM specification A36 describes a class of structural steels with minimum yield strength.

Tensile Strength

Another mechanical feature that can be identified from a stress-strain curve is tensile strength (or ultimate strength), which corresponds to the peak stress on the curve. It thus reflects the highest tensile stress that a metal can withstand. Tensile strength is not often utilized as a design criterion for ductile metals since they will continue to stretch even after their maximum tensile strength is attained. But because it is simple to determine tensile strength from a stress-strain curve, it is frequently employed as a method of quality control or for contrasting various materials. Tensile strength is more frequently used as a design criterion with such metals since brittle metals frequently break owing to tensile overload when the stress-strain curve is still climbing.

Ductility

The degree of plastic deformation that a metal experiences before fracture are referred to as ductility. With a tensile test, it can be calculated from the percentage of elongation or percentage of area decrease of the test sample after it has cracked. Impact loads harm the performance of metals with poor ductility. There may be significant ductility decreases in the heat-affected zone when welding some metals, such as steel.

Fatigue Strength

In terms of a metal's response to cyclic loading circumstances, fatigue strength is relevant. It is frequently described as the highest stress range that may be tolerated without failure for a given number of cycles. Geometrical elements in a part or fabrication that produce areas of concentrated stress during loading have a significant impact on fatigue parameters. This is because, even though the overall loading is not anticipated to exceed the material's yield stress, such localized portions may be subjected to loads that do. Welded connections frequently result in stress-concentrating zones, such as the weld toe, and as a result, they represent ideal locations for fatigue cracking.

Toughness

The term "toughness" describes a material's capacity to withstand fracture and absorb energy during impact-type loading. Toughness tests such as the Charpy V□Notch test. entail cutting a sharp notch in the test specimen, and striking it in such a manner that it fractures at the notch. Good toughness requires a mix of ductility and tensile strength, so it is conceivable for a material to have good ductility but poor toughness if its tensile strength is low. At the same time, a material with high tensile strength will perform poorly under impact loading if its ductility is low. Poor toughness can cause brittle failures that can be sudden and disastrous. Also, it should be pointed out that there is a difference between Charpy V□Notch toughness and "true" fracture toughness.

Mechanical Properties-Effect of Temperature

The service conditions become crucial since the metal's temperature has a major impact on its mechanical properties. The tensile and yield strengths will both decline with increasing temperature. While some metals, including alloys based on nickel, do not keep strong mechanical properties at extremely high temperatures, others do. On the other hand, at low temperatures, metals like steel may show a dramatic drop in ductility. This phenomenon, referred to as the ductile-to-brittle transition, can have a significant impact on the choice of steel and the relevant service conditions [4]–[6].

DISCUSSION

Physical Properties

Thermal Conductivity

Heat will be transferred more quickly from one metal to another if its thermal conductivity is higher. The metal's heat conductivity during welding may have an impact on several factors. A metal with poor thermal conductivity, for instance, can heat up considerably more quickly during resistance welding than one with excellent thermal conductivity. Due to the quick heat transmission away from the weld area during arc welding, it is nearly impossible to weld without preheating due to copper's high thermal conductivity. The rate of heat transfer through a given metal is, more precisely, a function of that metal's thermal diffusivity and is influenced by its density and specific heat capacity (greater levels of each attribute will slow down the rate of heat transfer). But since thermal conductivity alone typically prevails with metals that are significant for welding, it is conventional to neglect these other characteristics.

Melting Temperature

The melting point of a metal is the temperature at which it transitions from solid to liquid. The fact that a metal with a lower melting point will require significantly less energy to weld than one with a higher melting temperature may seem evident to a budding welding engineer. This would be accurate if the heat conductivity (or diffusivity) of all metals was the same. As it turns out, the melting temperature is significantly less important than the thermal conductivity of commonly welded metals. Aluminum, for instance, has a melting temperature that is less than half that of steel, yet welding requires more energy because heat transfers out of the weld region much more quickly. However, if a dissimilar metal weld combining metals with pronounced melting point differences is being attempted, melting temperature does become significant [7], [8].

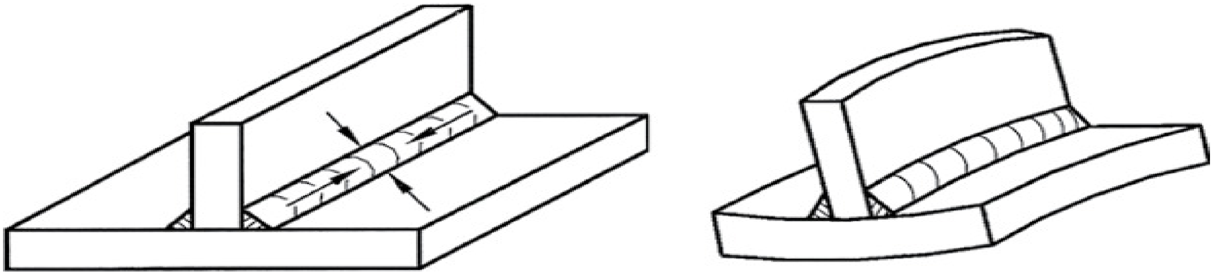


Figure 1 Weld distortion in fillet welds—the "T" and "L" refer to transverse and longitudinal residual stress in the weld region which creates distortion [Google].

Coefficient of Thermal Expansion

A metal expands when it is heated, and contracts when it is cooled. The metal's COE, or the coefficient of expansion, determines how much the metal will expand and then compress. Normal welding outcomes include uneven heating and cooling. The remaining stress and distortion in weldments are the result of this nonuniform expansion and contraction, which has its chain reaction. Because of this, metals with greater COEs, such as austenitic stainless steel, tend to distort significantly more than metals with lower COEs, like plain carbon steel.

Electrical Conductivity

Electrical conductivity, which determines how quickly a substance carries electrical current, is inversely related to resistance. Because it directly impacts how quickly a material can be heated through I2Rt (Joule) heating, it primarily affects resistance welding procedures. Aluminium has a far higher electrical conductivity than steel, making resistance welding much more challenging. Higher thermal conductivity is also present in materials with higher electrical conductivity, which makes it more challenging to produce enough Joule heating**.**

Design Elements for Welded Connections

Welded connections, which can be either joint- or weld-type connections, are used to link structural parts. The structural components, like plates, might be either tubular or not. Weld type describes how the weld is positioned in the joint, while joint type describes how the two work components being welded are orientated about one another. Although there are other methods including slot, seam, and spot, the two major weld kinds are fillet and groove. There are several types of groove welds, as the name suggests, and they are typically welded into grooves. When two matching work pieces form a corner, a fillet weld is used to join them. The five fundamental forms of joints are butt, T, lap, corner, and edge. Last but not least, the welding position plays a crucial role in the welding process and welder performance qualification exams. The welder's position about the components being welded is referred to as the welding position. The level of difficulty is frequently significantly influenced by the welding position. For instance, welding above is far more challenging than welding flat.

Joint and Weld Types

The five fundamental joint types are shown in Figure 1, and a representative weld setup is shown for each joint type in Figure 2. Numerous different weld styles can be used to bind each piece of metal together. The various types of groove welds are depicted in Figures 3 and 4, while fillet welds are represented in Figure 5.

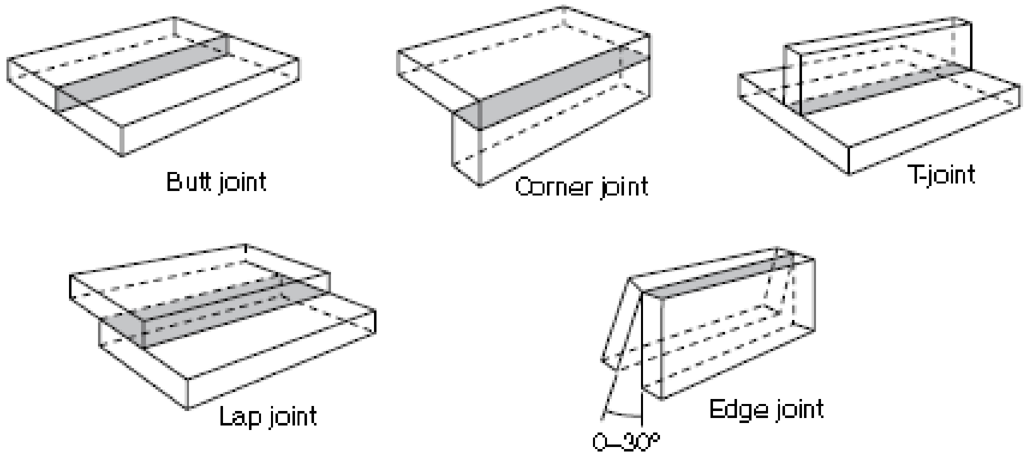


Figure1The five basic joint types[Google].

Joint and Weld Type Selection Considerations

The choice of the joint and weld type to be employed for a particular application is influenced by a variety of factors. Of course, making the joint accessible to the welder comes first. The anticipated loading circumstances may influence the type of weld selected. For instance, if fatigue loading conditions were present, welds (b) and (c) in Figure 6 should perform better than (a). But economics also frequently has a significant impact. The choice of which of the three methods in Figure 7 is ideal for creating a T joint may simply be based on economic considerations, taking into account the welding and machining expenses.

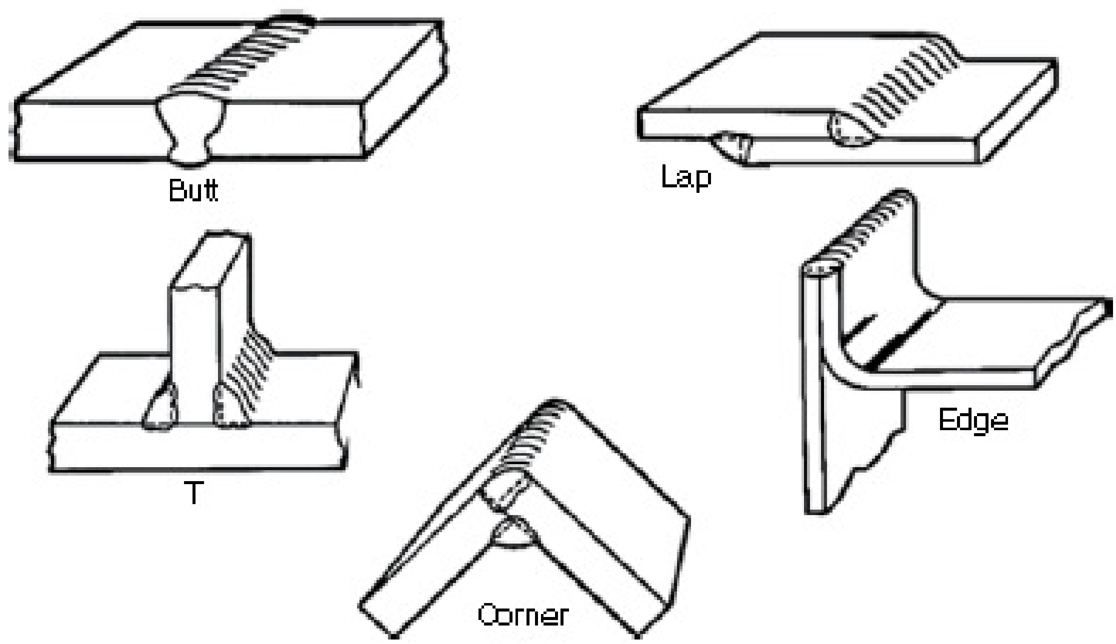


Figure 2 Typical approaches to welding the five joint types [Google].

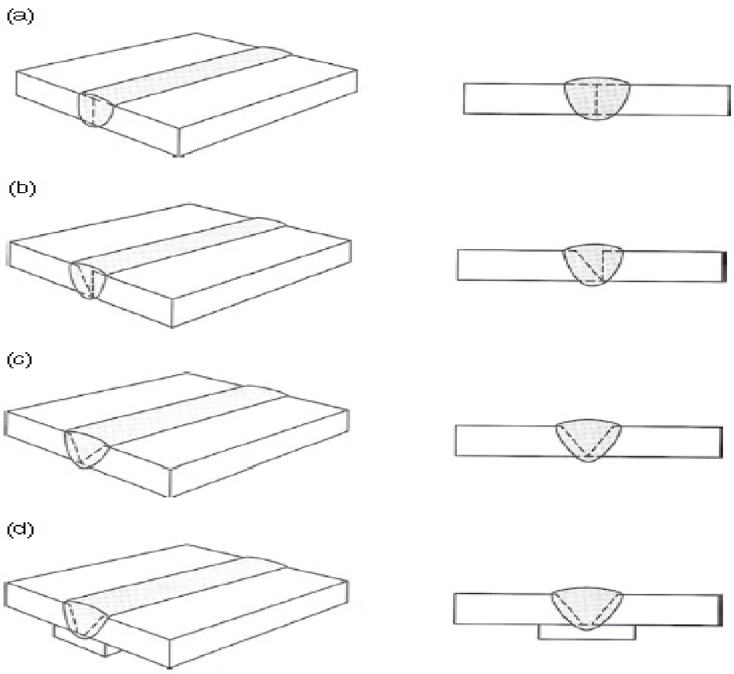


Figure 3 Examples of single□sided groove welds in butt joints. (a) Single□square□groove weld,(b) single□bevel□groove weld, (c) single□V□groove weld, and (d) single□V□groove weld with backing [Google].

Weld Joint Nomenclature Groove Welds

Understanding the terminology used to identify the various components of a weld joint is necessary for the development of a welding procedure.

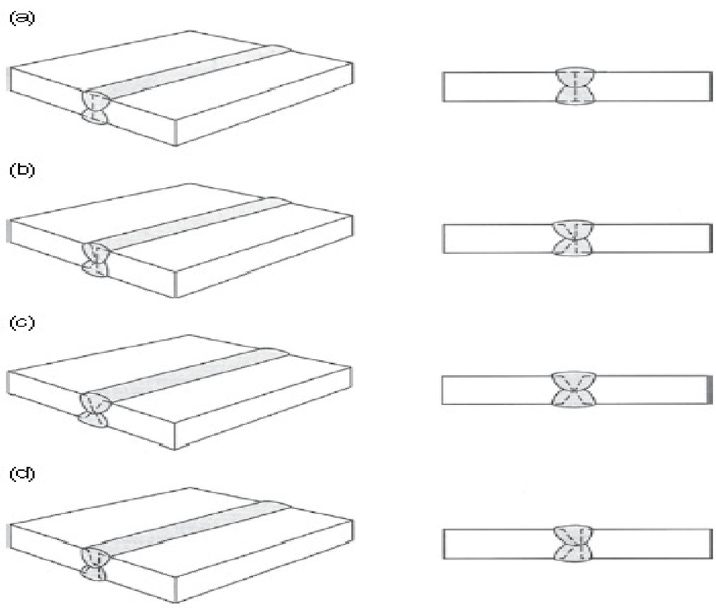


Figure 4 Examples of double□sided groove welds in butt joints. (a) Double□square□groove weld,(b) double□bevel□groove weld, (c) double□V□groove weld, and (d) double□J□groove weld with backing [Google].

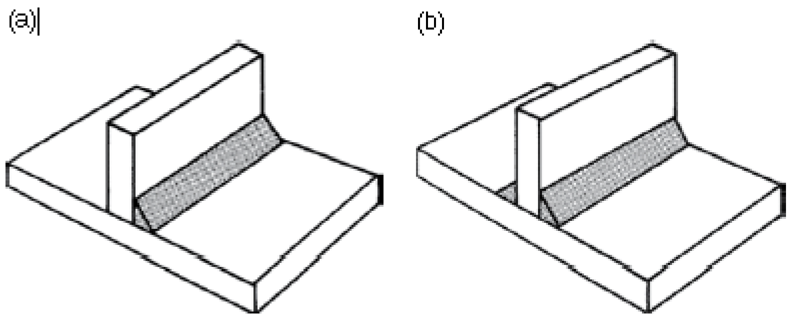


Figure 5 (a) Single and (b) double fillet welds in a T joint[Google].

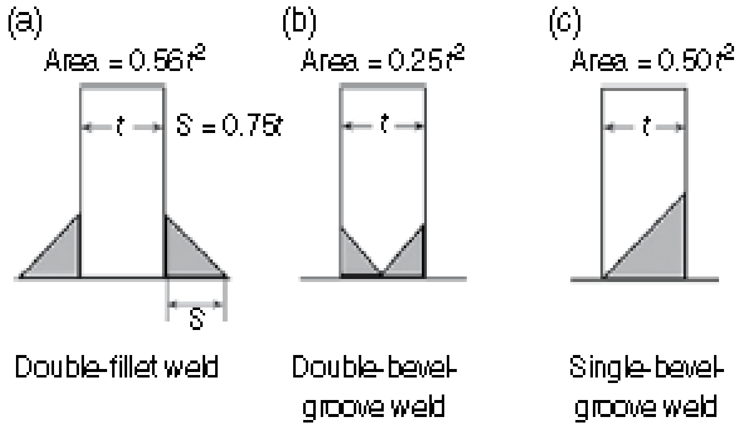


Figure 6 Three options for welding a T joint. (a) Double□fillet weld, (b) double□bevel□groove weld, and (c) single□bevel□groove weld [Google].

Describes the terminology used for groove welds, including terms used in joint preparation before producing the weld and those used to describe different aspects of the finished weld. Full penetration groove welds are required to achieve maximum strength, but in some cases, partial penetration welds are acceptable. Reinforcement refers to the measurable amount of weld buildup beyond the surfaces of the parts being welded and only applies to groove welds. Codes will often provide a maximum allowable amount of reinforcement. Where the weld metal meets the base metal is known as the weld toe. This is often a region where problems such as fatigue cracking and undercut can occur.

Weld Joint Nomenclature Fillet Welds

Depending on whether the weld surface is convex or concave, the name of the fillet weld changes. Draw the largest fictitious triangle that can fit in the weld profile, with its base determined by the component geometry, to better grasp fillet weld terminology. With the convex fillet weld, the triangle helps define the theoretical and actual throat. The effective throat adds a dimension that takes into account the depth of fusion into the joint in addition to the theoretical throat, which is the distance between the triangle's hypotenuse and corner. The effective throat plus the weld's convexity make up the actual throat. The convex weld has a leg and size that are identical to the base and height of the hypothetical triangle. With a concave fillet weld, real and effective throat are the same m dimensions, but leg and size differ. Because they both reflect the joint's ability to bear weight, weld size, and effective throat measurements are frequently used for quality control. To ensure conservatism when determining weld size or the effective weld throat, deviations between concave and convex welds are present.

Welding Positions

The term "welding position" describes the welder's placement of the weld joint. The position becomes a crucial factor in determining the suitability of a welding technique and a welder since welding is considerably easier in some positions than others. For example, a welder may be skilled enough to qualify for a weld in a flat position, but not skilled enough to produce the same weld in a vertical position. A welding position is indicated by a number-letter combination. The letter denotes the type of weld, such as F for a fillet weld or G for a groove weld, while the number denotes the position. It is necessary to mention a plate or pipe when discussing a welding location. While fillet weld positions are for T connections that only apply to plates, groove weld positions are for butt joints between either plates or pipes. As previously mentioned, some positions apply to both plate and pipe, while others are only applicable to a plate or only to a pipe. The pipe positions as they would seem to the welder, and the nomenclature for each. A groove weld in the flat position is referred to as 1G. Productivity can be increased by welding flat wherever it is practical. The horizontal position is likewise favored for overhead and vertical welding but is more prone to overlap and undercut faults than the flat position. The 1G and 2G positions are the same for the plate and pipe. In the 1G scenario, the weld puddle is in a flat position as it is transported along the groove, hence the 1G pipe position includes rotating a horizontally oriented pipe. The top of the pipe is where the weld is created as it spins, thus simulating the flat position on a plate. The 2G horizontal position is more challenging than the flat position because gravity now drags the weld puddle toward the lower plate or pipe. In the same way that the horizontal position for the plate generates a welding condition, the 2G position for the pipe denotes that the pipe axis is in a vertical position.

Welding Symbols

A print or drawing can communicate weld joint information quickly and effectively by using welding symbols. As shown, a variety of information may be presented at different points on the sign, but frequently, only a tiny amount of this information is included in the symbol. The horizontal reference line and the arrow are the only components of the symbol that must be present; all other parts are optional. The reference line, which is always horizontal, is essential since this is where a symbol designating the sort of weld to be made is placed. Because it directs attention to the joint at which the weld is to be made and serves as a reference point for the weld type information written on the reference line, the arrow is essential. the potential weld represented by symbols. These are referred to as weld symbols and constitute a significant component of the total welding symbol. The welding symbol reference line's position about the weld sign is shown by the dotted lines. It's crucial to distinguish between the welding symbol and the weld symbol. The weld symbol is a particular and significant part of the welding symbol that denotes the kind of weld to be utilized, whereas the welding symbol is the full symbol [9]–[11].

CONCLUSION

The concept of welding design in welding engineering covers a variety of subjects, including weld and joint types, economics, weld sizing for various loading scenarios, symbols, quality and testing, residual stress and distortion, and heat flow. Knowledge of all sections of the applicable welding code typically plays a key role in welding design, in addition to an awareness of the material being welded, how it was treated, and the weld filler metal is utilized. Welding design typically depends on having a thorough understanding of the expected loading scenarios and the necessary service life of the weldment. For example, a weldment subject to fatigue conditions will have different design requirements than a weldment subject to pure tensile or compressive pressure. Distortion and residual stress are typically important issues to consider when building a weldment since significant levels of either one may determine whether the weldment is acceptable. The welding engineer must also be familiar with the various nondestructive inspection methods before a weld is put into operation. While arc welding is the primary emphasis of this chapter's examination of welding design concepts, it's important to remember that other welding techniques entail related problems. For many of these issues, an understanding of the basic mechanical and physical properties of metals is required.

REFERENCES:

[1] J. Hensel, "Mean stress correction in fatigue design under consideration of welding residual stress," *Weld. World*, 2020, doi: 10.1007/s40194-020-00852-z.

[2] D. H. Phillips, "Design Considerations for Welding," in *Welding Engineering*, 2015. doi: 10.1002/9781119191407.ch7.

[3] C. L. Tsai and K. Masubuchi, "Mechanisms Of Rapid Cooling And Their Design Considerations In Underwater Welding," *JPT, J. Pet. Technol.*, 1980, doi: 10.2118/8527-PA.

[4] W. C. Mohr, "General Design Considerations for Arc Welding Processes," in *Welding Fundamentals and Processes*, 2018. doi: 10.31399/asm.hb.v06a.a0005558.

[5] R. Wood, "Design considerations for robotic welding cell safety," *Weld. J. (Miami, Fla)*, 2007.

[6] R. Li, M. Dong, and H. Gao, "Prediction of bead geometry with changing welding speed using artificial neural network," *Materials (Basel).*, 2021, doi: 10.3390/ma14061494.

[7] G. J. Brentrup, B. S. Snowden, J. N. DuPont, and J. L. Grenestedt, "Design considerations of graded transition joints for welding dissimilar alloys," *Weld. J.*, 2012.

[8] M. Haghshenas and A. P. Gerlich, "Joining of automotive sheet materials by friction-based welding methods: A review," *Engineering Science and Technology, an International Journal*. 2018. doi: 10.1016/j.jestch.2018.02.008.

[9] T. Nitschke-Pagel and J. Hensel, "An enhancement of the current design concepts for the improved consideration of residual stresses in fatigue-loaded welds," *Weld. World*, 2021, doi: 10.1007/s40194-021-01065-8.

[10] Kenn Lachenberg, "Design Considerations for Electron Beam Welding[1]," in *Welding Fundamentals and Processes*, 2018. doi: 10.31399/asm.hb.v06a.a0005614.

[11] V. K. Mahakur, K. Gouda, P. K. Patowari, and S. Bhowmik, "A Review on Advancement in Friction Stir Welding Considering the Tool and Material Parameters," *Arab. J. Sci. Eng.*, 2021, doi: 10.1007/s13369-021-05524-8.

CHAPTER 5

ADVANCE LASER BEAM MACHINING

Mr. Gangaraju, Assistant Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: gangaraju@presidencyuniversity.in

ABSTRACT:

One of the most prominent thermal energy-based, non-contact sorts of advanced machining processes that may be applied to nearly any material is laser beam machining (LBM). A laser beam is focused on the unwanted component of the parent material, melting and vaporizing it. This technology uses a variety of pieces, including a laser source, optics, a control system, a cooling system, and a delivery system. Laser beam machining (LBM) is one of the most extensively utilized thermal energy-based non-contact type advance machining methods which can be employed for a practically complete spectrum of materials. The laser beam is targeted for melting and vaporizing the undesired material from the parent material. Laser beam machining (LBM) is a method of machining that uses heat directed by a laser beam. This procedure employs heat energy to remove material from metallic or non-metallic surfaces. The high frequency of monochromatic light will fall on the surface, thus heating, melting, and vaporizing the material due to the impact of photons (see Coulomb explosion).

KEYWORDS:

Cutting Welding, Excited Atom Molecule, High Precision Accuracy, Leaser Action, Leaser Beam.

INTRODUCTION

The laser is a formidable light source with unique properties not present in ordinary light sources like tungsten lamps, mercury lamps, etc. The particular attribute of a laser is the extraordinarily low divergence of its light waves as they travel across very long distances. A typical light source releases light as a tangle of separate waves that cancel one another randomly and can only travel incredibly limited distances. A case where multiple pebbles are simultaneously tossed into a pool serves as an analogy. Each pebble makes its wave. Because the pebbles are flung at random, the waves they produce cancel each other out, forcing them to travel only a very short distance. In contrast, if pebbles are put into a pool one at a time, at the same position, and at regular intervals of time, the waves that are formed strengthen one another and move farther. In this instance, it is argued that the waves move coherently. The light waves in a laser are perfectly in phase with one another and have a defined phase relationship as a result [1]–[3].

Laser beam machining is best suited for brittle materials with poor conductivity, but can be used on most materials. Laser beam machining can be done on glass without melting the surface. With photosensitive glass, the laser modifies the chemical structure of the glass allowing it to be selectively etched. The glass is also referred to as photo machinable glass. The advantage of photo machinable glass is that it can manufacture perfectly vertical walls and the native glass is ideal for various biological applications such as substrates for genetic analysis.The laser phrase, which stands for "Light Amplification by Stimulated Emission of

Radiation," has been applied in more intriguing applications than any other scientific discovery of the 20th century. An American physicist named Charles Hard Townes and two Soviet scientists named Alexander Mikhailovich Prokhorov and Nikolai Gennediyevich Basov, who shared the renowned Nobel Prize in 1964, were the first to describe the basics of laser technology. The first person to experimentally demonstrate a laser by flashing light through a ruby crystal was TH Maiman of the Hughes Research Laboratory in California in 1960. These light beams are likewise marked by strong monochromaticity and directionality. As a result, during the path of a laser beam, the light waves have the same color (wavelength) in addition to being in the same phase. Ordinary light has a pretty quick dispersion in its beam. The laser beam, on the other hand, is closely focused and scarcely spreads. The spread of laser light has been revealed to be just roughly 3 kilometers broad even after traveling to the surface of the moon. Assuming that ordinary light was able to reach the moon, its beam would have fanned out greatly, resulting in a diameter of light on the moon.

The laser's capacity to concentrate its energy to very high intensities, with the intensity virtually keeping constant across long distances due to low divergence, is another significant characteristic. The intensity of a laser beam grows to a few hundred billion watts per square centimeter when it is concentrated by a lens to a point with a diameter of 1/1000 of a centimeter. This focused energy is so intense that sparks can readily be formed by the air it ionizes. Even the hardest materials, like diamonds, can be melted in a split second when the beam from a powerful laser is focused. Due to its specific properties, the laser is a significant tool in many applications. The first notable usage of the laser was in the lunar range experiment of the Apollo II Mission in 1969 when pulses from a ruby laser were sent from the earth to an array of retroreflectors placed on the moon's surface. The reflected beams were picked up by specialized detectors, and the distance between the moon and the earth was measured with a 15 cm accuracy by measuring the time it took the pulses to travel from the earth to the moon and back.

Since the inaugural laser demonstration in 1960, new laser applications in a range of fields are published practically every day. Applications for lasers In the domains of industry, medicine, military operations, research, and so forth. Additionally, the laser has already achieved substantial breakthroughs in engineering, data storage, holography, photography, surgery, and other domains. The primary significant laser applications are described in the Chapters on Laser Applications, even if it is not possible to demonstrate all of the lasers uses documented thus far in this tiny book. A breakthrough and quickly evolving field, laser beam technology has a wide range of uses in many different fields, including industry, medicine, communication, entertainment, and scientific study.

Laser beam technology takes use of tightly focused, coherent, and monochromatic light beams formed by photons' stimulated emission. Laser beams, in contrast to traditional light sources, may be concentrated to a very small point, enabling remarkable precision and accuracy. Due to their specific qualities, such as their great intensity, directionality, and quick pulsing, laser beams are an interesting technology for a range of tasks. When Albert Einstein initially put forth the theory of stimulated emission in the early 20th century, laser technology had its beginnings. Nevertheless, Theodore Maiman did not produce the first usable laser until the 1960s. Since then, the development of new laser types, better optics, and sophisticated control systems has sped up the development of laser technology.

Today, the manufacturing industry uses laser beam technology for several functions, including cutting, welding, drilling, marking, engraving, and surface treatment. Laser beams are applied in medicine for cancer treatment, surgery, and imaging diagnostics. While laser-based entertainment systems are utilized for light shows and special effects, laser communication systems are utilized to send high-speed data across enormous distances.

Laser beams are utilized in scientific studies for spectroscopy, microscopy, and holography as well as for examining the properties of materials. Furthermore, laser beams are utilized in remote sensing techniques like LIDAR (Light Detection and Ranging), which employs laser beams to measure distances and build three-dimensional maps of the environment. In conclusion, the advancement of laser beam technology has considerably benefited many different sectors and revolutionized how we live and work. Future potential and innovation are being fueled by the creation of new laser technologies and applications.

History of Laser Technology

The first CO2 laser was built in 1964 and only produced one milliwatt of power. CO2 lasers with a power output of greater than 1,000 watts were practical by 1967. In May 1967, Peter Houldcroft of TWI (The Welding Institute) in Cambridge, England, used an oxygen-assisted CO2 laser beam to cut through a sheet of steel that was 1 mm thick, marking the beginning of commercial laser materials processing.1970s The initial "Laser Machining" applications were made possible by continual advancements to CO2 lasers as well as the introduction of new kinds of lasers. In 1975, Laser-Work AG produced the first 2-axis laser system. The earliest applications were driven by the car and aviation industries, which were finding how beneficial lasers were for metal cutting and welding. 1980s. A new era of "Laser Materials Processing" began with the introduction of small, cheap lasers like the Carbon Dioxide Slab Laser. Applications now include processing organic materials like plastic, rubber, and foam in addition to cutting and welding metal [4]–[6].

DISCUSSION

A laser is a device that uses optical amplification to produce a coherent light beam. Gas lasers, fiber lasers, solid-state lasers, dye lasers, diode lasers, and excimer lasers are only a handful of the various types of lasers. These many laser types all share the same core elements.

Laser beam machining (LBM) is an outstanding material processing technique to manufacture a wide range of advanced materials, including difficult-to-machine sophisticated ceramics and composites. LBM can be utilized to treat these materials with intricate forms and sizes with better precision even in difficult-to-reach places. LBM is a nonconventional subtractive machining method utilizing the thermal energy of laser beams. During the machining process, a high-energy laser beam falls on the workpiece surface and eliminates the workpiece material by heating, melting, and vaporizing.Laser is an abbreviation for Laser Amplification by Stimulated Emission of Radiation. it is a contrivance for producing a narrow beam of light, capable of traversing across large distances without dispersion. It is also capable of being concentrated to give large power densities (108 watts per cm2 for high-energy lasers). A laser converts electrical energy into a highly coherent light beam

Principle of Laser Machining

It works based on the conversion of the electrical energy of a flash lamp into heat energy to emit the laser beam by pumping the energy. The laser beam is then focussed by a lens to deliver high energy in the concentrated form and helps to melt and evaporate the substance of workpiece. As the laser interacts with the material, the energy of photons is absorbed by the work material leading to a rapid rise in local temperature and result s in the melting and vaporization of the work material [7], [8].

Literature Survey

laser beam machining and discussed laser beam machining (LBM) is a commonly used thermal advance machining technology capable of high-accuracy machining of practically any material with complex geometries. co2 and nd:yag lasers are generally employed for industrial purposes. Drilling, cutting, grooving, turning and milling are the applications of LBM with distinct material removal techniques. Modeling and simulation of the LBM process are crucial for optimization purposes. Modeling can be done by using analytical, numerical, experimental, and artificial intelligence-based methodologies. This study presents a summary of the various methodologies used for modeling and simulation of the laser beam machining process as well as major research done on this topic so far.

laser beam fundamentally is a coherent, monochromatic beam of electromagnetic radiation that can propagate in a straight line with little divergence and occur across a wide range of wavelengths (ranging from ultraviolet to infrared). Lasers are frequently employed in manufacturing, communication, measurement, and medicine. The energy density of the laser beam can be adjusted by modifying the wavelength. This quality has made the lasers proficient in removing the extremely little amount of material and has led to the use of lasers to produce very small features in workpiece materials. The fabrication of small features (dimensions from 1 µm to 999 µm) in sheet materials by laser machining is defined as laser micromachining.

In the present study, the essential understanding of short and ultra-short laser ablation processes has been presented. The critical examination of numerous theoretical and experimental investigations is utilized to characterize the performance of laser beam micromachining (LBMM) on some of the sophisticated engineering materials.

Types of Laser Beam Technology

There are numerous varieties of laser beam technology, each with special characteristics and uses. The following are a few of the most popular kinds of laser beam technology:

1. **Solid-state lasers**: These lasers create the laser beam through a solid crystal or glass medium. They are commonly utilized in material processing processes like drilling, welding, and cutting. A solid-state laser is one in which the atoms that emit light are locked within a crystal or a glassy substance. For example,

   a. Ruby red (the chromium atoms embedded in the ruby's aluminum oxide crystal).
   b. Yttrium orthovanadate (Nd: YVO4), Yttrium lithium fluoride (Nd: YLF), and Yttrium aluminum garnet (Nd: YAG). They are used for cutting, welding, and marking of metals and other materials, and also in spectroscopy and for pumping dye lasers.

2. **Gas lasers**: These lasers produce the laser beam by employing a gas medium, such as carbon dioxide, helium-neon, or argon. They are utilized in procedures including laser surgery, academic research, and laser-based manufacture. Gas lasers often have a wide array of features. Gas lasers using numerous gases have been created and used for many purposes. They are one of the oldest types of lasers. For example,

   a. helium-neon (HeNe) laser is widespread in education because of its low cost.
   b. carbon dioxide lasers are extensively employed in industry for cutting and welding.
   c. metal ion lasers are gas lasers that create deep ultraviolet wavelengths. Another example is Argon-ion, Helium-silver (HeAg), neon-copper (NeCu), laser, etc.

3. **Semiconductor lasers**: These lasers produce the laser beam using a semiconductor substance, such as gallium arsenide or indium phosphide. They are commonly exploited in

communication systems like laser diodes and fiber optic networks. It is a unique, and possibly the most essential, type of laser. It is unusual because of its smaller size (mm×mm×mm), and its natural integration capabilities with micro-electrical circuitry. For example,

a. Silicon laser is significant in the field of optical computing.
b. Vertical cavity surface-emitting lasers, (VCSELs) whose emission direction is perpendicular to the surface of the water.
c. Quantum cascade lasers have an active transition between energy sub-bands of an electron in a system containing many quantum wells.

4. **Dye lasers**: The laser medium in these systems is a liquid dye. They are utilized in scientific research procedures like fluorescence microscopy and spectroscopy.

5. **Excimer lasers**: These lasers produce a high-energy laser beam using a combination of noble gases and halogens. They are commonly utilized in commercial and medical settings, including those requiring eye surgery and the manufacturing of microelectronics.

6**. Fibre lasers**: The laser medium in these devices is a fiber optic cable. They are often utilized in communication systems as well as in operations for processing materials like welding, cutting, and drilling.

7. **CO2 lasers**: The laser medium in these systems is carbon dioxide gas. They are often utilized in gynecology and dermatology as well as materials processing, such as metal cutting and welding.

How is Laser Technology Used

Many of the things we use daily use lasers as essential parts. Laser technology is used in consumer items like Blu-Ray and DVD players to read data from discs. Lasers are used in barcode scanners to process data. Numerous surgical treatments, like LASIK eye surgery, also involve lasers. Lasers are used in manufacturing to cut, engrave, drill, and mark a variety of materials.

Laser Action & Quantum Theory

Quantum theory's well-established principles serve as the foundation for laser action. The greatest modern physicist, Albert Einstein, stated that an excited atom or molecule will emit photons (packets of light) with the same wavelength as the impinging electromagnetic wave when stimulated by an electromagnetic wave (i.e., light). By designing and creating the first maser—an acronym for microwave amplification by stimulated emission of radiation—Charles Townes was the first to use this stimulated emission mechanism as an amplifier. A 1.25 cm wavelength in ammonia vapor led to the creation of the first maser. Townes and Arthur Leonard Schawlow invented the idea of employing a laser amplifier and an optical mirror cavity to create the maser at optical wavelengths.

Principle of Laser Action

The quantum theory claims that each atom can only have energies in certain discrete states or energy levels. The atoms are normally in their ground state, which has the lowest energy. The atoms in a substance can be stimulated to travel to one of the higher levels when light from a strong source, such as a flash lamp or a mercury arc, impacts it. Absorption is the name of this procedure. The atom emits a photon as it returns to its initial ground state after a very brief period at that level. This action is stated to be spontaneous or an emission. The two processes, called spontaneous emission and absorption, occur in a normal light source, If an outside photon with the exact energy needed for spontaneous emission strikes an atom while it is still in its excited state, the energy of the outside photon is augmented by the energy emitted by the excited atom. Additionally, both photons are discharged from the same excited state at the same phase. The operation of lasers depends on this procedure, known as stimulated emission. The laser is therefore analogous to a spring that has been cranked up and cocked, as the atom is stimulated or encouraged to emit its photon earlier than it would have done ordinarily under spontaneous emission.

To unlock it, a key is required, More and more atoms are compelled to emit photons when favorable conditions are formed for the stimulated emission, creating a chain reaction and releasing a vast quantity of energy. This results in a rapid accumulation of energy that generates light of a given wavelength (monochromatic light), traveling coherently in a certain, fixed direction. Amplification by stimulated emission is the name given to this phenomenon.

The population of a level is the total number of atoms present there at any specific time. The population of the lower level or ground state is generally higher than that of the upper level when the material is not activated externally. Population inversion is the process that occurs when the regular occupancy is inverted, with more people living on the upper level than on the lower level. For a laser action, this scenario is necessary. The met stable state, or upper energy level, must have a long lifetime for any stimulated emission to occur, meaning that the atoms must pause there for a longer length of time than they do at the lower energy level, Consequently, the exciting pumping mechanism for laser activity.

The cornerstone for the operation of lasers is a method called stimulated emission, which Albert Einstein initially defined in 1917. A photon of a given frequency interacts with an excited atom or molecule to activate a process known as stimulated emission, which leads to the release of a second photon that has the same frequency, direction, and phase as the first photon.

The original photon gets amplified as a result of this. Pumping energy into a medium, such as a gas, solid, or semiconductor, and causing a sufficient number of atoms or molecules to get excited, generates a population inversion in a laser. A second photon with the same frequency, direction, and phase as the first is released when a photon of the proper frequency interacts with an excited atom or molecule. This mechanism is known as stimulated emission. Following this, the second photon interacts with additional excited atoms or molecules, creating additional stimulated emission and an avalanche effect. This causes a succession of events to happen, and the end effect is the emission of a coherent, monochromatic, highly directional beam of light.

The properties of the laser medium and the laser cavity determine the attributes of the laser, such as wavelength, pulse duration, and power. With each trip through the laser medium, the laser beam is amplified because the laser cavity is an optical resonator made up of two mirrors, one of which is slightly reflective. While the type of mirror coating and the caliber of the laser medium affect the laser's pulse duration and strength, the distance between the mirrors governs the laser's wavelength and beam quality. Overall, the basis of laser action is the stimulation of emission, which amplifies light and forms a coherent, monochromatic beam of light with particular features.

Advantages and Disadvantages

Depending on the application and environment, laser beam technology has several benefits and drawbacks. The following are some of the most notable benefits and drawbacks of laser beam technology:

Advantages:

Great precision and accuracy: Laser beams may be concentrated to a very small point, resulting in great precision and accuracy in manufacturing operations such as drilling, welding, and cutting.

Non-contact: Because laser beams don't need to come into direct touch with the workpiece, there is less chance of contamination or damage, and processing can proceed at a fast rate.

Flexibility: A variety of materials, including metals, polymers, ceramics, and composites, can be worked with by laser beams.

Efficiency: Laser beams can be very effective, using little power and generating little waste.

Speed: High-speed processing with laser beams enables quicker production at more affordable prices.

Disadvantages

Safety risks: If not utilized appropriately, laser beams can constitute a safety risk by potentially damaging the eyes, burning the skin, or igniting a fire.

Price: The cost of laser beam technology can be high because it calls for specialized tools, facilities, and skilled workers.

Limited depth of penetration: Lasers may not be able to penetrate deeply into all materials, which limits their applicability in some situations.

Surface deterioration: Some materials may experience surface deterioration from laser beams, such as cracking or discoloration, which may change the material's characteristics.

Environmental impact: The use of laser beam technology may result in the production of hazardous waste, such as contaminated materials or toxic fumes, which must be properly disposed of.

Application of Laser Beam Technology

Lasers can be used for welding, cladding, marking, surface treatment, drilling, and cutting among other production operations. It is utilized in the automobile, shipbuilding, aerospace, steel, electronics, and medical industries for the precision machining of complicated parts.

Laser welding is useful in that it can weld at speeds of up to 100 mm/s as well as the capacity to weld incompatible metals. Laser cladding is used to coat cheap or weak items with a tougher substance to improve the surface quality. Drilling and cutting with lasers is advantageous in that there is little to no wear on the cutting tool as there is no touch to create damage. Milling with a laser is a three-dimensional procedure that requires two lasers, yet substantially decreases the costs of machining items. Lasers can be used to change the surface qualities of a workpiece. the appliance of laser beam machining differs based on the industry. In light manufacturing, the machine is used to engrave and to drill other metals. In the electronic industry laser beam machining is utilized for wire stripping and skiving of circuits. In the medical industry, it is used for cosmetic surgery and hair removal [9]–[11].There are many applications for laser technology including the following:

Laser welding

it is useful for combining sheet metal or stock parts of about 2.5 mm thick or less. Many metals and alloys can be welded by lasers like low carbon steel, stainless steel, titanium and its alloys, silicon bronze, etc. Another advantage of laser welding is no requirement of grinding after welding.

Laser cutting

A laser beam can be utilized in cutting metals, polymers, ceramics, fabrics, cloth, and even glass. It may also be utilized for cutting intricate shapes with sharp concern and slots. It is useful for cutting steel, titanium, nickel, certain refractory materials, and polymers but the cutting of aluminum and copper has been especially problematic.

Laser engraving

laser beam can be utilized for making or engraving to produce the controlled surface pattern on a workpiece.

Laser drilling

It can make small and very small holes of shallow depth. Most of the laser beam machining is used for the drilling of small holes in fuel filters, carburetor nozzles, hypodermic needles, jet engine blades cooling holes, etc. in the aircraft turbine industry, laser drilling is used for producing holes for air bleeds, etc.

CONCLUSION

The "laser" stands for "light amplification by stimulated emission of radiation." Resonant effects are what make lasers function. A coherent electromagnetic field is what a laser produces. All of the waves in a coherent electromagnetic energy beam have the same frequency and phase. Laser machining of composite materials requires short beam-material interaction durations (short pulse and high scanning speed) and/or short wavelengths, to minimize heat effects. A multiple-pass method is generally utilized for material removal. Compared with mechanical and water-jet cutting procedures, laser machining is slower, but some problems such as tool wear and water penetration can be avoided. With the availability of high-power picosecond/femtosecond lasers and high-power third or fourth harmonic diode pumped solid state lasers, laser machining of composite materials may become commercially viable and extremely competitive. Laser Beam Machining is one of the extensively utilized unconventional machining methods that are capable of manufacturing complex and exact shapes with very minimal tolerance. The main focus is related to laser drilling, laser cutting, and laser-induced bending. The execution of this LBM needs professional competence and operational expenditures are fairly pricey. With time there is plenty of advancements in the LBM and its assisted procedures as well as optimization strategies, which made some new research scopes in the LBM. Developments in modeling approaches have made new research scopes in the LBM and increased the performance of the LBM process.

REFERENCES:

[1] A. K. Dubey and V. Yadava, “Laser beam machining-A review,” *International Journal of Machine Tools and Manufacture*. 2008. doi: 10.1016/j.ijmachtools.2007.10.017.

[2] Y. Xie *et al.*, “Deep learning for the monitoring and process control of femtosecond laser machining,” *JPhys Photonics*, 2019, doi: 10.1088/2515-7647/ab281a.

[3] S. Gao and H. Huang, “Recent advances in micro- and nano-machining technologies,” *Frontiers of Mechanical Engineering*. 2017. doi: 10.1007/s11465-017-0410-9.

[4] P. Parandoush and A. Hossain, "A review of modeling and simulation of laser beam machining," *International Journal of Machine Tools and Manufacture*. 2014. doi: 10.1016/j.ijmachtools.2014.05.008.

[5] P. Patel, P. Gohil, and S. Rajpurohit, "Laser Machining of Polymer Matrix Composites : Scope , Limitation and Application," *Int. J. Eng. Trends Technol.*, 2013.

[6] S. Umredkar and V. Bhoyar, "Advance Manufacturing Processes Review Part V: Laser Beam Machining (LBM)," *Int. Res. J. Eng. Technol.*, 2019.

[7] G. Chang and Z. Wei, "Ultrafast Fiber Lasers: An Expanding Versatile Toolbox," *iScience*. 2020. doi: 10.1016/j.isci.2020.101101.

[8] Q. McCulloch, J. G. Gigax, and P. Hosemann, "Femtosecond Laser Ablation for Mesoscale Specimen Evaluation," *JOM*, 2020, doi: 10.1007/s11837-020-04045-3.

[9] J. Dutta Majumdar and I. Manna, "Laser processing of materials," *Sadhana - Acad. Proc. Eng. Sci.*, 2003, doi: 10.1007/BF02706446.

[10] M. K. Bhuyan *et al.*, "High aspect ratio nanochannel machining using single shot femtosecond Bessel beams," *Appl. Phys. Lett.*, 2010, doi: 10.1063/1.3479419.

[11] W. Wei, Z. Di, D. M. Allen, and H. J. A. Almond, "Non-traditional machining techniques for fabricating metal aerospace filters," *Chinese J. Aeronaut.*, 2008, doi: 10.1016/S1000-9361(08)60057-6.

CHAPTER 6

ADVANCED GAS WELDING TECHNOLOGY

Mr. Aravinda Telagu, Assistant Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: aravinda@presidencyuniversity.in

ABSTRACT:

Gas welding can be used to fuse nonferrous (metals without iron) and ferrous metals, and it doesn't need electricity to do so. Oxy-acetylene welding, which mixes oxygen and a fuel gas (typically acetylene), is usually used to attach thin metal pieces. To provide a graduate the advantage they need to achieve a welding career, it combines in-depth technical knowledge, welding expertise, and exposure to cutting-edge technology. The core talents needed by businesses, such as production, product invention, and inspection processes are discussed in this chapter.Gas welding is the procedure in which a gas flame is utilized to raise the temperature of the metals to be welded. The metals are heated up to melt. The metal flows and on cooling it solidifies. A filler metal may be introduced to the flowing molten metal to fill up the cavity produced during the end preparation.

KEYWORDS:

Fuel Gas, Filler Metal, Peen Hammer, Carbon Steel, Metal Pieces.

INTRODUCTION

The joining of two or more pieces of metal with gas welding requires the employment of a flame formed by the combustion of a fuel gas, such as acetylene, and oxygen. The edges of the metal pieces are melted with this heat, and as they cool, they fuse.The following steps are frequently included in the gas welding process:

The configuring up the equipment comprises attaching the welding torch's oxygen and fuel gas tanks and configuring the gas flow and pressure. Preparing the metal surfaces: To establish a solid, flawless bond, the edges of the metal parts that will be welded are normally cleaned and ready. The edges may need to be filed or ground, and any rust, oil, or other impurities may also need to be eradicated. The flame is ignited using a spark lighter or another ignition source, and it is then shaped and heated to the necessary degree. Metal heating: The flame is focused on the metal components, heating them until they start to melt.

Filler metal is introduced to the joint when the metal starts to melt to aid in the merging of the pieces. Usually, a wire or rod is injected into the joint to function as the filler metal. To achieve a strong, continuous weld, the filler metal and torch are moved back and forth along the joint, melting the metal and adding filler as necessary.Cooling the weld: After the welding is finished, the junction is given time to progressively cool. This aids in preventing cracking and other weld problems.

The kind of fuel gas utilized, the size and temperature of the flame, as well as the welder's expertise and experience, can all have an impact on the quality of a gas weld. Gas welding, however, can be a very effective and dependable way to join metal pieces if done correctly with the necessary instruments and techniques. Oxy-fuel welding, sometimes known as oxy welding or gas welding, is a method of fusing metals by using the heat produced by a gas flame. When the fuel gas usually used for welding, acetylene, is coupled with the correct amount of oxygen, a very high flame, ranging from 3150 to 3300.

Gas welding can be used to fuse nonferrous (metals without iron) and ferrous metals, and it doesn't need electricity to do so. Oxy-acetylene welding, which mixes oxygen and a fuel gas (typically acetylene), is usually used to attach thin metal pieces. To provide a graduate the advantage they need to achieve a welding career, it combines in-depth technical knowledge, welding expertise, and exposure to cutting-edge technology. The essential competencies needed by business, such as production, product innovation, and inspection processes[1]–[3].

The following are the essential tools for doing gas welding:An oxygen gas cylinder in a black hue with a brass valve with right-hand threads, An acetylene gas cylinder with a valve that has left-hand threads and is maroon or red in hue, An oxygen pressure controller, An regulator for acetylene pressure, Black oxygen gas hose, Red/maroon acetylene gas hose, A gas lighter, blowpipe with a pair of nozzles, and a welding flame, Carts for hauling cylinders of oxygen and acetylene, A set of spanners and keys, Fluxes and filler rods, Welder safety gear, such as an asbestos apron, gloves, and safety glasses.

We shall investigate gas welding's concepts, procedures, tools, varieties, applications, benefits, and downsides. In the liquid state welding procedure known as "gas welding," fuel gases are burned to produce heat. The contact surfaces of welding plates that are held together to form a junction are also melted utilizing this heat. The fuel gas used in this process is mostly oxy-acetylene gas. You can carry out this process with or without the use of filler material. If the filler material is employed, it is manually supplied into the weld zone.Most industrial procedures that call for welded joints use gas welding. The definition of welding is the application of heat to combine two metals, whether they are similar or dissimilar. The warmth supplied The essential instrument in oxyacetylene welding is the flame. The main objective of the welding device is to keep the flame alive and under control. To perform at its finest, the flame must have a suitable size, shape, and condition. By adjusting the acetylene and oxygen ratios, one can make three different types of flames. By employing tremendous heat to melt the components together and then allowing them to cool, which results in fusion, welding is a fabrication procedure that connects materials, often metals or thermoplastics. Welding is independent of lower temperature procedures that don't melt the base metal (parent metal), such as brazing and soldering.

The base metal is generally melted first, followed by the addition of filler material to generate a pool of molten metal (the weld pool), which cools to form a joint that, depending on the welded design (butt, full penetration, fillet, etc.), may be stronger than the base metal. To form a weld, pressure can either be applied alone, in combination with heat, or both. A form of shield is also necessary during welding to safeguard the filler. Welding can be done with a variety of energy sources, such as gas flames (chemical), electric arcs (electrical), lasers, electron beams, friction, and ultrasound. Welding can be done in a variety of places, including the open air, underwater, and in space, even though it is typically an industrial operation. Welding is a harmful activity, hence safety measures must be taken to prevent burns, electric shocks, eye impairment, inhalation of toxic gases, and exposure to strong ultraviolet radiation.

DISCUSSION

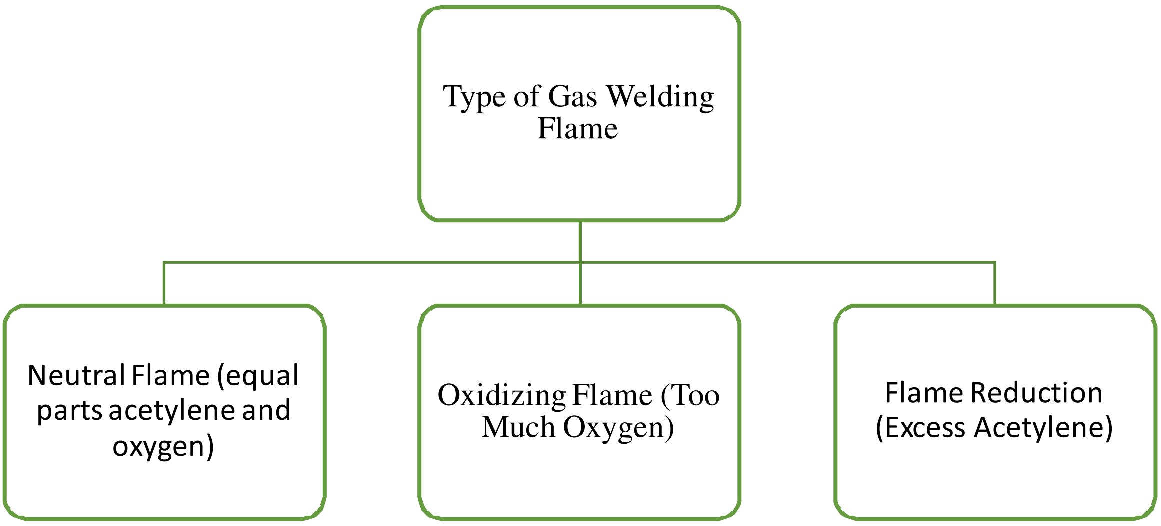
Compared to arc welding, the gas welding technique is significantly less difficult. All of the equipment is carefully linked during this operation. Through pressure regulators, the gas and oxygen cylinders were attached to the welding torch. Now, gas and oxygen are delivered to the torch at the optimum pressure so that they can combine properly. A striker ignites the flame. Make sure the torch's tip is pointing down. At this stage, the welding torch's valves are employed to control the flame. Depending on the welding situation, the flame is set at the natural flame, carburizing flame, or oxidizing flame. The welding torch was now going along the line where the joint was to be constructed. This will permanently link them by melting the interface component. The essential instrument in oxyacetylene welding is the flame. The main objective of the welding device is to keep the flame alive and under control. To perform at its finest, the flame must have a suitable size, shape, and condition. By adjusting the acetylene and oxygen ratios, one can make three different types of flames.

A file is a piece of high-grade steel that has been hardened and has rows of teeth that are inclined inward. It is used to remove superfluous material to smooth or fit metal parts. Typically, high carbon steel or tungsten steel is used to forge files, and then the teeth are cut, the steel is hardened, and the steel is tempered.

The gas-welding process uses an extremely high-temperature burst that is produced by the absorption of gas or a gas combination. The workpieces to be joined are afterward squeezed using this engaged blast in conjunction with an outside filler material for lawful welding. The most well-known type of gas welding is oxyacetylene gas welding. When welding using oxyacetylene gas, an oxygen and acetylene mixture burns and ignites at a temperature of roughly 3500°C.

According to Shiri, Nazarzadeh, Sharifitabar, and Afarani, when the engaged fire comes into contact with the workpieces, it softens the surface, generating a liquid pool and allowing welding to proceed. This kind of welding can also be used for brazing, bronze welding, metal shaping, and cutting[4]–[6].

Type of Gas Welding Flame



TYPE OF GAS WELDING FLAME

Tools And Accessories Used in Welding Shop

Flat file

A file is a piece of high-grade steel that has been hardened and has rows of teeth that are inclined inward. It is used to remove superfluous material to smooth or fit metal parts. Typically, high carbon steel or tungsten steel is used to forge files, and then the teeth are cut, the steel is hardened, and the steel is tempered.

Hack saw

The success of your project hinges on the hacksaw blade you use. If you select the incorrect blade, you can have problems cutting through the intended material. Similarly to this, a blade that is the incorrect size will not fit on a hacksaw. The length of the hacksaw should be your first focus. The length of these instruments varies from 6 to 12 inches. The blade you choose should fit the saw's length. The kind of material you're working with is the next thing to think about. Blades constructed of carbon steel are suitable for general-purpose use on hard plastic or soft metals like copper or lead, but bimetal blades are preferred when working with hard metals like stainless steel.

Try square

Try squares are mostly used to mark lines on work-pieces, check the squareness of neighboring surfaces or edges, and flatness of filed surfaces. It consists of a steel blade and stock that are fixed securely at a 90-degree angle to one another.

Steel rule/ Brass rule

A rounded, ball-shaped peen on one end of the head distinguishes the ball peen hammer from other sorts of hammers. In metalworking, this style of hammer is widely used to shape and form metal as well as to drive and set tiny nails or pins. You can also strike metal or other items with the flat side of the hammerhead. Other types of hammers include sledgehammers, which have a large, heavy head and are used for heavy-duty tasks like breaking concrete or driving stakes, claw hammers, which have a curved claw on the opposite end of the head from the peen, and mallets, which have a softer head and are used for tasks that require a soft touch.

Ball peen hammer

A hammer is a hand tool made of tool steel, largely used for striking metals. A hammer is named after its peen. The ball-shaped peen hammer is known as the ball peen hammer. The peen and face are hardened A rounded, ball-shaped peen on one end of the head distinguishes the ball peen hammer from other sorts of hammers. In metalworking, this style of hammer is widely used to shape and form metal as well as to drive and set tiny nails or pins. You can also strike metal or other items with the flat side of the hammerhead.

Other types of hammers include sledgehammers, which have a large, heavy head and are used for heavy-duty tasks like breaking concrete or driving stakes, claw hammers, which have a curved claw on the opposite end of the head from the peen, and mallets, which have a softer head and are used for tasks that require a soft touch. The gas welding technique does not directly entail the use of punches. A gas flame is used to heat metal to its melting point, and after that, a filler metal is used to glue the heated metal pieces together. This process is less focused on employing punches and more on heating, melting, and joining metal components. Punches may, nevertheless, be utilized in gas welding-related metalworking or manufacturing activities. For instance, metal parts that need to be welded together may be marked with punches to ensure perfect alignment and placement during the welding operation. Punches can also be used to generate microscopic depressions or indentations in metal components.

Punches

The gas welding technique does not directly involve the use of punches. A gas flame is used to heat metal to its melting point, and after that, a filler metal is used to glue the heated metal pieces together. This procedure is less focused on using punches and more on heating, melting, and connecting metal components.Punches may, however, be utilized in gas welding-related metalworking or manufacturing procedures. For instance, metal pieces that need to be welded together may be marked with punches to ensure exact alignment and location throughout the welding process. Punches can also be used to make tiny depressions or indentations in metal components.

Chipping Hammer

The chipping hammer has served the welding industry well for many years as the basic tool for the removal of slag from Shielded Metal Arc Welding and Flux Core Arc Welding. Fabricators, currently utilize alternative ways in production facilities to speed up the removal of slag from welds. The best slag is one that peels off by itself and only needs a modest effort to remove the balance it. Getting the correct filler metal, shielding gas, if employed, and flux combination will aid in this aspect. Besides the chipping hammer, air chisel, and air hammer, numerous additional pneumatically propelled instruments are utilized. The needle scalar is also extensively used for removing slag that is attached to the weld and doesn't readily come right off. The needle scalar leaves fewer tool marks than an air chisel or air hammer. In larger production facilities, especially the steel construction makers, the employment of a tool called the Wheelabrator is another more extensive piece of powered equipment for cleaning up base material after welding. Sandblasting and shot blasting are other choices for post-weld cleanup in large-scale operations where hand-working the components is cost prohibitive or not possible.

Electrode holder

The insulated handle that clamps onto the electrode is known as an electrode holder. To regulate the arc when welding, the welder uses this tool. Excellent current transfer between the electrode and the holder is one benefit. Using two holes at 45° and 90° to weld in various positions.

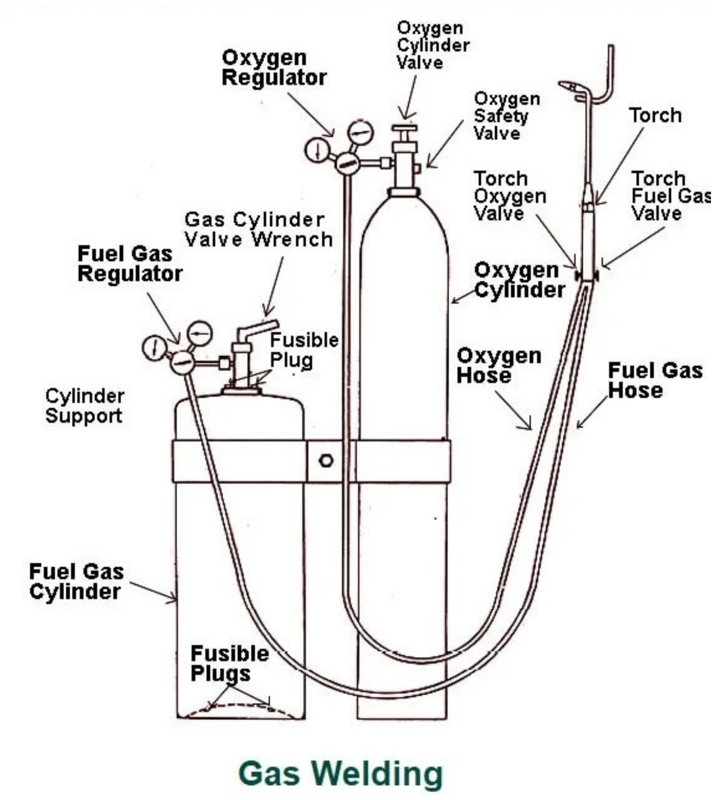


Figure 1 Gas Welding Arrangement Diagram.

Tongs

When welding, a sort of tool called tongs can be used to handle hot metal. They are meant to prevent the welder from touching the hot surface directly while holding and manipulating metal objects. For safety reasons, this is vital since it can help avoid burns or other accidents. Tongs typically have two arms linked by a pivot or hinge and are built of metal. The metal object may be moved around by the welder since the arms are built to grab it securely. Some tongs may have specific tips or ends that are built for carrying out particular duties, such as grabbing spherical items or squeezing into narrow spaces. It's vital to get the correct tongs for welding. are used to handle the hot metal (welding job) for positioning or while cleaning[4], [5], [7].

Wire brush

A wire brush can be kept in position using tongs. Wire brushes are widely used in welding to clean the metal's surface and remove slag from the welds. The wire brush usually has a wooden handle or grip with bristles or steel wires placed on it. The welder typically scrubs the metal's surface back and forth when using a wire brush for cleaning. This helps remove the surface of any dirt, rust, or other material that may be there. The welder will typically use the wire brush to gently scrape away any additional material that has accumulated on the weld's surface when removing slag from the joint.

Earth clamp

The earth clamp must offer the electrical current utilized in welding a secure and predictable path of return. When the welding machine is in use, electricity is created. This energy flows from the welding machine through the electrode, into the workpiece, and then returns through the earth clamp to the ground terminal of the welding machine. The electrical circuit would be incomplete without a securely fitted earth clamp, which could result in difficulties like welding errors or even electrical shock. The welder would generally choose a position on the workpiece or welding table where the clamp may be safely fastened before utilizing an earth clamp. The connection is then made strong and stable by tightening the clamp against the metal surface.

Advantages and Disadvantages

Advantages

1. It is simple to use and does not need a highly skilled operator.
2. In comparison to other welding methods like MIG and TIG, equipment costs are modest.
3. It may be applied on-site.
4. More portable than other types of welding, the equipment.
5. Additionally, it can be used to cut gas.

Disadvantages

1. It offers a rough surface finish. After welding, this technique needs a finishing step.
2. Large heat-impacted zones during gas welding might influence the mechanical properties of the parent material.
3. High-temperature naked flames present a greater safety risk.
4. It only works with thin, soft sheets.
5. No shielding area which causes more welding defects.

Application:

1. A multitude of industries employs gas welding. Here are a few of the most typical.
2. Repair work: One of the most often used gas welding applications is for repairs.
3. Fabrication of sheet metal: Gas welding is a simple method for joining thin to medium-gauge sheet metals.
4. Aviation industry Welding with oxygen-acetylene is frequently used to connect different aircraft elements.
5. Used in the automotive sector to weld frame and chassis components.
6. Joining High carbon steel: High carbon steel may be melted very effectively with gas welding.

As we've seen, one of the most significant and popular welding techniques is gas welding. Gas welding is one of the most often used welding techniques due to a combination of its comparatively low cost, simplicity of usage, and portability[8]–[10].

Safety Precautions in Gas Welding

While working in a welding shop, the following safety precautions must be taken into consideration:

1. Gas cylinders should always be handled carefully.
2. Before opening a cylinder valve, the regulator's adjustment screw must be completely loosened.
3. Never light a torch with matchsticks.
4. Never use grease or oil to lubricate the regulator valve as this could result in an explosion.
5. Wear eye protection whenever working.
6. The shop must have adequate ventilation.
7. Acetylene cylinders should be kept upright when being stored.
8. Avoid opening acetylene cylinders close to flames or sparks.
9. Never use pliers to remove torch tips.
10. The cylinder must not leak.
11. Consistently cover the valves with safety caps.
12. Bear in mind where the fire extinguishers are.

CONCLUSION

Nonferrous (metals devoid of iron) and ferrous metals can be fused using gas welding, which doesn't require electricity. Most typically, thin metal parts are joined by oxygen-acetylene welding, which combines oxygen and a fuel gas (generally acetylene). It brings together in-depth technical knowledge, welding expertise, and exposure to cutting-edge technology to provide a graduate the edge they need to land a welding career. This chapter covers the core skills required by businesses, such as production, product invention, and inspection procedures.To provide a graduate the advantage they need to establish a welding profession, it combines in-depth technical knowledge, welding expertise, and exposure to cutting-edge technology. The key talents needed by businesses, such as production, product invention, and inspection processes are described in this chapter. Gas welding is the method in which a gas flame is utilized to boost the temperature of the metals to be welded. The metals are heated up to melt. The metal flows and on cooling it solidifies. A filler metal may be supplied to the flowing molten metal to fill up the cavity generated during the end preparation.

REFERENCES:

[1] T. Yang, L. Chen, Y. Zhuang, J. F. Liu, and W. L. Chen, "Arcs interaction mechanism in Plasma-MIG hybrid welding of 2219 aluminium alloy," *J. Manuf. Process.*, 2020, doi: 10.1016/j.jmapro.2020.05.014.

[2] S. Egerland, J. Zimmer, R. Brunmaier, R. Nussbaumer, G. Posch, and B. Rutzinger, "Advanced Gas Tungsten Arc Weld Surfacing Current Status and Application," *Soldag. Inspeção*, 2015, doi: 10.1590/0104-9224/si2003.05.

[3] S. Kleinbaum, C. Jiang, and S. Logan, "Enabling sustainable transportation through joining of dissimilar lightweight materials," *MRS Bull.*, 2019, doi: 10.1557/mrs.2019.178.

[4] M. Rafieazad, M. Ghaffari, A. Vahedi Nemani, and A. Nasiri, "Microstructural evolution and mechanical properties of a low-carbon low-alloy steel produced by wire arc additive manufacturing," *Int. J. Adv. Manuf. Technol.*, 2019, doi: 10.1007/s00170-019-04393-8.

[5] H. Oguma, K. Tsukimoto, S. Goya, Y. Okajima, K. Ishizaka, and E. Ito, "Development of Advanced Materials and Manufacturing Technologies for High-efficiency Gas Turbines," *Mitsubishi Heavy Ind. Tech. Rev.*, 2015.

[6] N. Ahmed, *New developments in advanced welding*. 2005. doi: 10.1533/9781845690892.

[7] P. Thejasree, N. Manikandan, J. S. Binoj, K. C. Varaprasad, D. Palanisamy, and R. Raju, "Numerical simulation and experimental investigation on laser beam welding of Inconel 625," 2020. doi: 10.1016/j.matpr.2020.07.042.

[8] B. K. Henon, "Advances in Automatic Hot Wire GTAW (TIG) Welding," *Http://Www.Arcmachines.Com/News/Case-Studies/Advances-Automatic-Hot-Wire-Gtaw-Tig-Welding*, 2014.

[9] J. Vekeman, S. Huysmans, and E. De Bruycker, "Weldability assessment and high temperature properties of advanced creep resisting austenitic steel DMV304HCu," *Weld. World*, 2014, doi: 10.1007/s40194-014-0166-3.

[10] M. Grujicic, G. Arakere, A. Hariharan, and B. Pandurangan, "A concurrent product-development approach for friction-stir welded vehicle-underbody structures," *J. Mater. Eng. Perform.*, 2012, doi: 10.1007/s11665-011-9955-7.

CHAPTER 7

ADVANCED PROCESS DEVELOPMENT TRENDS: A STUDY

Mr. B Muralidhar, Assistant Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: muralidhar@presidencyuniversity.in

ABSTRACT:
The fundamental motive for welding process improvement is the requirement to improve the entire cost-effectiveness of joining processes in fabrication and manufacturing industries. Other factors may, however, influence the necessity for new procedures. Concerns regarding the safety of the welding environment and the probable shortage of experienced experts and operators in many countries have become key research topics. Many of the classic welding procedures mentioned are regarded as costly and risky, but it is feasible to enhance both of these qualities greatly by applying some of the advanced process innovations discussed in the following chapters. The background to the development of some of the major developments and current trends in the application of advanced processes are addressed here.

KEYWORDS:

Cost, Joint, Processes, Procedures, Rate, Welding.

INTRODUCTION

The basic motivator for welding process development is the requirement to increase the total cost-effectiveness of joining processes in fabrication and manufacturing industries. Other circumstances may, however, influence the necessity for new procedures. Concerns over the safety of the welding environment and the possible shortage of experienced specialists and operators in many countries have become significant study subjects. Many of the classic welding processes stated are regarded as costly and risky, but it is easy to boost both of these traits substantially by employing some of the advanced process innovations detailed in the following chapters. The background to the development of some of the significant developments and current trends in the application of advanced processes are addressed here [1]–[3].

Arc welding requires filler materials because they supply the necessary metal to create a solid link between two or more pieces. Depending on the type of metal being welded, the welding process, and the desired mechanical qualities of the resulting weld, filler materials are commonly available as wires, rods, or sticks. For arc welding, the most often employed filler materials are alloys of carbon and stainless steel, aluminum, and nickel. The melting temperature, chemical makeup, and mechanical strength are only a few of the distinctive characteristics that each material possesses and which have an impact on the welding procedure.It can be difficult to choose the best filler material for a particular welding application since there are so many things to take into account, including the type of connection, the thickness of the materials being welded, and the required weld quality. To maintain the strength and longevity of the completed weld, the proper filler material must be chosen. The creation of new filler materials with enhanced corrosion resistance, greater strength, and better ductility has attracted increasing attention in recent years. To enhance the caliber and uniformity of the welding process, researchers are also looking into new techniques for making filler materials, such as powder metallurgy and additive manufacturing.

Cost-Effectiveness

The cost of constructing a welded joint is the sum of costs related to labor, materials, power, and capital plant depreciation. The entire cost of welding operations in Western countries is generally dictated by the cost of labor and, in many traditional welding procedures, this can account for 70 to 80% of the total. This is depicted schematically. In the past, it seems to have been considered that the economic effectiveness of welding techniques was wholly dependent on the deposition rate. procedures that gave enhanced deposition rate were explored and a comparison of the common consumable electrode procedures. In general, the higher the deposition rate, the shorter the weld cycle time and the lower the personnel cost. Some of the more recent developments in methods with high deposition rates are addressed in the following chapters. Deposition rate may, however, be a false picture of cost-effectiveness if, for example, quality is lost and greater repair rates are necessary. The deposition rate is also an inadequate way of defining 'single shot' high joint-completion rate autogenous procedures such as explosive welding and laser welding. For a more full assessment of cost-effectiveness, it is obvious that the following additional criteria should be considered:control of joint quality, joint design, operating efficiency, equipment and consumable costs.

Control of Joint Quality

Traditional welding methods are regulated by a large number of interrelated operational factors and the joint quality typically depends on the optimization of these parameters as well as the careful control of pre-weld and post-weld treatments. To assure repeatable joint quality, the operating parameters derived from a combination of established 'rules and welding trials are described for each joint in the form of a welding method. For critical structural joints, this welding method and the operator may require formal certification by a certifying body. This process of procedure generation and qualifying is both time-consuming and costly and, once a method has been created, the additional cost required in adopting a new process may be prohibitive unless the cost of re-qualification can be recovered from the prospective savings. The success of this control strategy also depends on ensuring that the predetermined procedure is followed in production; this, in turn, requires monitoring the operation of the equipment utilized and ensuring that the operator conforms to the original technique. Unfortunately, this is not always the case, and additional costs are typically paid in post-weld inspection and weld repair. The development of procedures that enable the welding process to be regulated more effectively should have a substantial impact on prices. The use of more tolerant consumables, more repeatable equipment and processes, automation, online monitoring, and real-time control systems all contribute to improved overall process control. In addition, there is renewed interest in the use of modeling and parameter prediction approaches to enable the optimum welding parameters to be established for a given welding condition [4]–[6].

Joint Design

Over-specifying the joint requirements has a substantial influence on the cost of welding; in the example of a basic fillet weld, a 1 mm increase in the stipulated leg length can increase the cost by 45%. The choice of a specific joint design can automatically preclude the use of the most cost-effective process; for example, limited access or complex joint profiles may limit the process choice and the designer needs to understand the limitations of the joining process to avoid these restrictions. Conversely, the selection of an appropriate procedure may reduce both joint preparation expenses and joint completion time. In general, the joint completion time is related to the necessary weld metal volume and it can be observed. that this will vary greatly depending on the joint design. For example, utilizing the electron beam method, a butt joint in 20 mm thick steel will be finished more quickly than the identical GMAW weld which will require a 50∞ to 60∞ included angle to give good access. Process advancements that need low weld metal volume and limited joint preparation are therefore anticipated to be more cost-efficient

DISCUSSION

Operating efficiency

The operating efficiency of welding operations is commonly stated as the 'operating factor'1 which is the ratio of welding time to non-welding time given as a percentage. Values of operating factor of 15 to 20% are very unusual for MMAW welding but figures of 30 to 50% may be achieved with manual GMAW. Improvements in operating factors have a major influence on costs since they directly influence the labor element. The influence of operating factors on the labor cost The operational factor is frequently referred to as the 'duty cycle'; this is, however, liable to be mistaken with the duty cycle terminology which is used to define the output rating of equipment [7].

Post-Weld Operations

The welding process may cause difficulties that need to be resolved after welding. The most prevalent problems of this type are deformation and residual strains, however, metallurgical concerns such as grain growth and hydrogen-driven cold cracking and cosmetic problems such as damage to surface coatings and spatter deposits must also be considered. The necessity to carry out extra mechanical or thermal procedures following welding will increase the cost of fabrication and process advancements that lessen this requirement are desirable.The risk of defects often generates a requirement for costly post-weld inspection and non-destructive examination and, although recent codes of practice allow the significance of defects to be related to the service conditions, if rectification is required, this involves increasing the value of work in progress, causes production delays and is often labor intensive. Early identification of potential quality problems is therefore both desirable and cost-beneficial.To prepare the welded joint for its intended use, a series of activities are performed after the welding process. These activities are known as post-weld operations. In der Regel sind these operations are necessary to guarantee the quality and integrity of the weld and to improve the overall appearance of the finished product. Post-Welding operations include:

Inspection

After welding, the welded joint must be inspected to make sure it meets the required quality standards. Depending on the application and the specific requirements, this may include visual inspection, non-destructive testing, or destructive testing.

Safety and environmental factors

While the operator is typically covered by protective clothing, local screening, and ventilation, other employees in nearby locations may need further protection. These steps could be expensive in both affecting the overall effectiveness of the production process and themselves. Therefore, it is preferable to establish processes that reduce operating risks or enhance the workplace environment.

Skill and training requirements

Many of the traditional welding techniques needed highly skilled and dexterous operators, which could necessitate expensive training programs, especially when the aforementioned procedural requirements need to be met. The More sophisticated equipment has, unfortunately, sometimes taken the place of some of the skill reductions offered by modern processes, and the time spent setting up the process parameters may cause a drop in operating factor. Below are some developments that aim to make using the equipment simpler, but even the most cutting-edge procedures and tools can only be used to their full potential with the right amount of operator and support staff training. The increased productivity and quality will typically soon pay for the cost of this training.

Areas for development

If new welding techniques have the following benefits, they may be justified.

1. increased deposition rate
2. reduced cycle time
3. improved process control
4. reduced repair rates
5. reduced joint preparation time
6. removal of the operator from a hazardous area
7. reduced weld size
8. reduction in post-weld operations
9. improved operating factor
10. reduction in potential safety hazards;
11. simplified equipment setting.

Many of the more sophisticated process developments that have taken place have met some or all of these requirements; they will be detailed in the coming chapters, but the present trends in the application of Below, this technique are examined.

Process application trends

On a global scale, there are several significant developments in the use of welding methods, including:

1. process change in consumable electrode arc welding processes;
2. the increased use of automation;
3. increased interest in new processes (e.g. laser welding);
4. the requirement to fabricate advanced materials.

Consumable trends

Consumer behavior and consuming habits are subject to changing patterns and preferences, which are referred to as consumable trends. These patterns are driven by a number of variables, including societal transformations, environmental issues, population shifts, and technology improvements. For businesses to modify their goods, services, and marketing plans to satisfy changing consumer demands and expectations, it is essential to understand consuming trends. Here are some current trends in consumables. Products that are ecologically friendly and sustainable are in greater demand as people become increasingly concerned about the environment. They look for goods that are produced ethically across the supply chain, with no negative influence on the environment. This trend emphasizes organic and natural materials, recyclable and biodegradable packaging, and low carbon footprints.

Health & Wellness: As consumers' health and wellness become more important, there is an increase in the demand for goods that support both physical and mental well-being. This trend includes natural and organic beauty items, fitness and exercise gear, and wellness services like mindfulness and meditation applications. It also includes organic and healthy food options.Personalization and customization: Customers want experiences and goods that are tailored to their unique requirements and preferences. This trend comprises adaptable products, customised services that improve the user experience, and personalized suggestions based on data analysis and algorithms.

Digital transformation: As technology develops, customers are adopting digital platforms for communication, entertainment, and shopping. The way individuals consume goods and services has changed as a result of the growth of social media, mobile apps, and e-commerce. Customers anticipate flawless online interactions, customized digital content, and simple digital payment methods.

Conscious consumerism: A growing number of people are approaching their shopping decisions with greater awareness and consciousness. They take into account things like how companies affect society, ethical sourcing, fair trade principles, and assistance for small businesses. This trend entails a move toward companies and goods that share the ideals of consumers and enhance society.

Convenience and On-Demand Services: The popularity of on-demand services is a result of consumers' desire for convenience and rapid fulfillment. Customers are looking for platforms that offer convenience in a variety of areas of their lives, including food delivery, transportation, and home services, as well as quick and effective delivery alternatives.

Consumers are increasingly prioritizing experiences over material goods in what is known as "experience-based consumption." Spending on travel, eating out, going to events, and taking part in unusual activities that form memories and emotional ties are all part of this trend. flux-cored wire for a multi-pass vertical butt weld in 20 mm thick steel results in a more cost-effective option.

Automation

Automation can be used more frequently when single-shot techniques like resistance spot welding and continuous processes like GMAW are used. The developments in robotics have been well covered in the media. In contrast to the more varied use of robotic GMAW and GTAW systems, the automotive industry has several uses for resistance welding robots. It is also obvious that Japan has adopted robotics at a faster rate than Western Europe, as well as faster than the United States.

Less is known about the use of simple mechanization and non-robotic automation in welding, but in more recent methods like laser and electron beam welding, automation is a crucial component of the system. Particularly for GMAW and FCAW processes, simple low-cost mechanization is acknowledged as a very effective way of automation, and its use is anticipated to rise. Recently, modular automation systems that are computer-numerically controlled (CNC) handle many of the tasks typically carried out by welding robots while also allowing for more flexibility. With the aid of robot- or computer-controlled welding cells, facilities like online data recording, automatic component recognition, online quality assurance, and automatic reporting of machine malfunction and production statistics may all be provided. Welding integration as a well-controlled process in a flexible manufacturing facility is now technically possible. Integrated fabrication facilities of this sort have substantial capital costs, but the economic benefits must be evaluated in light of overall productivity gains and end-product costs.

New processes

It appears that innovative joining methods including laser welding, MIAB, and diffusion bonding are becoming more popular. In the past, the use of these procedures was only seldom permitted, however as the advantages It is anticipated that the utilization of these techniques would increase due to automation and the need for high-integrity joints in emerging materials. As was noted in Chapter 1, friction stir welding has made great progress and is still finding new uses in ductile materials where high-speed distortion-free welding is necessary. The spectrum of applications for this method is anticipated to expand as it is developed further.

Since 1988, when sales were estimated to be around 3000 units, the total worldwide sales of industrial lasers have been growing at a rate of about 10% per year. [24] It is anticipated that this growth rate will continue, with CO_2 laser sales increasing at a rate of 13% per year and Nd: YAG sales growing at a rate of 7% per year. High-power (3–4 kW) units are predicted to account for the majority of YAG growth. 20% of this rise is most likely attributable to welding applications. Hybrid (laser/GMAW) welding has recently received significant development attention, and the method has applications in the shipbuilding and automotive industries. With output levels of 3–20 kW, more effective diode and fiber lasers are now readily available, and extensive research is being done on how to use these tools for welding and surface engineering. Recently developed methods, including magnetic impulse welding, are already finding use in some sectors of the automotive industry. In addition, advancements in equipment, consumables, and process control, which will be covered in the coming chapters, have increased the viability of many of these processes.

Advanced Materials

As fabrications are subjected to more demanding service conditions and, in many cases, economic and environmental considerations favor greater strength-to-weight ratios, there is a rising desire to use more modern materials. These tendencies are visible in a variety of industries, including airplane construction, construction of microcircuits and offshore constructions. High-yield, thermomechanically treated low alloy steels, fiber-strengthened composite materials (like aluminum), polymers, cermets, and ceramics are examples of advancements in advanced materials. The use of these materials may be based on how simple it is to create solid connections between pieces made of the same material or, more frequently, between surfaces of different materials, such as metal-to-ceramic linkages. Although procedures for joining these cutting-edge materials are still being developed, solid-phase bonding techniques have produced encouraging results for ceramic-to-metal junctions and are already available for high-yield-strength steels [8].

Advantages:

Advanced process development trends in manufacturing have many benefits, including:

Improved Efficiency: Advanced process development trends like automation, robotics, and 3D printing can significantly increase efficiency by streamlining production processes and reducing the time and resources required to make products.

Increased productivity: Manufacturers can increase productivity by producing more products in less time with the use of advanced process development trends. Reduces costs and increases profits.

Improved quality: Advanced process development trends can also improve the quality of manufactured products by reducing errors and inconsistencies in the production processes.

Cost Savings: Manufacturers can save money by making processes more efficient, cutting waste, and reducing manual labor.

Customizing: Manufacturers can quickly and cost-effectively make custom products with advanced process development trends like additive manufacturing.

Improved Safety: Robotics and automation can increase workplace safety by reducing the need for workers to do dangerous tasks.

CONCLUSION

The most recent tools and techniques for process optimization are referred to as "advanced process development trends." These trends seek to raise productivity, decrease waste, streamline processes, and ultimately improve a company's bottom line. The implementation of digital twins to simulate and analyze processes, the adoption of Industry 4.0 technologies like the Internet of Things (IoT), the use of advanced materials and sensors, and the use of artificial intelligence and machine learning are some of the key trends in advanced process development. Significant improvements are being driven by these trends in several sectors, including manufacturing, healthcare, and energy, among others. Businesses can boost their competitiveness, increase profitability, and lessen their environmental impact by utilising these trends. businesses have a lot of options to improve their operations, their goods, and their overall performance thanks to the advanced process development trends. Businesses may maintain their competitiveness in a market that is becoming more dynamic and quickly evolving by keeping up with these developments and carefully implementing them. This section has to be prepared very carefully as many readers go through this section and prepare a remark on the full paper.

REFERENCES

[1] G. B. Tabrizi and M. Mehrvar, "Integration of advanced oxidation technologies and biological processes: Recent developments, trends, and advances," *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering*. 2004. doi: 10.1081/LESA-200034939.

[2] U. M. Dilberoglu, B. Gharehpapagh, U. Yaman, and M. Dolen, "The Role of Additive Manufacturing in the Era of Industry 4.0," *Procedia Manuf.*, 2017, doi: 10.1016/j.promfg.2017.07.148.

[3] C. H. Lee, C. L. Liu, A. J. C. Trappey, J. P. T. Mo, and K. C. Desouza, "Understanding digital transformation in advanced manufacturing and engineering: A bibliometric analysis, topic modeling and research trend discovery," *Adv. Eng. Informatics*, 2021, doi: 10.1016/j.aei.2021.101428.

[4] C. Y. Lin and C. Lu, "Development perspectives of promising lignocellulose feedstocks for production of advanced generation biofuels: A review," *Renewable and Sustainable Energy Reviews*. 2021. doi: 10.1016/j.rser.2020.110445.

[5] T. Kobayashi and L. Nakajima, "Sustainable development goals for advanced materials provided by industrial wastes and biomass sources," *Current Opinion in Green and Sustainable Chemistry*. 2021. doi: 10.1016/j.cogsc.2020.100439.

[6] C. Maree, M. Yazbek, and R. Leech, "Process of development of a contemporary curriculum in advanced midwifery," *Heal. SA Gesondheid*, 2018, doi: 10.4102/hsag.v23i0.1037.

[7] M. Schober and D. Stewart, "Developing a consistent approach to advanced practice nursing worldwide," *Int. Nurs. Rev.*, 2019, doi: 10.1111/inr.12524.

[8] K. Golhani, S. K. Balasundram, G. Vadamalai, and B. Pradhan, "A review of neural networks in plant disease detection using hyperspectral data," *Information Processing in Agriculture*. 2018. doi: 10.1016/j.inpa.2018.05.002.

[9] S. L. Sing and W. Y. Yeong, "Laser powder bed fusion for metal additive manufacturing: perspectives on recent developments," *Virtual and Physical Prototyping*. 2020. doi: 10.1080/17452759.2020.1779999.

[10] M. Xu, C. Wu, and Y. Zhou, "Advancements in the Fenton Process for Wastewater Treatment," in *Advanced Oxidation Processes - Applications, Trends, and Prospects*, 2020. doi: 10.5772/intechopen.90256.

[11] O. M. Rodriguez-Narvaez, J. M. Peralta-Hernandez, A. Goonetilleke, and E. R. Bandala, "Treatment technologies for emerging contaminants in water: A review," *Chemical Engineering Journal*. 2017. doi: 10.1016/j.cej.2017.04.106.

CHAPTER 8

MONITORING AND CONTROL OF WELDING PROCESSES

Mr. Yarlagadda Kumar, Assistant Professor
Department of Petroleum Engineering, Presidency University, Bangalore, India
Email Id: dheerajkumar@presidencyuniversity.in

ABSTRACT:
Monitoring and control of welding processes entail the use of numerous approaches to ensure that welding operations are done to the necessary quality standards. This includes monitoring critical process variables such as voltage, current, and travel speed, as well as managing aspects such as arc stability, heat input, and shielding gas flow. The purpose of monitoring and control is to improve the welding process to achieve the target weld quality, productivity, and efficiency while minimizing faults, rework, and downtime. Techniques such as real-time monitoring, closed-loop control, and process automation are typically employed to attain these aims. Effective monitoring and control of welding operations can enhance weld quality, reduce costs, and increase production, making it a crucial part of modern welding technology. In any manufacturing process, it is vital to guarantee that the outcome of the operations carried out matches some predetermined target. This involves controlling the operation of the process in some way, To get the intended result it is required to: Establish control relationships that enable the influence of the control variables on the process performance to be predicted. Monitor the process to ensure that it is running within boundaries set by the control relationships.

KEYWORDS:

Control, May, Parameters, Process, Procedure, Monitoring, Quality Weld.

INTRODUCTION

Compared with other production processes, welding has earned a reputation for being more difficult to manage and less likely to produce consistent quality. This is probably a result of the variety of associated control parameters, the complexity of the control connections, and the difficulty of monitoring process performance. It is also impossible to determine weld integrity without comprehensive non-destructive examination and mechanical properties cannot be assessed without destructive testing of the fabrication. These difficulties are recognized in international quality standards and welding is designated as a unique process in ISO 9000 and the control procedures required for welded fabrication are defined in ISO 3834. An indication of the number of control parameters that need to be considered for two opposing arc welding procedures. The classic manual control approaches will be explained in this chapter and the influence of improvements in processes and equipment will be explored [1]–[3].Substantial progress has also been made in the determination of control parameters, monitoring techniques, and automatic process control, and these improvements will be explained in detail.

Manual control techniques

Traditionally, welding operations have been managed by establishing appropriate operating envelopes for a given application, typically by trial and error, storing the most satisfactory parameters and applying them in production. In certain circumstances, it has been left to the welder to interpret inadequate drawings and establish conditions that satisfy the design criteria; for example, to produce a fillet weld of a given dimension. When improved control is necessary a welding technique is devised. This is a formal record of the parameters that have been determined to generate the required outcome and it is used to outline the actions necessary to achieve repeatable weld quality. Procedure control has become the standard way when high-quality joints are being produced.

Formal welding procedure control

1. establishing satisfactory operating parameters (procedure development
2. gaining acceptance of the proposed procedure (procedure qualification)
3. following the accepted procedure in practice (procedure management).

Procedure development

Welding method development involves the selection of the most suitable welding process; the identification of a suitable combination of welding parameters; the assessment of the performance of sample joints; and the amendment of parameters if test results fail to satisfy criteria. These factors are addressed below.

Selection of welding process. The choice of the process will rely on the material to be bonded, its thickness, and the welding position. In most cases several processes will fit the basic criteria of the application and the ultimate choice will depend on practical considerations (e.g. availability of equipment and personnel), constraints imposed by codes (see below), and economics. The choice of the process will affect the number of control parameters that need to be examined and the nature of the control linkages. Computer software developed to facilitate welding procedure selection is also available.

Determination of welding parameters. The welding parameters include all the factors which need to be set to assure repeatable performance. This may involve the joint design, cleaning, edge preparation, preheating, and post-weld treatment as well as the process control parameters such as speed, voltage, and current. The application may call for a certain joint arrangement, but it is usually important to establish the details of the plate preparation. Predetermined joint profiles are accessible from published literature and welding codes.

These codes contain 'safe' preparation information which has been tested for the application specified by the standard. They give a straightforward technique of joint design, but, in some circumstances, they may restrict the choice of procedure and joint profile. Even when these recommended joint designs are employed, it is usually still important to qualify the operation especially if a novel process/technique is to be applied. The process control parameters can also be calculated by reference to public data, pre-qualified methods, or codes and standards. Alternatively, welding trials may be essential to determine optimal parameters, operating tolerances, and the optimum welding circumstances. At this step, the combination of process and parameters are chosen must be capable of generating a joint of the specified repeatable quality cost-effectively. The avoidance of probable defects must be taken into account when choosing the process and may significantly influence the selection of welding consumables, operating parameters, pretreatment, post-weld heat treatment, and inspection [4]–[6].

The challenges which need to be considered are determined by the weldability of the material as described. In the case of structural steel, the possibility of hydrogen-assisted or hydrogen-induced cold cracking (HACC/ HICC) must be considered. Fortunately, the principles governing the formulation of These characteristics are sometimes referred to as 'essential variables' and if these are changed outside permitted limits requalification of the technique may be necessary for safety procedures to avoid heat impacted zone (HAZ) HACC2 are well established and are covered in most national and international codes. These principles show the necessity for hydrogen-controlled filler materials, and enable the preheat and heat input needs to be derived from a knowledge of the chemical composition of the steel or its carbon equivalent and the total thickness of the material. The conclusion of the development process will be a formal welding procedure specification (WPS) or proposal which may consist of a basic list or more frequently it will be created as a printed. At this stage, the technique is a 'proposal' and, although it may have been generated from comparable applications, it is untested or unqualified.

Assessment of cooperative performance. To evaluate whether the procedure will create the desired joint properties, it will be necessary to carry out mechanical and non-destructive analysis of sample welds which are made using the prescribed welding parameters. Whilst HAZ HACC is widely understood, the incidence of weld metal HACC has increased as higher-yield steels are utilized. The guidelines for the control of weld metal HACC are more complex and currently under examination. Amendment of process. If the described procedure fails to achieve the needed results, it may be necessary to repeat the process and change the welding parameters.

Procedure qualification

The agreed WPS, frequently under the supervision of the client or an independent approving agency. The welded joints are submitted to a prescribed selection of non-destructive and mechanical tests, the results of which are documented in a procedure qualification record (PQR). The competence of the welder is typically a crucial element in deciding the final weld quality. The welder's skill may be measured and 'calibrated' using a generic approval process. It may also be required to qualify a specified welder to carry out a certain procedure.

Procedure management

Management of welding procedures employing this technique involves maintenance of procedure specification and qualification records; calibration of welding and ancillary equipment; and monitoring compliance with the defined procedure. Maintaining procedural records.

Having established a satisfactory procedure and secured procedure qualification, it is vital to maintain a record of the parameters and techniques utilized and to manage the delivery of this information to the shop floor to enable consistent joint quality to be achieved. In many circumstances, this information will be required on an irregular basis particularly when small batches of fabrications are required. The welding method specification documents will also be necessary when tendering for new projects, when establishing procedures for new work, or when investigating production difficulties.

A fabricator will soon develop a vast library of procedures and it is vital to devise a suitable method for storage and retrieval. Many firms are now employing computer database systems for procedure management to decrease duplication and increase access to procedure data. Validity of parameters and calibration of equipment. The legality of the procedure will depend on the feasibility of establishing the same operational conditions: when the process is employed with the stated parameters, by a different operator in a different workplace using equipment and consumables of the defined kind. If the parameters supplied are vague or ill-defined, the final weld may well be poorer than those prepared at the method development stage.

For example, in GMA welding when voltage is utilized as a control parameter, the voltage provided should be the arc voltage measured as near to the arc as possible. Open circuit (or no-load) values may be easier to measure but are meaningless unless the static properties of the power source are also specified. In addition, since there may be a large voltage drop in the welding cable at greater currents the terminal voltage of the power source, as shown by the power source meters, is likely to be higher than the arc voltage and prone to vary with cable length and diameter. In the case of welding consumables, these should be specified according to a recognized national or international code that regulates their composition restrictions and performance rather than by commercial names. (In some circumstances, the user may need to impose explicit constraints on performance and composition.) The method of measurement of electrical parameters should be stated [e.g., root mean squared (RMS) or mean] and, in some situations, it may be required to indicate the type of instrument and the measuring technique. The tolerances on procedure variables should be defined with careful respect to the equipment capabilities and constraints. For example, new equipment will be calibrated following a manufacturing standard, but the tolerances allowed are typically fairly large; for most equipment, values of ±10% of those specified are permissible and repeatability of settings between equipment cannot be guaranteed. Calibration of existing equipment may also be challenging, for example in the case of cheap MMA equipment which often has poorly defined marks on controls that are vulnerable to wear. In GMAW, equipment meters, where equipped, often become damaged and deteriorate in the usual welding environment and cannot be depended on for calibration reasons.

DISCUSSION

Welding Procedure Control

Control of the welding may be an informal process, where the welding engineer or the welder is left to analyze the requirements and select appropriate welding settings, or a more formal method may be employed, in which the adequacy of the welding procedure is checked and documented [7].

The traditional approach of control by use of formal welding procedures depends on:

1. developing and proving satisfactory welding parameters by procedure trials and testing
2. keeping the same parameters in production
3. monitoring using final inspection and non-destructive examination (NDE)
4. rectification of faults by repair and rework

It is anticipated that, provided all the process inputs remain fixed, a sufficient repeatable output, in terms of weld quality, will be obtained. Any input faults or interruptions in the process that cause deterioration of quality may not be recognized until final inspection. This may be considered to be an open-loop system since the quality of the output is not used directly to control the process; the control loop is closed by manual intervention to correct any errors, but this is often carried out after the weld has been completed and the only means of correction is repaired. Full qualification and approval of operations in this way is a costly and time-consuming process and is usually only warranted when particular joint quality requirements must be reached. However, in many circumstances, it is essential to apply these strategies to obtain an acceptable amount of control and satisfy quality assurance criteria.

Monitoring

Measurement of welding parameters and calibration of equipment is essential when any kind of control is to be implemented. The prerequisites for formal welding procedure control have been mentioned above, but the availability of proper monitoring methods is also a prerequisite of any automatic control system. Considerable advancements in the methods of monitoring welding operations have been made and some of the techniques available will be explored here.

Welding parameters and measuring techniques

The techniques will be discussed under the following headings:
These procedures may need to be adopted to satisfy quality systems standards such as the ISO3834, ISO 9000 EN 29000 series, or specialized fabrication standards e.g. for pipelines, pressure vessels, and bridges**.**

1. conventional meters
2. computer-based instrumentation
3. measurement of welding parameters
4. stability measurement
5. dynamic resistance measurement
6. deviation monitors
7. vision systems

Conventional meters

Analog and digital measuring. Both analog and digital techniques are utilized in the measuring of welding parameters. In analog systems, the signal to be measured is turned into an indication which changes continuously in response to fluctuations of the input signal. In analog meters, the incoming voltage may be transformed into the deflection of an indicator needle electromagnetically. Alternatively, for quickly changing signals, the indicator may be a beam of electrons that is scanned across a cathode ray tube screen by the deflecting coils of an oscilloscope. Analog measuring techniques give a strong visual representation of the rate of change of parameters and are important when monitoring process stability. Analog meters also give a decent estimate of mean output levels when the signal is subject to random changes (e.g. when monitoring the current in MMA welding).

Quantitative measurements may be made by reading a calibrated scale. The indication offered by this sort of meter is continuous and the resolution relies on the scale and the care with which the readings are collected. To be precise, the meter scale needs to be huge, but, with conventional systems, this entails a rather hefty mechanical movement which may reduce the rate of response of the instrument. To obtain a permanent record of the indicated values it is necessary to record the movement of the indicator on paper or film; this may be achieved using a strip of continuously moving recording medium, which is marked by a pen attached to a moving potentiometric carriage or a light beam which is deflected onto photosensitive paper by a galvanometer. In digital measuring systems, the analog signal is transformed into a number on a preset scale before it is shown. The resolution of the instrument will depend on the analog-to-digital conversion (ADC) device employed, an eight-bit device will provide a resolution of 256 increments, but a 12-bit device will give 4096 and a 16-bit device will allow 65 536 increments to be resolved.
4Oscilloscopes give a clear indication of the amplitude and frequency of regular, periodically fluctuating signals but for transient or irregular signals single-shot instruments such as the computer-based systems described below must be employed. If the full-scale reading of the instrument is 256 V, an eight-bit ADC would give a resolution of 1 V and a 16-bit device

would provide 0.004 V resolution. For many welding applications, eight-bit accuracy is adequate, particularly if the signal is conditioned to limit the full-scale value. The advantage of digital measurement systems is that they provide a direct numeric output and this may be saved or recorded electronically as discussed below.

Digital systems are often more resilient than analog meters, however, they are sometimes subject to electrical interference. The downside of the digital approach is that it is difficult to comprehend the digital display if the parameter being monitored is fluctuating fast and the 'mean' values may be arrived at in multiple different ways (e.g. by electronic processing of the incoming signal or by calculation). This may lead to modest discrepancies between the numbers measured with different digital meters and may be responsible for substantial variances when compared with classic analog meters.

Computer-based data loggers

Computer-based data loggers as used in general process control and biomedical applications were originally solely employed in welding research applications, but purpose-built monitors for calibration and control of welding operations are now available.The notion of computer-based instrumentation is illustrated. The analog signal to be monitored is amplified or attenuated by a signal-conditioning circuit, which consists of standard electrical components. The output of this stage may be electrically isolated from the remainder of the instrument by isolation amplifiers, and hardware filters may be incorporated to reduce electrical noise. Isolation is particularly necessary when high voltage welding signals are being detected, where common-mode difficulties emerge and to avoid spurious signals when low currents or voltages are being monitored.

The analog signal is digitized by an ADC similar to that used in digital voltmeters. The use of eight-bit ADC converters is again acceptable for many welding applications assuming the input is scaled to an appropriate level. To give facilities for monitoring several welding parameters, the conditioned analog signal from several inputs may be scanned by a multiplexer before being transferred to the ADC.

Common mode problems: when monitoring welding current and voltage simultaneously, it is possible to connect the instrumentation in such a way as to short-circuit the output of the power supply.

A high-current path may mistakenly occur either in the interconnecting leads or, more seriously and less clearly, through the ground or earth connection of the instrument. Such mistakes can result in catastrophic damage to welding instrumentation. The digital output from the ADC is sampled at a rate set by the clock rate of the CPU and the control program. A range of programs and operating settings may be stored in the program memory (typically an EPROM) and the proper sample circumstances may be chosen for a specific application. The microprocessor also specifies where the digitized values are stored, how they are processed, and whether they are displayed on some in-built indication or sent to an external device for storage or display.

Systems of this type are capable of reading the instantaneous value of the input level every 100 ms or even faster. It is possible to keep these instantaneous values in the RAM and they may be shown to reproduce the waveform of the incoming signal in much the same way as an oscilloscope, the difference being that the data are stored and may be studied repeatedly. The data may also be transferred to non-volatile memory (e.g. floppy disc, battery-backed RAM, tape) and a tangible copy of the waveform may be obtained with the aid of a printer or plotter. In more sophisticated systems, the data may be exported via an Ethernet link, the internet, or a factory bus to remote sites.

To avoid inaccurate representation of the waveform, known as ‘aliasing’, the sampling frequency should be at least ten times that of the waveform being measured; with inter-sample times of 100 ms, the sampling frequency is 10 kHz and signal frequencies lower than 1 kHz are accurately represented; this response is perfectly adequate for a general assessment of the common welding waveforms found in pulsed GTAW and GMAW although higher sampling speeds are sometimes required when investigating highspeed transient events. The welding waveform in memory may be displayed on a monitor and evaluated. Some devices additionally allow computations to be conducted on the waveform and discrete values of pulse parameters may be presented. The number of data which may be captured is, however, regulated by the memory available, and, at high sample rates, the random-access memory will be filled extremely quickly. If extensive information concerning the waveform is not required the incoming signal may be handled in real-time and a more compact data file preserved. Two typical strategies which have been employed in welding applications are event monitoring and derived data storage.

Normal welding parameter monitoring

Temperature. The high temperatures reached in welding may be measured using temperature-indicating paints or crayons, fusible indicators, bi-metal thermometers, thermocouples, infrared thermometers, or thermal imaging. Temperature-indicating paints and crayons change color about the surface temperature of the material. They are easy for site usage, but their accuracy depends to a certain amount on the care with which they are applied and the interpretation of the colours. Fusible indicators melt and, in some circumstances, change shape when they reach a prescribed temperature. They give a clear indicator that a given temperature has been attained, but no direction on the actual temperature of the material during the heating and cooling cycle. Bi-metal thermometers are contact devices that rely on the response of a bi-metal strip to temperature, the deflection of the strip being converted mechanically into the movement of a needle. The indication of temperature is continuous and easily read, however, the accuracy is generally less than 10% of full scale.A more accurate form of temperature measuring involves the use of a thermocouple as a sensor. The thermocouple junction produces a small voltage that is proportional to its temperature; this voltage may be detected directly by an analog meter or it may be digitized and shown directly or stored as a permanent record. The signal from the thermocouple is usually tiny Thermistors and resistance thermometers may be used to provide similar electrical output signals, but thermocouples are usually more suitable for the range of temperatures normally encountered in welding and related processes.

Stability monitors

The measurement of process stability is of interest for assessing the performance of the consumable electrode arc welding processes. It may be used to assess the process performance during production as well as support the development of consumables and equipment. The operating performance of standard SMAW and GMAW procedures may be verified by welding trials done by a skilled welder.

Deviation monitors

Dynamic resistance. The quality of resistance spot welds may vary according to the surface conditions of the plate being welded, electrode wear, electrode force fluctuations, current shunting, and transient changes in the welding parameters. Various ways of monitoring spot weld quality to determine the effect of these fluctuations have been presented but the dynamic resistance technique is probably the most suitable for industrial application. In this system, the instantaneous welding current and voltage are detected and the resistance of the metal between the electrodes is determined.If computer-based procedures are utilized to capture the data, the resultant dynamic resistance curve may be plotted on the monitor screen immediately after the weld has been performed. The normal dynamic resistance curve for a decent weld in plain carbon steel. The curve may be separated into three zones:

Automated control techniques

Using adequate monitoring systems and mechanized welding, it is possible to remedy process irregularities automatically without the need for physical involvement. All of the approaches involved rely on the application of a control systems approach and it is vital to grasp the basic concepts of control as applied to industrial processes before considering the common applications.

Basic requirements for closed-loop control

For successful closed-loop control in welding, adequate feedback signals must be collected; these must be coupled in some way to the parameter to be managed. A proper error signal must be generated and the system must be able to respond to the required correction. The feedback signals may be obtained by monitoring the normal welding parameters or by employing sensors or transducers which offer indirect data. The relationship between the output and the control parameters may be defined by a mathematical model, algorithm, or equation. How the control parameters are corrected is defined by the control strategy and its efficacy will largely depend on the reaction rate of the system. The emergence of electronically regulated power sources has enabled considerable advancements to be achieved in this field. The main uses of automatic process control in welding are line following/seam tracking, arc length control, penetration control, and online quality control. These are discussed below.

Many line-following and seam-tracking systems have been developed for welding and these may be categorized according to the sensor systems employed. Tactile sensors. The simplest tactile sensor is the spring-loaded guide wheel which maintains a fixed relationship between the welding head and the joint being followed. This low-cost method may be utilized extremely well on simple mechanized tractors and delivers reduced set-up times and increased uniformity. A more sophisticated tactile sensor utilizes a probe that translates displacement to an electrical signal which is fed back to the motorized welding head allowing the torch to be repositioned to follow the seam[8]–[10].

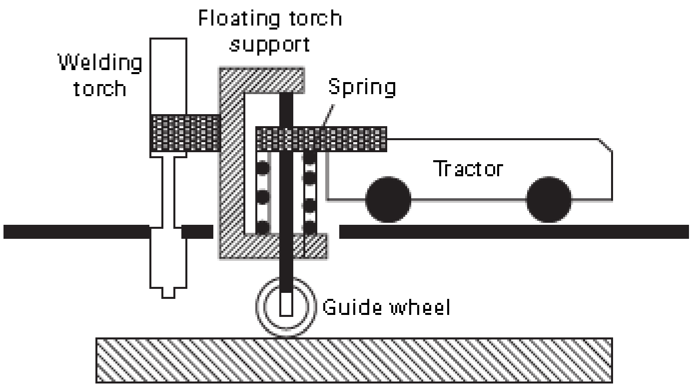


Figure 1Tactile torch height control (research gate)

Whilst these methods are essentially simple, tracking errors may emerge if the surface condition of the plate is poor or in multi-run conditions, where the probe must trace a convex weld deposit. These issues may be avoided by utilizing customized probe tips (e.g. to cope with tack welds). Pre-weld sensing/joint location. In fully automated and robotic welding cells, the seam may be found before welding using tactile or non-contact sensors. A common strategy is to utilize the end of the GMAW electrode as a contact probe. In robot applications the torch moves to a taught position in the area of the joint, the head is then moved from the taught point along the z-axis until it comes into contact with the workpiece, (contact is detected by a high-voltage, low-current DC signal). The contact point is confirmed by a short slow sweep along the x-axis away from the contact spot and returning. The torch then travels along the x-axis until it contacts the other plate and again a short, slow-speed traverse away from and back to the second contact site is conducted. From the measured data the joint intersection point is computed and the torch is moved to a suitable start position [11]–[13].

CONCLUSION

The study carried out within the scope of this work permits us to infer that it is vital to continue the research in the field of the control and monitoring of welding parameters, sensors, and automatic control approaches. We have uncovered new links between the parameters and the final quality will be examined for industrial applications. With modern electronic circuits and existing advanced equipment, it is possible to control processes in real-time with the appropriate quality. Control of welding penetration is one of the factors required more frequently by which continues the development of systems for this goal. The capture of the thermal image sensors and laser sensors is incredibly efficient but constitutes a significant cost. The optical sensors are the most versatile and sophisticated but are also the most expensive. Other systems, utilized for the control of the features of the arch, are efficient in many applications and are accessible at a low price. In the market, there are systems of hardware and software quite diversified and suited for monitoring and control of welding applications. The present collection of data allows us to infer that now on the market there is a large selection of products for the control and monitoring of the welding. The user seeking a solution to a specific case should be understood that an effective system for the control and monitoring of a given application of welding technology requires integration, for example, for a certain type of sensor with welding equipment and a system of positioning and monitoring between the torch and the piece.

REFERENCES:

[1] Z. X. Ma, P. X. Cheng, J. Ning, L. J. Zhang, and S. J. Na, "Innovations in monitoring, control and design of laser and laser-arc hybrid welding processes," *Metals*. 2021. doi: 10.3390/met11121910.

[2] D. Mishra *et al.*, "Real time monitoring and control of friction stir welding process using multiple sensors," *CIRP J. Manuf. Sci. Technol.*, 2020, doi: 10.1016/j.cirpj.2020.03.004.

[3] D. Mishra, R. B. Roy, S. Dutta, S. K. Pal, and D. Chakravarty, "A review on sensor based monitoring and control of friction stir welding process and a roadmap to Industry 4.0," *Journal of Manufacturing Processes*. 2018. doi: 10.1016/j.jmapro.2018.10.016.

[4] J. Breitenbach, T. Dauser, H. Illenberger, M. Traub, and R. Buettner, "A Systematic Literature Review on Machine Learning Approaches for Quality Monitoring and Control Systems for Welding Processes," 2021. doi: 10.1109/BigData52589.2021.9671887.

[5] Y. Wang *et al.*, "Coordinated monitoring and control method of deposited layer width and reinforcement in WAAM process," *J. Manuf. Process.*, 2021, doi: 10.1016/j.jmapro.2021.09.033.

[6] R. H. G. E. Silva, J. C. Dutra, and G. Locatelli, "A didactic computational tool for monitoring and control of arc welding processes - Teaching and research," *Comput. Appl. Eng. Educ.*, 2012, doi: 10.1002/cae.20390.

[7] M. Ramakrishnan and V. Muthupandi, "Application of submerged arc welding technology with cold wire addition for drum shell long seam butt welds of pressure vessel components," *Int. J. Adv. Manuf. Technol.*, 2013, doi: 10.1007/s00170-012-4230-0.

[8] N. Chandrasekhar, M. Vasudevan, A. K. Bhaduri, and T. Jayakumar, "Intelligent modeling for estimating weld bead width and depth of penetration from infra-red thermal images of the weld pool," *J. Intell. Manuf.*, 2015, doi: 10.1007/s10845-013-0762-x.

[9] C. Xia *et al.*, "A review on wire arc additive manufacturing: Monitoring, control and a framework of automated system," *Journal of Manufacturing Systems*. 2020. doi: 10.1016/j.jmsy.2020.08.008.

[10] H. C. Wikle, F. Chen, S. Nagarajan, and B. A. Chin, "Survey of infrared sensing techniques for welding process monitoring and control," *J. Chinese Inst. Eng. Trans. Chinese Inst. Eng. A/Chung-kuo K. Ch'eng Hsuch K'an*, 1998, doi: 10.1080/02533839.1998.9670426.

[11] B. Wang, S. J. Hu, L. Sun, and T. Freiheit, "Intelligent welding system technologies: State-of-the-art review and perspectives," *Journal of Manufacturing Systems*. 2020. doi: 10.1016/j.jmsy.2020.06.020.

[12] M. Kos, E. Arko, H. Kosler, and M. Jezeršek, "Penetration-depth control in a remote laser-welding system based on an optical triangulation loop," *Opt. Lasers Eng.*, 2021, doi: 10.1016/j.optlaseng.2020.106464.

[13] G. Locatelli and J. C. Dutra, "An integrated system for data monitoring and differentiated control of welding processes," *Weld. Int.*, 2010, doi: 10.1080/09507110902844659.

CHAPTER 9

WELDING AUTOMATION AND ROBOTICS: A COMPREHENSIVE REVIEW

Dr. Udaya Ravi Mannar, Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: udayaravim@presidencyuniversity.in

ABSTRACT:
Welding is the uniting of metals. What welding does is unite metals or other materials at their molecular level with the technology we have at present. I say "at the moment" because welding technology is always changing, and with so many armed forces relying on it to create their defense products, there are welding procedures we are yet to learn about. What we know about modern welding is that there are four components to a weld. The four components are the metals themselves, a heat source, filler material, and some type of protection from the air. Until the end of the 19th century, the sole welding procedure was forging welding, which blacksmiths had used for generations to combine iron and steel by heating and pounding. Arc welding and oxy-fuel welding were among the first procedures to evolve late in the century, and electric resistance welding followed soon after.

KEYWORDS:

Automation, Control, Robot, Welding, Weld.

INTRODUCTION

Welding technology grew significantly during the early 20th century as World War I and World War II boosted the demand for reliable and economical joining methods. Following the wars, various modern welding techniques were developed, including manual methods like SMAW, today one of the most prevalent welding methods, as well as semi-automatic and automatic procedures such as GMAW, SAW, FCAW, and ESW. Developments proceeded with the invention of laser beam welding, electron beam welding, magnetic pulse welding (MPW), and friction stir welding in the latter part of the century. Today, the science continues to develop. Robot welding is prevalent in industrial settings, and researchers continue to create new welding procedures and gain a greater understanding of weld quality Due to continuing increase in the necessity of high production rates, precision, and labor costs, automation has been adapted to the welding technology. The first automation applications started with mechanized, automatic, and semi-automated MIG-MAG systems [1], [2].

Many traditional welding procedures are work-intensive and a review of welding costs suggests that approximately 70 to 80% of the entire cost may be accounted for by the human element. Welding automation is a technique of decreasing the overall cost of the welding operation by replacing some or all of the manual work with an automated system. The introduction of automation may, however, have considerably more relevance than its primary effect on labor costs; in particular, its effect on the following factors must be considered: safety and health; product quality, and supply flexibility.

Safety and Health

Most welding methods are potentially hazardous; they emit particulate smoke, poisonous gases, noise, and a range of electromagnetic radiation, which varies from ultraviolet radiation with arc procedures to x-rays in electron beam welding. These risks are well known and techniques for dealing with them have been created. The steps which must be taken to protect the welder and accompanying personnel are, however, costly and may complicate the welding operation or necessitate the use of cumbersome protective clothing. There is also the danger of human error which may expose welders and those around them to unnecessary risk.In addition to these process-related hazards, there are risks associated with the application; such as welding in tight spaces, underwater, or in radioactive conditions. Automation is a way of separating the operator from the process- and application-related hazards and, in addition, it offers the prospect of increasing the control of the welding environment

Product Quality

Reproducible product quality may frequently be difficult to attain with manual welding procedures, particularly when sophisticated materials and complex joint designs are involved. Increasing the amount of automation can considerably enhance uniformity, increase throughput and minimize the cost of inspection and rejection.

Supply flexibility

It is typically easier to match output to demand with automated systems than it is with labor-intensive activities. This is particularly true in welding circumstances where lengthy training and qualifying of welders may be required before a productivity improvement can be realized.

Automation options

Welding automation may vary from simple positioners to fully integrated systems. For clarity, the various possibilities will be described under the following headings:

1. simple mechanization
2. dedicated and special-purpose automation
3. robotic welding
4. modular automation
5. programmable control
6. remote-control slave and automated systems.

Simple mechanization

The most frequent simple mechanization systems may be grouped under the following headings**:**

1. tractor systems
2. positioners and manipulators

Tractor systems

These are based on a basic electrically operated tractor, which may be driven over the plate surface or may be put on a track and driven by a rack and pinion. The welding head is mounted to the tractor usually in some type of movable clamp. Direct-mounted friction drive systems are normally deemed sufficient for submerged arc welding, whereas, for GMAW and flux-cored wire welding, track-mounted gear-driven systems are preferred since they are less prone to slip. The track is generally supplied in straight lengths for linear seams but it is possible to obtain circular track rings for pipe welding and complete annular tracks for circle cutting and welding. The user may also adapt these devices to suit a particular application using a wide range of standard accessories; these include torch oscillation devices to allow positional GMAW welds to be performed, trailers to carry ancillary equipment (e.g. wire feed units), motorized cross slides and tactile seam-following devices [3], [4].

Applications of the driven device

The portability of the equipment makes this sort of device particularly suitable for welding applications on big fabrications such as marine structures, buildings, and storage tanks. A noteworthy example of this type of application is the use of a tractor and oscillator for the completion of some 5000 m of vertical and horizontal butt welds in the manufacture of austenitic stainless steel cell liners at the British Nuclear Fuels Ltd. (BNFL) reprocessing plant at Sellafield. The joint configuration was a square butt weld in 304L stainless steel, welded onto a plain carbon-steel or stainless-steel angle which was precast into the concrete of the cell walls. In this application, pulsed transfer GMAW was employed with a solid filler wire, and electronic power sources were provided with synergic control. In this example, the fabricator was able to manufacture consistent high-quality joints in a time that would have been impossible to accomplish with manual welding. A comparable system was utilized in the construction of 96 m of butt welds in a 24.4 m diameter crane tub in 35 mm thick BS 4360 50D material. It was anticipated in this instance that the cost saving was around £30 000 compared with vertical welding utilizing the manual metal arc procedure. These tractor-based systems are exceedingly versatile and with a little ingenuity may be designed to fit a wide range of applications. An example of the utilization of a standard tractor system for a new application.

The application required the stainless-steel nut insert to be welded at intervals into huge carbon-steel plates. A leak-proof fillet weld was required and skilled GTAW welders were not available. GMAW welding with a small diameter stainless-steel filler wire and a helium/argon/CO2 shielding gas was found to offer an acceptable bead profile, however, access and the high welding speed made it impossible to maintain consistent quality using manual procedures.

The tractor and track system was accordingly changed as illustrated; a GMAW torch was substituted for the conventional oxy-fuel cutting system, and an insulated peg was used to place the assembly in the insert (and protect the thread from splatter damage). The overall cost of the automation system was under $2000 and a significant number of high-quality joints were produced with an average welding time of 20 s. This example indicates that, although these systems are normally more suitable for long weld seams with simple geometry they may also be applied to considerably smaller connections. They are also more easily applied with the consumable electrode methods (GMAW, FCAW, SAW) although special systems for GTAW and plasma welding are also available. This sort of automation still requires regular monitoring by a welder, but the welder is away from the immediate proximity of the heat source, and the exposure to fumes is decreased; the fatigue factor is also reduced.

DISCUSSION

Fixed welding stations

Simple rotary positioners and welding lathes may be used to move relatively tiny components under a fixed welding head or even a manually held flame. Using simple jigging, this type of automation may easily be justified for relatively small batch volumes. It is particularly ideal for circular weld paths, but fixed linear slides are also available for straight seams. Even low-cost systems can have facilities for synchronization of power source switching and weld crater fill facilities. For bigger workpieces, column and boom positioners, motorized beams, roller beds, and turntables are offered. Like tractor systems, these units are best ideal for simple geometric shapes and consumable electrode procedures, and they are flexible to a range of applications restricted only by the size and weight of the components being joined. The key advantage of this sort of technology is the ability to carry out welding in the down-hand position which permits higher deposition rates and higher quality to be attained. These advantages are most significant on heavier sections and can result in huge cost reductions despite the high initial cost of the positioning equipment. Typical setups of these systems are presented [5], [6].

The most typical application area for columns and booms, roller beds, and heavy turntables is for longitudinal and circumferential seams in the fabrication of pressure vessels and power generation equipment. Very big units have also been utilized for constructing circumferential joints in submarine hull sections and power generation system drums.

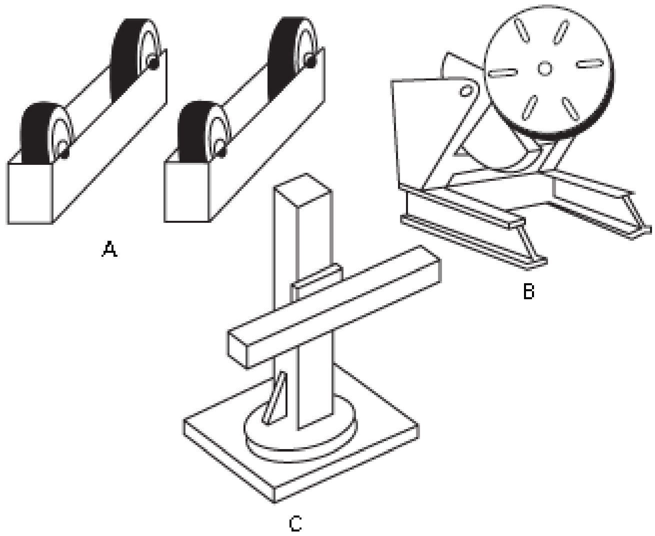


Figure 1 Heavy positioning equipment (not to scale): A, roller bed; B, tilting turntable; C, column, and boom.

Dedicated automation

Dedicated automation entails the creation of a unique welding system for a particular application and the resultant equipment may not be flexible to changes in joint or component design. This form of automation is usually only warranted for large production volumes of components with an extended design life. Dedicated automation has typically been utilized for automotive components such as road wheels and exhaust systems using a wide range of welding methods including resistance spot, GTAW, and GMAW. The welding head is often merely a single station of a multi-station automation system, which prepares the component for welding and also carries out finishing processes; in such circumstances a 'carousel' design with a single-load–unload station is often utilized.

Dedicated welding systems have also been deployed, where lower production numbers and shorter product life cycles are foreseen, but the welding environment is very hostile or the quality of the finished product is of key concern. Examples of this type of application are to be found in the nuclear sector, both in the processing of radioactive materials and the creation of important fabrications. An example of the sort of equipment utilized for this latter use was employed for GTA welding of the advanced gas-cooled reactor (AGR) standpipe joints on the Heysham and Torness (UK) power station projects. The deployment of costly dedicated automation with a sophisticated power source1 and control system was justified on the grounds of the unacceptability of errors and the repeatability of performance. The necessity to purpose design the specialized systems around a specific component usually makes the cost of such equipment costly and many dedicated automation applications are now being tackled using the modular or the robotic approach.

Special-purpose Automation Systems

Special-purpose automation has been designed for certain applications where comparable joints are to be performed on a range of component sizes. Some examples are simple seam welders, orbital welding systems, and the GMAW stitch welder.The power supply used was a transistor series regulator with facilities for pulsed GTAW, programmed touch starting, and arc length control. The welding head was additionally equipped with a vision system for remote monitoring of the weld area.

Seam welders

The seam welding of sheet metal using the GTAW, plasma, and GMAW processes to make simple cylinders or continuous strips has been a commonly repeated necessity. To cater to this type of application, conventional automated equipment which clamps the neighboring edges and moves a welding head along the seam has been designed. The equipment is suited to a range of material thicknesses and workpiece dimensions but is devoted to longitudinal seam welding.

Orbital welding systems

The necessity to produce circumferential welds in pipe and tube fabrication applications is answered by a range of orbital welding systems, which include tube-to-tube heads, tube-to-tube plates, and internal bore welders. These are usually portable systems which locate on or in the tube to be joined and revolve a GTAW head around the joint. Larger devices may be tractor-mounted on a circumferential track similar to the simple tractor systems described above, whilst the smaller systems utilize a horseshoe clamp configuration. Wire feeding and arc length control may be implemented in the welding head and more advanced systems may allow the welding parameters to be altered gradually as the torch advances across the seam. These techniques are extensively utilized in power station construction for boiler tube joints and tube-to-tube plate welds.

A notable illustration of the productivity savings that may be realized with these techniques as compared with manual welding is the application of orbital welding techniques to the production of more than 60 000 butt welds in stainless-steel pipework at the BNFL reprocessing plant. The introduction of orbital welding equipment, coupled with enhanced pipe preparation and purging techniques, yielded an improved first-time pass rate (from 50–60% to 87–90%) for each weld and more than halved the person-hours per weld. The use of a preplaced consumable socket permitted basic square-edge pipe preparations to be employed, provided joint alignment, prevented the use of a wire feed system, and allowed a single-pass welding method to be implemented. As in many applications of this type, extra benefits were realized by customizing the automation technique to suit the application.

GMAW stitch welder

The GMAW stitch welder is a revolutionary device in which a GMAW welding flame is positioned on a small motor-driven slide. The assembly is mounted in a head which automatically locates in the weld seam and mechanically fixes the torch height and angle.

The weld length and welding speed are preset by the operator (up to a maximum of 150 mm with this machine) and the welding process is launched by a simple press button. The device is perfect for producing consistent-size fillet welds and has been built for ease of usage with the user holding the unit in a vertical or horizontal posture.

Robotic welding

Industrial robots are not humanoid welders but are characterized by the British Robot Association as: An industrial robot is a reprogrammable device meant to both manipulate and move components, tools or specialized production implements through changeable programmed motions for the completion of specified manufacturing activities. In the case of welding robots, the 'tools or specialized manufacturing implements'3 comprise welding heads, wire feed systems, and tracking devices.

The methods for which robot welding systems are presently offered include GMAW, FCAW, SAW, GTAW, plasma, resistance spot, laser, and NVEB welding.

The normal industrial robot welding system comprises:

1. A mechanical arm or manipulation system
2. A welding packages
3. A control system.

Mechanical manipulation systems

A range of common configurations of manipulating systems has evolved and these are presented. The most typical arrangement for general-purpose welding robots is the articulated arm usually with six or more axes of movement. The advantage of the articulated arm is its flexibility The word robot was first used by Karel Capek in his play Rossum's Universal Robots which was first published in 1920. The notion of computer-controlled humanoids has remained in science fiction and if anything, the robot has been humanized further initially by Asimov and more recently by Adams, 'Marvin the Paranoid Android'. Although industrial robots may be given human traits, particularly when they fail to operate in the intended manner, they are simply programmable and, usually, computer-controlled actuators. Unfortunately, the fictitious image has tended to color our perception of industrial robots and may have boosted our expectations or influenced our assessment of their applicability. Often referred to as 'end effectors.

capacity to reach tough access locations (it may be no coincidence that it has a similar configuration to the human arm). The SCARA (Selective Compliance Assembly Robot Arm) configuration has traditionally been employed for assembly operations and has limited positional capabilities; it has, however, been used by some manufacturers as the basis of a simple, easily taught four to the five-axis machine for small batch production. A SCARA robot system has also been deployed for the refurbishment of worn crusher hammers. This is not a traditional application of robots due to the unexpected wear profile. In this situation, the differences in wear were accommodated by leveraging the tolerance of the FCAW process combined with the manual selection of one of three preprogrammed 'jobs' based on visual assessment of the wear. Other uses of robotic wear replacement have depended on pre-machining the worn item to a predefined profile before robotic build-up.

Cartesian or gantry robots have been designed for very small high-precision applications and where very large operating envelopes are required. These typical configurations may be customized to specialized uses; for example, it is usual to suspend articulated arm robots from overhead gantries for improved access and it is feasible to design special robot configurations by rearrangement of the axes. Whilst the latter system may not appear to be related to the typical welding robot, it nevertheless offers an important facility for re-programmability to suit diverse applications. One modification of the common layout is the use of a linear slide to enable the full robot to traverse the length of a component or a weld seam. Miniature portable and rail-mounted robots of this type have been created for welding huge constructions [7]–[9].

Drive systems

The arm may be driven by pneumatic, hydraulic, or electrical actuators. Hydraulic power systems are appropriate for applications requiring great load-bearing capability and restricted speed control and may be used for resistance spot welding. Most fusion welding robots, however, are now equipped with DC servo motor drives. Stepper motor drives have been employed for small precision systems; these offer the advantage of inherent feedback of output shaft position but suffer from a lack of power.

The welding packages

The welding package for robotic welding will depend on the method being employed, but several significant aspects of these packages may be recognized.

Welding Packages for Resistance Welding

For resistance welding, the robot end effector needs to carry a portable resistance welding gun. The cannon must be durable to ensure repeatable functioning but it must also be small and maneuverable. Inevitably, this leads to some sacrifice in design and, to carry the weight of the conventional resistance welding head and the related wires, it is normally necessary to utilize a heavy-duty robot. The welding transformer may be detached from the welding head, although this necessitates the use of hefty secondary wires and potential power losses. Some gun designs allow the electrode assembly to be swapped during normal operation to access different regions of the fabrication. Resistance welding is a ‘pick and place’ type application: the robot places the welding head at the joint position; the electrodes close on the joint and the weld is created; the robot then moves the welding head to the next point and repeats the welding operation. The travel between points is carried at a high speed and neither the speed nor the absolute position in space need be carefully maintained during this motion. Since the resistance spot welding robot is not frequently required to follow a seam, it is not normally necessary to use joint location and the following equipment.

Welding Packages for Arc Welding

For arc welding applications a power source with facilities for remote control and output stabilization is required. The utilization of electronic regulatory systems and computer control was discussed. simplifies the control interface between the robot controller and the welding system as well as ensuring that repeatable performance can be obtained. In the GTAW system, the robot merely needs to carry a reasonably lightweight torch and cables, whereas, in GMAW and FCAW applications, the filler wire must be provided to the welding head. Trouble-free wire feeding is vital to avoid system failure and it is recommended to put the wire feeder at the rear of the robot arm with a fairly short conduit to conduct the wire from this feeder to the torch. Some systems employ an auxiliary feeder immediately adjacent to the torch to enable positive wire feeding and it is typical to use large-capacity pay-off packs of low-curvature wire to improve findability. Wire-cutting and torch-cleaning facilities must also be provided and in certain situations, replaceable torch heads are also employed; these are stored in a carousel and may be automatically replaced during the robot cycle.

Welding packages for laser welding

In laser welding applications the laser beam may be carried down the robot arm to the workstation via a series of mirrors in the case of a CO2 laser or using flexible fiber optic cables in the case of Nd: YAG diode and fiber lasers.

Robot control systems

The robot control system is required to:

1. control the position of the welding head
2. control the welding package
3. interface with auxiliary systems
4. interface with the operator
5. provide program storage.

Control of position

By driving three or more actuators simultaneously the end of the robot arm may be made to trace any path inside its three-dimensional operational region. However, to enable the position and velocity of the end effector to be regulated, information indicating the position and rate of change of position of each actuator or axis must be acquired and processed. The location of the individual actuators is normally retrieved through a shaft encoder which is mounted to the output shaft of the drive motor. The information from these encoders is fed into the control system, where it is recorded to enable the position of the arm to be reproduced. Very early systems recorded the encoder positions directly on magnetic tape and the information was played back through the servo motor controllers to reproduce the preset path. The present generation of robots use microprocessor control systems and the positioning information is usually compressed and stored in some type of non-volatile memory.

Control of welding functions

The control system must coordinate the motion of the arm with the required welding functions. It must be able to commence and stop the welding operation in a controlled manner and should have facilities for adjusting the operational parameters of the process.

Interface with auxiliary functions

The control system must be capable of receiving information from several auxiliary systems; for example, it must be able to respond to an instruction to start the welding operation and should be capable of checking various conditions, such as the presence of the workpiece in the welding jig and the closure of safety doors. It should also be capable of delivering output signals to auxiliary systems; to trigger the movements of a work-handling fixture for example. Most robot controllers are provided with a significant number of configurable input/output facilities of this type. Ethernet and other factory bus systems (such as CAN bus) are growing widespread as auxiliary and welding system connections. Such technologies offer access to remote networks.

Interface with the operator

There are numerous layers of operator interface with most robot systems. The simplest of these is the teaching/programming interface and the production/ operator interface. The programming interface allows the welding process to be taught and checked, and the production/operator interface may allow the selection of a particular preprogrammed job, but often just allows the welding cycle to be launched or terminated. The general structure of the robot controller and its interfaces is illustrated[10]–[12].

CONCLUSION

Robotic welding is a vital tool for many industrial organizations because it enables them to produce high-quality items faster and more efficiently than ever before feasible using manual procedures. Welding is the joining of metals. What welding does is combine metals or other materials at their molecular level with the technology we have now. I say "at the moment" because welding technology is always improving, and with so many armed forces relying on it to build their military products, there are welding techniques we are yet to learn about. What we know about modern welding is that there are four components to a weld. The four components are the metals themselves, a heat source, filler material, and some sort of protection from the air. Until the end of the 19th century, the sole welding process was forge welding, which blacksmiths had used for generations to combine iron and steel by heating and pressing. Arc welding and oxyfuel welding were among the first processes to arise late in the century, and electric resistance welding followed soon after.

REFERENCES

[1] C. Loukas *et al.*, "A cost-function driven adaptive welding framework for multi-pass robotic welding," *J. Manuf. Process.*, 2021, doi: 10.1016/j.jmapro.2021.05.004.

[2] J. Norberto Pires, "Robotic Welding, Intelligence and Automation," *Ind. Robot An Int. J.*, 2009, doi: 10.1108/ir.2009.04936bae.005.

[3] J. Norrish, "Welding automation and robotics," in *Advanced Welding Processes*, 2006. doi: 10.1533/9781845691707.218.

[4] J. Muhammad, H. Altun, and E. Abo-Serie, "Welding seam profiling techniques based on active vision sensing for intelligent robotic welding," *Int. J. Adv. Manuf. Technol.*, 2017, doi: 10.1007/s00170-016-8707-0.

[5] H. Amrutha, J. Ajinkya, and M. Surabhi, "Application of failure modes and effects analysis (FMEA) in automated spot welding process of an automobile industry: A case study," *J. Eng. Educ. Transform.*, 2021, doi: 10.16920/jeet/2021/v34i0/157156.

[6] R. Singh, *Applied Welding Engineering: Processes, Codes, and Standards, Third Edition*. 2020. doi: 10.1016/C2019-0-03490-5.

[7] J. Ogbemhe and K. Mpofu, "Towards achieving a fully intelligent robotic arc welding: A review," *Ind. Rob.*, 2015, doi: 10.1108/IR-03-2015-0053.

[8] Tzyh Jong, "Robotic Welding, Intelligence and Automation, RWIA'2010," *Lecture Notes in Electrical Engineering*. 2011.

[9] Y. Xu, G. Fang, N. Lv, S. Chen, and J. Jia Zou, "Computer vision technology for seam tracking in robotic GTAW and GMAW," *Robot. Comput. Integr. Manuf.*, 2015, doi: 10.1016/j.rcim.2014.09.002.

[10] J. Norrish, "Monitoring and control of welding processes," in *Advanced Welding Processes*, 2006. doi: 10.1533/9781845691707.179.

[11] Y. Chen, S. Su, Q. Li, and H. Yang, "Multi-sensor data fusion for online quality assurance in flash welding," 2019. doi: 10.1016/j.promfg.2019.06.162.

[12] H. Li *et al.*, "Transient temperature and heat flux measurement in ultrasonic joining of battery tabs using thin-film microsensors," *J. Manuf. Sci. Eng.*, 2013, doi: 10.1115/1.4024816.

CHAPTER 10

EXPLORING THE NARROW-GAP WELDING TECHNIQUES

Mr. Sagar Gorad, Assistant Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: goradsagarramachandra@presidencyuniversity.in

ABSTRACT:
Low distortion, excellent weld mechanical qualities, and very high joint finishing rates are all characteristics of the one-pass-per-layer narrow gap welding technique. Unfortunately, the procedure is prone to centerline cracking and a lack of sidewall fusion. These two flaws are both connected to variances in the joint opening. Machined levels and incredibly tight joint opening tolerances are needed to prevent these flaws. The design, development, and qualification of a specialized Narrow Gap Welding System are covered in the accompanying paper. Through-the-arc tracking and closed-loop adaptive control are both used by the computer-controlled system to prevent common flaws. To weld thick portions more affordably, narrow gap welding, also known as narrow groove welding, was created. Small, included angles, often in the range of 2–20°, are used in this welding technique to create joints that require less welding material and less time to fill.For the construction of huge structures and pressure vessels, narrow gap welding is crucial because it reduces the amount of weld metal and deformation brought on by shrinkage.

KEYWORDS:

Narrow-Gap, System, Joint, Welding, Low Distortion.

INTRODUCTION

When a weld is prepared with nearly parallel sides, which distinguishes narrow gap joint designs, the first benefit grows with plate thickness while the latter effect remains constant. Although there isn't a consensus on what constitutes a "narrow" gap, the authors contend that a joint aspect ratio of 5 or higherwhich compares plate thickness to gap widthis sufficient. This would increase the minimum plate thickness for a 12mm gap to 60mm, which is around the minimum thickness required to obtain economic benefits from using arc welding methods to join thin gaps. For a given thickness, other techniques like EBW or ESW would have various aspect ratios and, as a result, distinct economic advantages [1]–[3].

The post-weld inspection and repair process can be better controlled to result in cost savings, or the joint completion time can be shortened. The goal of many process advances has been to use automation and higher metal deposition rates to shorten the time it takes to construct the joint, which will lower labor costs. Reduce the weld size or joint volume as an alternative. The potential of a lower weld size in fillet welds will rely on design limitations, and the process operating conditions can easily be adjusted to create a smaller weld volume. Significant changes in weld metal volume in butt welds may necessitate changing the joint configuration, the process, or both. A collection of process advancements that have been specially created to reduce the amount of weld metal in butt welds is referred to as "narrow-gap" welding. The majority of the development and application of the procedures listed below are related to low-alloy and plain carbon steels.

Principles and features of narrow-gap welding

The joint volume and, thus, weld completion time, in typical "V" preparations, substantially rise in proportion to the square of the thickness. The weld metal volume and joint completion rate drop as the preparation angle is decreased, and if a tiny parallel-sided gap is employed, the difference becomes significant, especially on thicker sections. Certain methods, including flash butt, friction, MIAB, plasma keyhole, laser, and electron beam welding, have these small parallel-sided gaps or square closed-butt preparations built-in. However, to use tighter gaps with the traditional arc welding procedures, special techniques must be used.Narrow-gap welding procedures may increase welding economics, but they may also result in less distortion and more consistent joint characteristics. Numerous researchers have noted that narrow-gap joints' mechanical qualities are superior to those obtained with traditional V-butt arrangements. This is probably because of the relatively moderate heat input and the successive runs' gradual refining of the weld bead. The difficulties of post-weld inspection and maintenance may become an issue for thicker portions. As a result, it becomes necessary to perform welding operations consistently and to implement suitable in-process control and monitoring.

Narrow-gap welding processes

The narrow-gap welding techniques share the following characteristics:

- They frequently require a particular welding head or equipment
- they use a special joint configuration
- They typically need arc length control and seam tracking, and they can need special consumables.

The straight, parallel-sided gap with a backing strip is the most basic joint design, but there are other preparation variations depending on the method and the application. a few common preparations. The gap width varies as well depending on the equipment and the process, ranging from about 8 mm for GTAW to 20 mm for SAW. With some operations, normal automatic welding equipment can be used, while thicker portions (above 100 mm)1 require the use of special equipment. The limiting thickness for switching from standard to specialized narrow-gap equipment is variable and is determined by the application and the economics of the process. constructed torches to ensure appropriate gas or flux cover and to facilitate access.

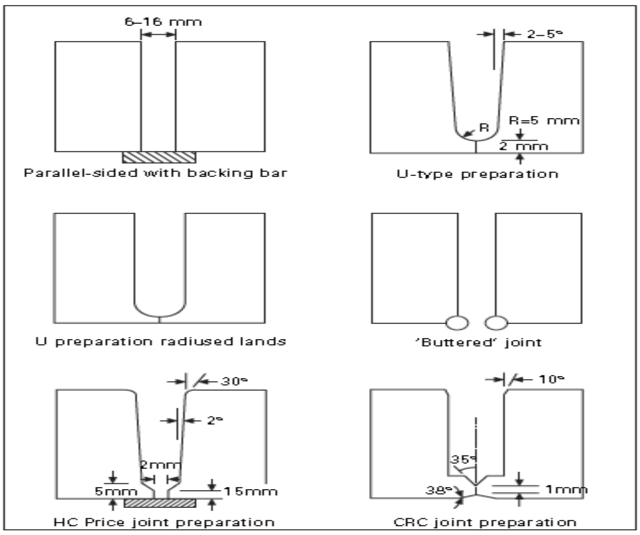


Figure 1Typical narrow-gap joint preparations [Google].

Standard power sources and wire feed systems may also be employed, but they must produce an output that is consistent and repeatable. A seam tracking and height-sensing device are typically required to maintain the torch height and its position about the gap's sidewalls at predefined values. To produce an adequate bead profile and, in the case of slag-shielded procedures like FCAW and SAW, to make it simple to separate the hardened slag, the consumables may need to be modified [4]–[6].

GTAW

Cold wire GTAW

Since tiny welding torches are readily available and thinner portions merely require that the electrode project further from a standard gas shroud, the GTAW method is easily adaptable for narrow-gap operation. A filler wire must also be fed into the weld pool, but once more, ordinary equipment is frequently adequate for thicknesses up to 12 mm. A unique torch design is necessary for thicker portions to enable appropriate gas cover and trustworthy wire arrangement. Since the shielding gas is given through rectangular slots on each side of the electrode and may also be supplied through holes in the side of the blade, narrow-gap GTAW-specific torches are typically lengthy. Although the design is, in theory, pretty simple, it has been discovered that it is quite challenging to achieve appropriate gas cover without entrainment of air from the surroundings. To supplement the gas shroud, flexible surface baffles and telescopic gas shrouds are frequently used The method has been used for circumferential welds and pipework, as well as welding thicknesses of up to 200 mm.

Hot wire GTAW

Due to its ability to raise deposition rate to levels comparable to GMAW, the hot wire GTAW process discussed is especially well suited for narrow-gap welding. Hotwire addition is used in many commercial applications of narrow-gap GTAW, and the RoboweldTM system, which was created for welding gearbox pipelines on both land and on pipe lay barges, is an intriguing example. One of the approaches mentioned may be used to accomplish accurate positioning of the electrode and seamless tracking of the electrode, but some systems also have video monitoring capabilities that allow the user to manually fix the torch position by overriding the automatic control. The electrode can oscillate or the arc can be magnetically deflected to facilitate sidewall fusion.

DISCUSSION

GMAW

The potential for using narrower weld preparations and smaller included angles for GMAW has often been stated as an advantage of the technique when compared with SMAW. However, although some exceptions are allowed in the construction requirements, this advantage has not been completely used in manual welding presumably due to the difficulties of maintaining consistent fusion with constrained access. Reduced preparation widths are, nevertheless, used in automatic welding if enhanced control is available. The developments in narrow-gap GMAW fall into two categories [7]–[9].

1. The use of regular automatic systems and narrower gaps
2. The use of customized narrow-gap GMAW systems and narrow gaps.

Reduced gap/angle GMAW

A key application in the first category is the systems developed for transmission pipeline welding. The CRC Evans system, for example, uses a compound bevel. In comparison with a typical American Petroleum Institute (API) bevel, this preparation reduces the weld metal volume by more than 20%. The pipe position is fixed with its longitudinal axis in the horizontal plane and welding must thus be carried out in the 5G position (i.e. with the welding system revolving around the pipe). This is achieved by employing a tractor equipped with an oscillator and typical operating conditions Systems such as these have been utilized effectively for welding pipe diameters of 600–1500 mm with wall thicknesses of 8–22 mm.

Narrow-gap GMAW developments

The use of narrow-gap GMAW for the welding of submarine hulls was recorded as early and, by the mid-1970s, a range of modifications of the process were being employed on industrial applications in Japan. Very thick sections may be bonded by GMAW utilizing a parallel-sided gap if special torches are applied; these torches, like narrow-gap GTAW torches, are blade-shaped with lengthened gas delivery nozzles. Several different ways have been adopted in an attempt to limit the danger of lack of fusion in the narrow gap GMAW process; they are addressed below. Bead placement. The fusion may be regulated by careful placement of the weld beads and the use of a two-pass per layer approach. The torch is re-positioned after each run or two separate torches may be used.

Consumable adjustments. The fusion characteristics of the process may be improved by using a high level of CO2 in the shielding gas, but this often leads to low process stability and excessive spatter build-up; whilst this may be acceptable when conventional torch designs are used it is likely to cause operational problems with specialized narrow-gap torches. The option is to employ high helium gas combinations (helium + argon + CO2 + oxygen). It has been observed that these deliver superior penetration to argon-rich mixtures and provided the oxygen and CO2 levels are carefully regulated the arc stability is good and the mechanical qualities of the joints are superior to those produced with either CO2 or argon/CO2 mixtures.

The position of the filler wire within the joint dictates the arc root location and will influence the incidence of fusion faults. Normal GMAW filler wires have a natural curvature (known as cast) and spiral (referred to as helix), and this gives rise to the random oscillation of the wire tip. Specially straightened wire is available for automatic welding and automatic equipment generally incorporates some means of wire straightening. These procedures ensure a stable arc position, but a novel variation of the filler wire, which exploits the presence of a helix to produce more controlled arc oscillation, has been employed as a means of boosting fusion. This approach, known as twist arc, requires creating a unique filler wire by twisting two smaller-diameter wires together. The principle of the procedure. The welding head travels along the longitudinal axis of the weld and with a gap width of 14 mm, enough fusion is accomplished at both sidewalls. The arc oscillation pattern may be modified by adjusting the relative diameter of the wires, the pitch of the spiral, and the operational conditions.

Torch or wire oscillation. Lateral oscillation of the torch may be used or an eccentric contact tube may be rotated to induce circular oscillation of the wire tip. These systems are relatively sophisticated and the minimum gap width is sometimes limited by the necessity to move the whole welding head. Alternative solutions that rely on the controlled distortion of the filler wire as it travels through the feeding system have therefore been developed. These devices use bending rollers to produce a wave-like or spiral distortion into the wire to cause regulated oscillation of the arc. Although the mechanism required to produce the deformation may be sophisticated, the part of the torch that enters the joint is compact and suitable joints can be formed with gap widths down to around 9 mm. Modification of process operating mode. Many of the systems that are now available use the pulsed transfer GMAW techniques discussed in Chapter 7 to improve process control and prevent spatter generation.

Applications of Narrow-Gap GMAW

The narrow-gap GMAW procedure has been employed for down-hand welding of circumferential joints in the pipe and shafts with the workpiece rotated under the welding head. The GMAW procedure may also be utilized for positional (5G) welding of the pipe as mentioned and has also been employed for welding horizontal joints in tubular constructions and building columns as particularly in Japan.In the offshore industry, interest has been indicated in the application of the method to horizontal wells (2G) in the vertical pipe for 'J' laying of transmission pipes at sea. Although this has been determined to be achievable, it requires very careful control of the process parameters and gap width to guarantee that consistent bead profile and fusion characteristics are maintained.

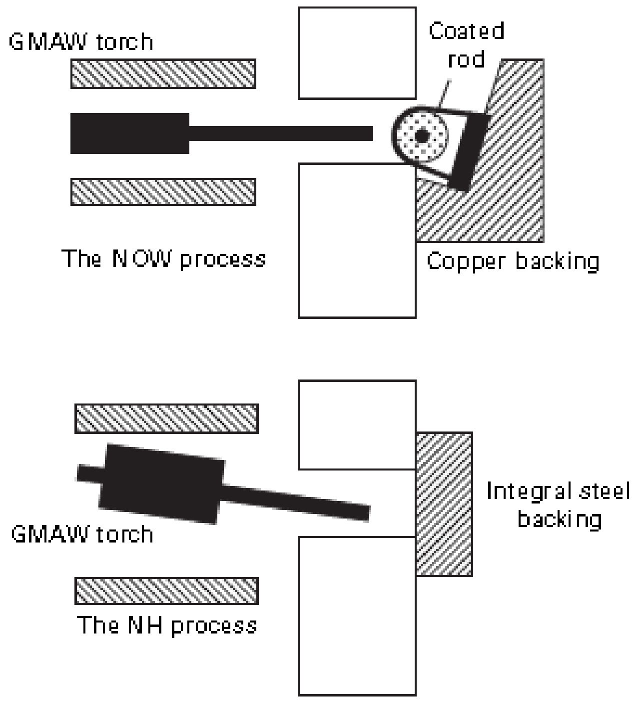


Figure 1 Horizontal narrow-gap techniques.

Narrow-Gap SAW

The narrow-gap submerged arc technique is capable of manufacturing high-quality joints in thick sections in the down-hand position with major improvements in running costs. Conventional submerged arc welding equipment may be utilized for moderately thick material (e.g., 70 mm) but special-purpose equipment is available for welding thicknesses up to 600 mm.

Single-Pass Technique

The use of a single-pass approach, which is potentially more productive, is limited by the possibility of sidewall fusion flaws, slag entrapment, and a larger average heat input when compared with multiphases modes. Research work using mathematical modeling techniques has shown, however, that it is possible to optimize the welding parameters so that defects such as lack of fusion, undercut, and slag removal problems may be overcome in thicknesses up to 70 mm with conventional equipment and a single pass per layer. It was observed that using the parameters predicted by the model the bead shape could be managed to generate concave surfaces (for ease of slag detachment), optimum depth-to-width ratios (to minimize solidification cracking), and maximum lateral penetration (to prevent sidewall fusion faults).

MultiphasesPer Layer Technique

The multiphases approach requires a higher gap width for a similar wire diameter (e.g., 18 instead of 10 mm with a 4 mm filler wire and two passes) and the joint completion rate is therefore lower. The approach does, however, provide greater control of sidewall fusion, weld metal refinement, and improved access for flux removal and inter-run cleaning. For these reasons, most commercial applications of the technique use the two-pass-per-layer mode with a single electrode. Typical values of gap width and welding parameters. For thicknesses beyond 100 mm a special narrow-gap torch is required; this is usually rectangular with facilities for flux feed and recovery, seam tracking, and height control. A common torch assembly uses touch sensors to control torch height and optoelectronic sensing of the torch position within the gap. The procedure is often applied to longitudinal and circumferential joints in large cylindrical components; in both situations, a heavy column and boom will be required to carry the torch head and, in the case of circumferential connections, the workpiece must be rotated under the welding head. For these circumferential applications, it is vital to eliminate fluctuation in the lateral position of the seam as it rotates, and feedback control devices are generally placed in the roller bed to sense and correct the position of the component.The single filler wires used most typically have diameters in the range of 3.2–4.8 mm; smaller wires are prone to generate random arc wander, particularly with the relatively long electrical stick-outs that are utilized, and bigger diameter wires are more difficult to feed. Although it is possible to utilize normal fluxes, unique flux formulations with superior slag release properties have been designed for narrow-gap SAW. The power utilized is DC electrode positive or AC; AC affords more resistance to magnetic arc blow and square wave AC power sources have also been employed to increase control of the operation.

Developments

Increased productivity and greater process control may be accomplished by adopting the techniques generally applied to conventional submerged arc welding to the narrow-gap process, i.e.:

1. extended stick-out
2. twin wire
3. hot wire
4. metal powder addition
5. flux-cored consumables.

Applications

The standard NGSAW procedure has been in use in various commercial applications since the early 1980s. Some of these are summarized; they range from nuclear reactor containment containers in 600 mm thick Ni/Cr/Mo alloy steels to the welding of 60 mm material for offshore tubular**.** Narrow gap welding (sometimes termed narrow groove welding) was created to weld thick portions more efficiently. This welding process uses joint preparations with small, included angles, often in the range of 2-20°, which need less weld metal and less welding time to fill. The utilization of shorter joint spacing and reduced preparation angles can result in considerable productivity improvements. The usage of techniques that entail the inherent use of a tiny gap (EBW, laser, plasma, friction, MIAB) naturally utilizes these advantages, whilst technologies have been developed to allow tight gaps to be employed with GTAW, GMAW, and SAW processes.

Narrowgap type arrangements have been employed for GMAW in thicknesses from 15– 22 mm upwards. Narrow-gap SAW is typically thought to be viable at thicknesses above 60–70 mm, but, if conventional equipment is utilized, this lower economic limit may be reduced until it overlaps traditional square butt SAW operations in thicknesses down to 12 mm. Optimization of welding parameters and in-process control are essential to avoid defects in narrow gap applications; the restricted access of the gap will make progressive repair difficult, but good procedure control should obviate these problems and the use of narrow-gap welding may be seen as a way of imposing a reasonable level of discipline into the control of welding operations [10]–[12].

CONCLUSION

Narrow gap welding has been developed and deployed into production at Babcock & Wilcox. Both GMAW and SAW have been used successfully on steel and alloy steel. SAW has been developed for use on Nickel Alloy 600. The results in production have been good with reductions in filler metal usage and significant reductions in weld completion times. There has also been a reduction in weld faults and good operator acceptance of the techniques. The experience obtained at Babcock & Wilcox has shown with a proven piece of equipment, appropriate development and implementation time, and a dedication to doing all it takes to make the process work, narrow gap welding will succeed in production use. The possible savings in operational costs must be assessed against the capital cost of the equipment, but it is noted that high-cost, sophisticated narrow gap submerged arc systems have been justified for welding 350-mm thick high-pressure feed-water heater shells. The minimal economic thickness for narrow-gap technology varies with the process and operating mode. Narrowgap GTAW welding may be justified on thicknesses down to 15 mm.

REFERENCES

[1] R. Mishra, A. Kumar Upadhyay, A. Singla, and Y. Singh, "Effect of Groove Designs on Residual Stress and Transverse Shrinkage in GMAW and PGMAW of A333 Seamless Steel Pipes," *J. Adv. Manuf. Syst.*, 2020, doi: 10.1142/S0219686720500377.

[2] R. A. Ribeiro, P. D. C. Assunção, E. B. F. Dos Santos, A. A. C. Filho, E. M. Braga, and A. P. Gerlich, "Application of cold wire gas metal arc welding for narrow gap welding (NGW) of high strength low alloy steel," *Materials (Basel).*, 2019, doi: 10.3390/ma12030335.

[3] W. Guo, D. Crowther, J. A. Francis, A. Thompson, and L. Li, "Process-parameter interactions in ultra-narrow gap laser welding of high strength steels," *Int. J. Adv. Manuf. Technol.*, 2016, doi: 10.1007/s00170-015-7881-9.

[4] K. Sotoodeh, "Dissimilar welding between piping and valves in the offshore oil and gas industry," *Weld. Int.*, 2021, doi: 10.1080/09507116.2021.1919495.

[5] J. Norrish, *Advanced Welding Processes*. 2006. doi: 10.1533/9781845691707.

[6] C. Zhang, G. Li, M. Gao, and X. Y. Zeng, "Microstructure and mechanical properties of narrow gap laser-Arc hybrid welded 40 mm thick mild steel," *Materials (Basel).*, 2017, doi: 10.3390/ma10020106.

[7] B. Kessler, D. Dittrich, B. Brenner, J. Standfuss, and C. Leyens, "Extension of the process limits in laser beam welding of thick-walled components using the Laser Multi-Pass Narrow-Gap welding (Laser-MPNG) on the example of the nickel-based material Alloy 617 occ," *Weld. World*, 2021, doi: 10.1007/s40194-021-01112-4.

[8] S. Das Banik, S. Kumar, P. K. Singh, S. Bhattacharya, and M. M. Mahapatra, "Prediction of distortions and residual stresses in narrow gap weld joints prepared by hot wire GTAW and its validation with experiments," *Int. J. Press. Vessel. Pip.*, 2021, doi: 10.1016/j.ijpvp.2021.104477.

[9] J. H. Lee *et al.*, "Assessing mechanical properties of the dissimilar metal welding between P92 steels and alloy 617 at high temperature," *J. Mech. Sci. Technol.*, 2016, doi: 10.1007/s12206-016-0911-1.

[10] R. Nivas *et al.*, "A comparative study on microstructure and mechanical properties near interface for dissimilar materials during conventional V-groove and narrow gap welding," *J. Manuf. Process.*, 2017, doi: 10.1016/j.jmapro.2016.12.004.

[11] J. Norrish, "Gas metal arc welding," in *Advanced Welding Processes*, 2006. doi: 10.1533/9781845691707.100.

[12] V. S. M. Ramakrishna R, P. H. S. L. R. Amrutha, R. A. Rahman Rashid, and S. Palanisamy, "Narrow gap laser welding (NGLW) of structural steels—a technological review and future research recommendations," *International Journal of Advanced Manufacturing Technology*. 2020. doi: 10.1007/s00170-020-06230-9.

CHAPTER 11

GAS METAL ARC WELDING

Mr. Bhairab Gogoi, Assistant Professor
Department of Petroleum Engineering, Presidency University, Bangalore, India
Email Id: bhairabjyoti@presidencyuniversity.in

ABSTRACT:

Gas metal arc welding (GMAW), also known as metal inert gas (MIG) welding, is a quick and affordable procedure. During this procedure, an arc is created between the base metal and a consumable electrode that is continually supplied. This creates filler metal for the weld. Due to its benefits, including its higher rate of weld metal deposition, lower skill need, and ability to produce high-quality welds in a variety of situations, the Gas Metal Arc Welding (GMAW) technology is utilized in the fabrication of structures and welding of pressure vessel components. Metal inert gas (MIG) and metal active gas (MAG) are two of the subtypes of gas metal arc welding (GMAW), which is a welding process in which an electric arc forms between a consumable MIG wire electrode and the workpiece metal or metals, heating them to the point of fusion (melting and joining). A shielding gas that passes through the welding cannon with the wire electrode protects the procedure from ambient contamination.

KEYWORDS:

Current, Droplet, Electrode, Wire, Welding.

INTRODUCTION

Gas metal arc welding (GMAW) can increase productivity compared to that attained with the GTAW and SMAW procedures because of its high operating factor and deposition rate. Although there is a definite trend towards more use of GMAW globally as a result of the need to capitalize on the process's economic advantages, it has historically been challenging to achieve reliable quality. Therefore, the main focus of development has been to enhance control and obtain more reliable quality. It is required to revisit the process fundamentals, particularly metal transfer in GMAW and control of traditional GMAW, to explain the advancements that have been accomplished in this regard [1]–[3].

Both automatic and semi-automatic processes are possible. The most typical power source for GMAW is a constant voltage, direct current power source, but alternate current and constant current systems can also be employed. In GMAW, there are four main metal transfer techniques: globular, short-circuiting, spray, and pulsed spray. Each technique has unique qualities and related benefits and drawbacks. GMAW, which was initially created in the 1940s for welding aluminum and other non-ferrous materials, was quickly used to weld steels because it required less time to weld than other welding methods. Up until a few years later, when the use of semi-inert gases like carbon dioxide became widespread, the cost of inert gas restricted its usage in steels.

Metal Transfer In GMAW

The stability, spatter production, weld quality, and positioning capabilities of the GMAW process are all significantly impacted by how the material is moved from the consumable electrode tip into the weld pool. High-speed or stroboscopic film and video techniques have been used for phenomenological analyses of the manner of metal transfer. The many natural transfer types have been divided into groups. a more straightforward basic classification.The free-flight transfer involves maintaining an arc between the electrode and the workpiece while transferring the metal as droplets.Multiple subdivisions of free-flight transfer are required to account for the potential wide differences in droplet size and transfer frequency. Common free-flight settings include:

1. Globular (drop and repelled
2. Spray (drop projected streaming

Globular Drop Transfer

Globular drop transfer is characterized by large droplets and low transfer. It is normally found at low currents and fairly high arc voltages, although this will depend on the diameter of the filler wire, its composition and the shielding gas used. For example, with 1.6 mm diameter aluminum wire in an argon shield droplet transfer frequencies of less than 1 Hz may be observed at 100 A. In CO2-shielded GMAW of steel, the globular transfer occurs with a range of wire sizes at currents above 200 A. Both the appearance of the droplet and the observation of droplet formation indicate that the transfer mechanism is dominated by gravitational forces. i.e. the droplet detaches when its size has grown to a stage where the downward detachment force due to its mass overcomes the surface tension force which acts to prevent droplet separation. Although electromagnetic forces exist, they are not sufficiently developed to influence the droplet detachment at low currents. A low mean current is used but the process has very limited positional capabilities with solid wire GMAW because of the dominant nature of gravitational forces [4]–[6].

Globular Repelled Transfer

In some circumstances, a droplet may form at the end of the electrode and be deflected to one side or even expelled from the arc. This behaviour is commonly found when electrode negative polarity is used with a solid wire and is illustrated. The dominant transfer force is gravitational but repulsion is caused by electromagnetically induced plasma forces or vapor jets which act on the base of the droplet, at the arc root, to lift the molten material. Once the droplet has been lifted in this way an asymmetrical magnetic field is created and the droplet may be rotated or expelled under the influence of the resultant forces as discussed below. This mode of transfer is usually undesirable due to the poor stability and high spatter levels which result.

Projected Spray Transfer

As the current is increased, the size of the droplet usually decreases and the frequency of transfer increases. In addition, it is found that the droplets are projected axially through the arc with some force. In some cases (e.g., carbon steel in argon-rich gas mixtures and aluminum in argon) there is a clear transition between the globular and projected spray modes of transfer as the current is increased. The current at which this transition occurs is an important process characteristic and is known as the spray transition current. Its value depends on the filler material size and composition as well as the composition of the shielding gas. Below the transition current, the transfer is either globular or dip and, above the transition current, the transfer is in the form of a steady stream of small droplets, whose diameter is similar to that of the filler wire. Since this mode of transfer only occurs at relatively high currents, the heat input is high and the weld pool large. These features are attractive for high deposition-rate down-hand welding but limit the positional capabilities of the process.

Streaming Transfer

As the current increases, the droplet size decreases further and the electrode tip becomes tapered. A very fine stream of droplets is projected axially through the arc. This mode of transfer is called streaming and it is caused by a significant increase in electromagnetic forces. It occurs more readily with high-resistivity, small-diameter wires (e.g., austenitic stainless steel) operating at currents above 300 A. Weld pool turbulence and gas entrainment may limit the usefulness of this mode of transfer.

DISCUSSION

Drop Spray Transfer

Although an important intermediate transfer mode can occur in this transition range, the switch to projected spray transfer occurs over a relatively small current range. Spherical droplets that are only a little bit larger in diameter than the diameter of the filler wire is first suspended from the tip before being removed in this manner of transfer, which is characterized by the creation of a solid conic neck on the wire tip. High droplet velocities and extremely small spatter losses are observed, indicating that detachment happens very effectively. Drop velocities of 7 m min-1 have been recorded for a 1.2 mm carbon steel wire in this transfer mode, which occurs between 250 and 270 A in argon/5% CO2, and a minor increase in melting rate is seen [7]–[9].The drop spray mode is effective and 'clean' with very little spatter and particulate smoke, but under typical steady DC operation conditions, it necessitates very precise control of the welding parameters, which can only be accomplished with the high-quality electronic power sources mentioned. The operational range is also quite constrained. However, by utilizing the pulsed transfer techniques outlined below, the process range can be increased.If there are no results involved in your paper (e.g., graphs, plots, charts, tables, etc.), then change the title of this section to simply ‘DISCUSSION’.

Dip Transfer

The electrode will eventually cross the arc gap and dip into the pool if it is supplied towards the workpiece more quickly than the arc can melt the wire on its own. While this phenomenon, which is infrequently seen during free-flight transfer and is thought to represent a fault state, is feasible, it is also possible to regularly short-circuit the arc gap at frequencies above 100 Hz provided the settings are chosen carefully. Dip or short-arc transfer is the name of this kind of transfer, which is diagrammatically shown.The order of operation is as shown below.

Although the wire is fed continuously, there is not enough burn-off throughout the arcing phase to keep the arc length constant. Arc gap closing occurs before the wire finally makes contact with the weld pool. The current from the power source increases quickly in response to this electrical short circuit, creating resistive heating in the tiny filament of wire that spans the gap. The arc is restored after the bridge breaks and some of the heated electrode material is transferred to the weld pool.

The short-circuiting technique can be repeated repeatedly if the wire feed rate and power source output are correctly matched. waveforms of transient voltage and current that are typical. In reality, the arc must be kept relatively short (2-3 mm) to maintain a consistent, high dip requency, and upward motions in the weld pool frequently start the short circuit. The short circuit must be broken with high currents (normally 200–400 A), but because the arcing current is low and the arcing period is typically longer than the short-circuit time, the mean current is kept at a low level. The short circuit will explode explosively and metal will be spattered from the arc if the current during the short circuit is too high.

There is some uncertainty regarding the precise volume of metal removed during each short circuit when the process is functioning normally. Although the gap between short circuits typically follows a normal distribution, the time between short circuits, the arc time, and thus the frequency of transfer, varies. The distribution's standard deviation can be used as a measure of the process's stability; under ideal circumstances, the standard deviation in time is at its lowest value. Dip transfer is a method that works well for positional welding and welding thin sheets of steel since it has a low mean current, little heat input, and a small, quickly freezing weld pool as a result.Potential drawbacks of dip transfer include the randomness of short-circuiting, process instability, and the risk of significant spatter levels. However, these issues can be managed either by selecting shielding gases or by using electronic approaches, as explained below.

Explosive Droplet Transfer

It has been noted that pendant drips on the electrode tip can cause explosive material ejection. This is believed to be the result of internal chemistry (gas-metal or slag-metal) reactions. These explosions typically result in instability in GMAW but may facilitate transfer in FCAW.

Rotating Transfer

Although the term rotating transfer is also used to refer to the rotation of an extended metal filament between the solid wire tip and the droplet in streaming transfer, the droplet may rotate in the rejected mode as previously stated. Although it has been used for surface applications utilizing both the "plasma-MIG process" and the "T.I.M.E." process detailed below, the occurrence of this mode of transfer at high currents is typically unwanted.

FCAW And Slag-Protected Transfer

The slag produced by the flux constituents in flux-cored wires may have an impact on the transfer phenomena. Using a high-speed image converter camera, the following transfer phenomena have been discovered. The type of transfer depends on the flux system being employed. These outcomes are demonstrated.

Metal-cored wires

Consumable metal-cored wires typically behave like solid wires and have relatively little non-metallic flux. At low currents and higher currents, axial projected spray exhibits good dip transmission ability. Additionally, argon-rich argon/CO_2 gas mixtures may be used to achieve stable electrode negative functioning. High burn-off rates and uniform weld bead profiles are produced by the streaming spray transfer that takes place at high currents for a 1.2 mm diameter wire).

Rutile Flux-Cored Wires

Consumables made of rutile flux-cored wire are typically used in spray mode, which provides smooth non-axial transfer. A tiny portion of the flux decomposes to produce shielding gases, while the remaining flux is carried to the weld pool where it melts and forms a protective slag blanket. Some of the flux melts to form a slag layer on the surface of the droplet. The wire's tip is where the flux that hasn't melted is extending.

Basic Flux-Cored Wires

At low currents and larger currents, the fundamental flux formulation results in irregular dip transfer and non-axial globular transfer, respectively. A distinct finger-like projection of the unbelted flux from the wire into the arc is formed. The impact of the flux formulation on the wires' gas-shielded flux-cored wires' droplet size.

Self-shielded flux-cored wires

With this kind of consumable, dip and globular resisted transfer are frequently observed, and very huge levitated globular 'boots' may form at the wire tip. Flux formulation may be used to lessen the globular propensity, and there is evidence of secondary transfer happening from the globule's base as well as explosive droplet transfer.

The physics of metal transfer

It is vital to think about the mechanisms more carefully to comprehend and improve transfer behaviour. The metal droplet is subjected to a balance of forces that leads to the transfer behaviour described above.Although the operating conditions (current, voltage, wire diameter, shielding gas, etc.) used will determine the dominant forces and their impact on metal transfer, in free-flight transfer the static balance of forces at the point of droplet detachment is illustrated diagrammatically and described by an equation of the form.

$$Fg + Fd + Fem = Fst + Fv$$

Except for Fem, the other forces in dip transfer may be fairly modest, and the surface tension force may act to aid detachment. Based on the widely recognised classical physics approach, the magnitude of these forces is indicated below. However, since many of the relevant parameters change with temperature and time, a complete theoretical study also needs to take into account dynamic processes.

Gravitational Force

The gravitational force is given by:

$$\mathbf{Fg = mg}$$

where q is the angle formed by the arc axis and the vertical, m is the mass of the droplet, and g is the vertical component of the acceleration caused by gravity (9.81 cos q m s-1). When cos q is +1 during down hand welding, the force will be at its highest positive value. When q is between 90 and 180 and cos q is negative during positional welding, the force will be at its maximum negative value. For 1.6 mm wires in argon shielding gas, measured values of this force (globular transfer) show values of 260 dyn for aluminium and 600 dyn for iron.

Aerodynamic Drag

A force, Fd, that the gas flow within the arc can exert on a droplet can be estimated fromwhere r is the droplet radius, d is the gas density, and V is the gas velocity along with C being the drag coefficient. When both the droplet diameter and gas velocity are large, the strength of this force will be at its greatest. As large droplets are typically found at low currents and high gas velocities are more frequently encountered at higher currents, it is uncommon for both variables to be at their maximum values at the same time. As a result, drag forces are typically minimal.

Electromagnetic Forces

A magnetic field and electromagnetic forces are created when a current runs through a conductor. The shape of the current channel has a significant impact on the strength of these forces in the vicinity of the electrode tip, the molten droplet, and the arc. It is possible to calculate the force's magnitude from:

$$F_{em} = \frac{\mu I^2}{4\pi} \ln \left| \frac{r_a^2}{R} \right|$$

where I is the current, ra is the current's 'exit' radius, R is its 'entry' radius, and m is the material's magnetic permittivity. Magnetic forces are dependent on current and can reach relatively high values (up to 0.02 I2 have been observed in GTAW arcs, for example). When the currents necessary for spray transfer are present, these forces frequently dominate the transfer.

Vapour jet forces

In the arc root region, there may be extensive surface vaporisation of the molten droplet at high currents. A force that inhibits droplet transfer is produced as a result of the thermal acceleration of the vapour particles into the arc plasma. The magnitude of this force on a flat surface with constant composition and temperatureis the vapour density, while DV is the current density. Typically, the vaporisation force only becomes substantial at higher currents or in the presence of components with low vapour pressure.

Surface Tension

Surface tension is a key factor in metal transfer; in dip transfer, it is the main force that pushes the droplet into the weld pool whereas in free-flight transfer, it is the main force that prevents droplet detachment. A simple static study of the globular transfer's drop-retaining force suggests that the force is provided by

Fst = 2□rw□f (rw/c)

where f(rw/c) is a function of the wire diameter and the capillarity constant c and rw, is the wire diameter, and s is the surface tension. The value of this equation approximates 2prw for large droplets. The significant temperature dependence and the dramatic impact of some surface-active elements, such as the effect of small amounts of sulphur on changing the surface tension/temperature, make it difficult to calculate the exact magnitude of the force caused by surface tension. For instance, at the melting point of steel, 0.1% oxygen will reduce the surface tension by about 30%. However, values of 600 dyn for steel and 300 dyn for aluminum have been estimated for globular transfer using a 1.6 mm wire.

Metal Transfer Phenomena

Metal transfer phenomena can be divided into two categories: free-flight and dip. Several different transfer types can be seen in the free-flight mode. The International Institute of Welding has developed a taxonomy that includes these phenomena, and this is demonstrated. A balance of forces that depends on the process's operating parameters will affect the mode of metal transfer. The main factors affecting metal transport are gravity, electromagnetic fields, and surface tension. In conventional GMAW, the strength of these forces and the subsequent transfer behaviour are governed by the material's and the shielding gas' physical characteristics, but the welding current has a considerable influence as well.

Control of Conventional

Mean current affects both the rate at which the filler wire melts and the transfer mechanism of the process as previously mentioned**.**

Melting rate phenomena: GMAW

The melting rate, MR, is usually expressed as

$$\mathrm{MR} = \alpha I + \frac{\beta l I^2}{a}$$

When I is the current, l is the electrical stick-out or extension, and A and B are constants and the cross-sectional area of the wire. For 1.2 mm plain carbon steel wire, the measured values of a and b are a = 0.3 mm A-1 s-1 and b = 5 10-5 A-2 s-1; for aluminium, a = 0.75 mm A-1 s-1 and b is negligible. Since these statistics pertain to fixed wire diameter, the area term is not present.The arc heating effect is represented by the first term in the equation, while the electrode's resistive heating is represented by the second term. The electrical resistance of the stick-out has a big impact on melting rates.

The electrode diameter/cross-sectional area, electrode resistivity, and extension length all affect the stick-out resistance. Although DCEN (direct current electrode negative) operation speeds up melting, it is typically challenging to keep a stable arc and guarantee appropriate fusion.If the electrode polarity and extension are fixed, the wire must be fed at a rate (the burnoff rate) that is equal to the rate at which it is consumed (i.e., the melting rate) for the process to operate steadily in any transfer mode1. It is possible to choose the optimal wire feed speed for a particular mean current by considering the relationship between wire feed speed and current, which is typically represented graphically in the form of burn-off curves of the kind.

Voltage–Current Characteristics

In the GMAW process, the resistive drop in the wire extension and the voltage fall across the arc is added to create the voltage between the end of the contact tip and the workpiece. Due to the severe temperature gradient in the wire and the temperature dependency of resistivity, calculating the resistance of the electrode stick-out is challenging. The relationship between mean current and voltage in the free-flight operating modes of the GMAW process is extremely close to the characteristic of a GTAW arc, according to measurements of the total voltage drop under a variety of operating situations.

For any shielding gas-filler wire combination at a fixed arc length, the voltage rises linearly with the current in the working range where the arc has a positive resistance. In dip transfer, the mean current-voltage characteristic exhibits the same pattern and represents the average of the short-circuit resistance and the arc resistance. The relationship between mean current and voltage can be stated in an equation of the following form in both dip and free-flight transfer:The mass of electrode material used per unit of time is sometimes referred to as the melting rate. The wire feed speed or burn-off rate is the pace at which the wire is used up. The term "melting speed" is occasionally used to refer to the rate at which the solid-liquid border or melting isotherm moves down the electrode wire.

$$V = M + AI$$

where M and A are constants, I is the current, and V is the arc voltage**.**

Control In Conventional GMAW Systems

Regardless of changes in the arc behaviour, conventional wire feed systems are made to keep the feed speed constant at a predetermined value. Conventional GMAW power sources have long had constant-voltage (CV) characteristics that enable the arc length to self-adjust and stabilise. When the arc length tends to fluctuate in these systems, the current varies dramatically, and the burn-off behaviour reacts in a way that counteracts the arc length change. Since the melting rate is dependent on current, the reduced current will result in reduced melting, which will result in less wire being consumed, thereby shortening the arc length. An increase in arc length causes an increase in arc voltage, and the power source output current must be reduced to meet the higher voltage demand. Arc length will once more return to its previous value since melting will rise with the greater current when the arc length is reduced [10]–[12].

CONCLUSION

One of the newest and most efficient welding techniques is GMAW welding. In the end, it provides a solid and lasting bond and uses shielding gas and a metal arc. But only professionals should attempt it. Therefore, no one can accomplish it flawlessly. The efficacy & lower labour costs make it the most widely used in industries. So, be careful to study it well if you intend to use it. GMAW, sometimes referred to as wire welding or gas metal arc welding, is a successful welding technique. By applying heat to the metal, an electric arc forms between the wire electrode. This permanently melts the metal and joins the pieces together.Due to its effectiveness, adaptability, and capacity to create welds of excellent quality, gas metal arc welding (GMAW), also known as metal inert gas (MIG) welding, is a well-liked welding technique used in a variety of industries. In conclusion, GMAW is a type of welding that uses a consumable electrode wire that is continually fed into the welding space combined with a shielding gas to keep the weld pool clean and free from outside contaminants. To create a solid and long-lasting bond, the electrode wire is heated and deposited onto the workpiece. GMAW can be used to weld a variety of materials, including carbon steel, stainless steel, aluminium, and other non-ferrous metals. It is particularly effective for welding thin to medium-thickness materials. GMAW can be used manually or with the aid of automated devices, and it is also quite simple to learn and understand.

REFERENCES:

[1] O. Panchenko, D. Kurushkin, F. Isupov, A. Naumov, I. Kladov, and M. Surenkova, "Gas metal arc welding modes in wire arc additive manufacturing of Ti-6Al-4V," *Materials (Basel).*, 2021, doi: 10.3390/ma14092457.

[2] W. I. Cho and S. J. Na, "Impact of driving forces on molten pool in gas metal arc welding," *Weld. World*, 2021, doi: 10.1007/s40194-021-01138-8.

[3] U. Reisgen, S. Mann, K. Middeldorf, R. Sharma, G. Buchholz, and K. Willms, "Connected, digitalized welding production—Industrie 4.0 in gas metal arc welding," *Weld. World*, 2019, doi: 10.1007/s40194-019-00723-2.

[4] M. Tanaka *et al.*, "Effect of shielding gas composition on gas metal arc welding phenomena using rare earth metal added wire," *Yosetsu Gakkai Ronbunshu/Quarterly J. Japan Weld. Soc.*, 2021, doi: 10.2207/QJJWS.38.438.

[5] A. Ebrahimi, A. Babu, C. R. Kleijn, M. J. M. Hermans, and I. M. Richardson, "The effect of groove shape on molten metal flow behaviour in gas metal arc welding," *Materials (Basel).*, 2021, doi: 10.3390/ma14237444.

[6] R. A. Ribeiro, E. B. F. Dos Santos, P. D. C. Assunção, E. M. Braga, and A. P. Gerlich, "Cold wire gas metal arc welding: Droplet transfer and geometry," *Weld. J.*, 2019, doi: 10.29391/2019.98.011.

[7] E. Karadeniz, U. Ozsarac, and C. Yildiz, "The effect of process parameters on penetration in gas metal arc welding processes," *Mater. Des.*, 2007, doi: 10.1016/j.matdes.2005.07.014.

[8] Y. Cheng, R. Yu, Q. Zhou, H. Chen, W. Yuan, and Y. M. Zhang, "Real-time sensing of gas metal arc welding process – A literature review and analysis," *Journal of Manufacturing Processes*. 2021. doi: 10.1016/j.jmapro.2021.08.058.

[9] B. Varbai, R. Kormos, and K. Májlinger, "Effects of active fluxes in gas metal arc welding," *Period. Polytech. Mech. Eng.*, 2017, doi: 10.3311/PPme.9756.

[10] Z. Zhou, H. Shen, B. Liu, W. Du, and J. Jin, "Thermal field prediction for welding paths in multi-layer gas metal arc welding-based additive manufacturing: A machine learning approach," *J. Manuf. Process.*, 2021, doi: 10.1016/j.jmapro.2021.02.033.

[11] B. Mvola, P. Kah, J. Martikainen, and R. Suoranta, "State-of-the-art of advanced gas metal arc welding processes: Dissimilar metal welding," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 2015. doi: 10.1177/0954405414538630.

[12] J. Nadzam, F. Armao, L. Byall, D. Kotecki, and D. Miller, "Gas Metal Arc Welding Product and Procedure Selection," *Tech Rep. C4.200*, 2014.

CHAPTER 12

GASES FOR ADVANCED WELDING PROCESSES

Mr. Madhusudhan Mariswamy, Assistant Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: madhusudhan@presidencyuniversity.in

ABSTRACT:

A gas flame is used to increase the temperature of the metals being connected during the process known as gas welding. Metals are heated till they melt. Metal flows and solidifies when it cools. To fill a void created during the final preparation, a filler metal may be added to the flowing molten metal. This paper discussed Gases for advanced welding processes**.** Arc welding is the process of joining metals by employing an arc as a heat source. In arc welding, the electrode (welding rod or wire) receives a positive voltage while the base material receives a negative voltage. As a result, an arc forms between the electrode and the base material. In several of the more recently developed welding processes, shielding gases are a crucial consumable, such as: gases for laser creation, shielding, and plasma management in laser welding. gases as the principal shielding medium in GTAW, GMAW, plasma, and gas-shielded FCAW.

KEYWORDS:

Electrode, Metal, Electric, Heat, Weld.

INTRODUCTION

A flame created by the combustion of almost equal quantities of oxygen and acetylene that are fed from gas bottles to a welding torch at equal pressures is used for gas welding. The flame's temperature, which is around 3100°C, is high enough to melt metals like steel [1]–[3].Shielding against ambient contamination and providing a suitable medium for the steady functioning of a prolonged low-voltage arc are the two main purposes of the shielding gas in arc welding procedures. Controlling the mechanical characteristics and shape of the weld bead are secondary, but equally significant, roles.The passage of current in an ionized gas maintains the arc. Therefore, the ability to start and keep the arc will depend on how easily the gas can ionize. The ionization potential of the gas indicates the ease of ionization, and values for the common gases are provided. Particularly low ionization potential gases like argon are frequently utilized in the TIG process. The arc stability will also be influenced by the gas's thermal conductivity; a high thermal conductivity may cause the diameter of the arc's conducting core to shrink, which may raise the voltage and weaken arc stability. When combined with argon, hydrogen, which has a lower ionization potential but a higher thermal conductivity than argon, raises the arc voltage and, if more than 8% is added, may have an impact on both arc stability and arc initiation.

Arc stiffness is typically thought to be advantageous in GTAW arcs with low current, however, as the current grows, the force acting on the weld pool increases and may cause an undercut. The arc force produced by helium-rich gas mixtures is substantially lower, though, and this may be advantageous at large currents. The method of metal transfer, which is controlled by the gas's impact on surface tension, the material's work function, and the ensuing arc root behaviour, is a major factor in GMAW and FCAW arc stability [4]–[6].

Shielding from Atmospheric Contamination

The gas's physical and chemical characteristics will determine how well it can protect against air pollution. If you want to prevent the tungsten electrode from oxidizing during TIG welding, inert gases such as argon or helium are often used. It is often required to utilizeoxidizing additives in GMAW and FCAW welding to promote excellent metal transfer, however, it is important to take into account how these gases may cause alloying elements to be lost (by oxidising metal droplets in the arc) Additionally, the weld metal must be shielded against unfavourable gas-metal interactions such as porosity, inclusions, surface oxidation, and embrittlement. Common active gases including oxygen, nitrogen, and hydrogen may result in issues in this regard. When heated in an oxidising environment, the majority of materials produce oxides, although nitrogen can produce soluble compounds with some metals (Fe, Mn, Cr, and W) and insoluble nitrides with others (Ti, Ta, V, and Nb). Although it can form compounds with reactive metals, hydrogen is soluble in the majority of metals.

In the liquid phase of several common metals, both nitrogen and hydrogen have large equilibrium solubilities. There is a chance that porosity will emerge when the extra gas tries to escape from the solidifying weld pool if the molten metal absorbs more of these gases than the solid solubility limit. In the case of nitrogen, absorption in steel is influenced by the alloying elements present as well as the quantity of oxygen and nitrogen. Under arc welding settings, it is discovered that the amount of gas absorbed is more than that which is predicted under equilibrium conditions with non-arc melting. Given that oxygen tends to increase the quantity of nitrogen absorbed and hence decrease the efficacy of shielding, this is particularly intriguing.According to current research, air entrainment into the arc environment has a significantly greater negative impact than a tiny contaminant like nitrogen. The physical characteristics of the gas, in particular its density, viscosity, and Reynolds number, will determine its capacity to sustain a lamellar gas flow and avoid air contamination. A summary of the common shielding gases' suitability for various types of materials is given.

Secondary functions of the gas

The secondary properties of shielding gases are just as significant as their core roles and, in certain situations, may help choose the best gas for a particular application. Control of joint properties and fusion characteristics are two of the most crucial secondary roles.

Fusion characteristics

The weld bead profile and fusion properties are greatly influenced by the shielding gas. Using gases that boost arc energy, such as He, H2, and CO2, increases the total fused area (at an equivalent current). In GMAW welding, using pure argon results in a sharp "finger" or "wine-glass" penetration profile, but using mixes of argon, CO2, and helium results in a more rounded profile. Additionally, the reinforcement's profile can be enhanced; for instance, argon/CO2 mixes often result in flatter weld beads and corresponding enhancements.in cost savings and fatigue resistance as compared to pure CO2 shielding. Shielding gas combinations can sometimes increase the uniformity of fusion. For example, argon/hydrogen mixtures have been shown to reduce cast-to-cast variance when GTA welding austenitic stainless steel.

Joint properties

The absence of flaws and the final weld metal microstructure, both of which are impacted by the shielding gas, will determine the mechanical characteristics of the weld. By choosing the right shielding gas and keeping a strong gas shield in place, porosity may be managed. By choosing a gas that provides more heat input, fusion flaws may be reduced, and oxide inclusions can be kept to a minimum by managing the gas's oxidizing potential.Due to its impact on heat input and weld metal composition, the gas may have an impact on the final weld microstructure. For instance, it has been discovered that raising the oxidizing potential of the GMAW shielding gas can increase the toughness of ferritic steels. This is believed to be the result of regulated levels of micro-inclusions initiating fine-grained acicular ferrite. However, a further rise in the oxidizing potential might cause the production of coarse oxide inclusions, which would worsen the toughness of the weld metal. These very minor impacts also depend on the welding wire's composition and the capacity for consistent process performance.

DISCUSSION

Shielding Gas Options

The requirement to meet the aforementioned requirements restricts the variety of practical shielding gas alternatives. The list below includes several typical gases.

Argon

One of the most used shielding gases for GTAW welding is argon. It has a high density in comparison to air and is completely inert. Arc striking and stability are facilitated by the low ionization potential.

Helium

In addition to being chemically inert, helium is less dense than air and requires a greater arc voltage than argon (at the same current and arc length). Although lower depth-to-width ratios are often seen, the resulting increase in power results in higher heat input and fusion area. Although helium is more expensive than argon, the welding rates that can be typically achieved make it a practical alternative, especially for materials with strong conductivity.

Carbon dioxide

Although it is denser than air and has a strong chemical activity, carbon dioxide. It may separate in the arc and release oxygen and carbon monoxide, which may lead to a decrease in the amount of silicon, manganese, and titanium in the weld metal and an increase in carbon. Its usage is limited to GMAW welding of steel due to its chemical activity. Compared to argon-based mixes, the arc voltage in $CO2$ is 1-2 V greater (for an equivalent current and arc length), and enhanced fusion is the result of a little larger heat input. Arc stability, operating tolerances, and transfer behaviour are often subpar, especially at high currents [7].

Oxygen

Despite not being employed as a shielding medium, oxygen is a crucial component of many gas mixes. It lessens the surface tension of steel when added to argon, which also enhances arc stability and arc root behaviour. Metal transfer and bead form are improved by the lower surface tension. Utilising oxygen will reduce the recovery of the more reactive alloying components, similar to $CO2$.

Hydrogen

When combined with argon, hydrogen raises the arc voltage and heat input. Its application is often limited to the GTAW and plasma processes, as well as to materials that do not experience any negative chemical or physical changes while it is present. When applied to austenitic stainless steels, their chemically reducing qualities can be advantageous since they encourage wetting and result in a better weld bead finish.

Shielding gas mixtures for specific applications

It is feasible to create mixes that fulfil the needs of the majority of material-process combinations by evaluating the impacts of the various component gases. Below is a description of the available range of gas mixtures' composition and attributes.

Combinations of gases for GMAW Welding of Low-alloy and Plain Carbon Steels

However, combinations based on argon with additions of oxygen and carbon dioxide are found to produce superior arc stability, lower spatter, and a larger working range (i.e. voltage, wire feed speed, and inductance settings are less crucial). Carbon dioxide may be utilised for dip transfer GMAW. Additionally, the weld bead profile has been enhanced, which results in less welding time and metal usage. The offered blends typically belong to one of the following categories:

1. argon plus 1–8% oxygen
2. argon plus 1–8% carbon dioxide
3. argon plus 8–15% carbon dioxide
4. argon plus 15–25% carbon dioxide
5. pure carbon dioxide
6. argon/carbon dioxide/oxygen mixtures

Since the arc is unstable and the resulting weld bead profile is uneven, pure argon is not appropriate for GMAW welding. Although the weld bead reinforcement is often excessive and the penetration profile has a wine-glass look, the addition of less than 1% oxygen results in a considerable increase in arc stability. For pulsed spray transfer GMAW welding, mixtures containing 1 to 2% oxygen may be employed, although while arc stability is extremely excellent, the penetration profile does not change with the addition of oxygen. Dip transfer welding of thin sheets can be done at higher oxygen concentrations of up to 8%. Unacceptable surface oxidation may happen if more oxygen is introduced than 8%. Although the bead form is marginally improved and steady operation is promoted, the wineglass penetration shape is still discernible when up to 8% CO2 is added to argon. Mixtures of 5% or less CO2 produce smooth spray, pulsed transfer, and dip transfer with little to no spatter. These mixes are most suited for high-current down-hand and horizontal vertical fillet welding, as well as pulsed transfer welding of positional welds in thicker materials.

The intermittent emergence of small inter-run porosity restricts the use of these low oxygen and carbon dioxide mixes for multi-pass welding of thicker materials. This is known to be lowered by increasing the operating current or boosting the CO2 content of the gas and has been linked to argon entrapment and nitrogen absorption. In the spray and pulse transfer operating modes, intermediate quantities of CO2 (argon plus 8–15% carbon dioxide) result in enhanced fusion and a lower risk of porosity while still maintaining acceptable operating characteristics.

Combinations of argon with 15–25% carbon dioxide exhibit greater fusion and bowl-shaped penetration profiles, although when the CO2 level approaches 25%, arc stability tends to degrade. These combinations are perfect for multi-run butt welds for welding bigger areas. The properties of the gas resemble those of pure CO2 when the CO2 level is more than 25 to 35 per cent.Good fusion properties are produced by pure CO2, although weld bead reinforcement is greater than in argon-rich mixtures. The arc's heat input is increased, which can result in somewhat greater performance on an oxidised or primed plate. Although CO2 may produce good dip transfers, the setup tolerances are tighter than they are for argon-based mixes, and transfers made under spray and pulsed circumstances tend to be globular with significantly more spatter. a demonstration of the differences in spatter levels between using

CO_2 and using CO_2 and argon. The performance parameters of ternary argon/carbon dioxide/oxygen mixtures are comparable to those of argon/CO_2, however, a modest improvement in arc stability has been seen. It can be observed from the results of the arc stability experiments for dip transfer in these three-part mixtures that combinations comprising 12 to 15 per cent CO_2 and 2 to 3%. O_2 provides outstanding stability. Even when operating with electrodes in the negative, the mixtures in this range exhibit strong spray transfer performance and fusion properties.

Gas Mixtures for GMAW Welding of Austenitic Stainless Steel

While argon and oxygen with minor quantities (1-2%) can be utilized to spray-weld stainless steel, dip-transfer operations usually result in poor bead appearance and fusion properties. Austenitic stainless steel may be welded using argon/5% CO_2, although the resulting welds' carbon content can rise beyond 0.04%, making this mixture inappropriate for low-carbon "L" grade steels.Many proprietary mixes are based on combinations of argon, helium, and CO_2, with tiny additions of O_2 and hydrogen in certain circumstances. Helium additions to an argon/CO_2 mixture produce enhanced fusion, lower wetting angle, and improved bead appearance. The typical stainless-steel combinations GMAW are divided into two groups.

1. high helium (60–80%)
2. low helium (20–40%)

The majority of high-helium mixes are used for dip transfer, where the greater helium content enhances bead appearance, speeds up welding, and upsets the frequency of dip transfers. Increased arc voltage and enhanced fusion, especially with low currents. The major applications for lower-helium mixtures in welding are spray and pulsed transfer. They provide good fusion, easy spray transfer, and superior bead profiles. By chemically decreasing the surface oxide, the addition of 1-2% hydrogen to these mixes enhances wetting and bead appearance.Although these combinations were created particularly for austenitic stainless steel, they may also be utilised with plain carbon steel in applications that demand faster processing times and better surface quality, such as automated welding of thin sheet steel components.

Gases For Gta Welding Of Steels

Although mixes of argon and up to 5% hydrogen are frequently employed, argon is the most popular gas for GTAW, especially for austenitic stainless steels where greater speed, better profile, and improved process tolerance are required. Ferritic steels cannot have hydrogen additives because they are prone to hydrogen-induced cold cracking.

For high-speed welding of steels, helium/argon mixtures of 30–80% helium can be utilised. On stainless steels, it has been discovered that both helium/argon and argon/hydrogen mixtures enhance the tolerance to cast-to-cast variation issues.

Gases For Gmaw And Gta Welding Of Aluminium Alloys

Although combinations of argon and helium with up to 80% helium give benefits in fusion and bead profile, argon is often advised for both GMAW and GTA welding of aluminium and its alloys. These combinations are especially helpful for thicker materials since they allow for fewer weld runs and preparation angles.

Gases For Gmaw And Gta Welding Of Copper And Its Alloys

Larger heat input in the arc is preferred, especially for GTAW, for materials like copper with good thermal conductivity. The required increase in heat input is provided by helium or helium/argon mixes, which also minimise the requirement for preheating, enhance welding rates, and improve process tolerance. For GMAW, nitrogen and nitrogen/argon combinations have been utilised; the nitrogen boosts heat input, but heat transport is subpar and spatter levels can be high.

Gases For Gmaw and Gta Welding Of Nickel And Its Alloys

For all nickel alloys, argon or argon/helium combinations may be utilised. While minor hydrogen additions (1–5%) enhance weld fluidity and decrease porosity, high nickel alloys are sensitive to nitrogen porosity. For GTA welding of cupro-nickels like Monel (66% Ni, 31% Cu), combinations of argon and hydrogen are frequently utilised.

Gases for plasma welding

The plasma gas and the shielding gas are the two gas supplies needed for plasma welding. The best plasma gas for many purposes is argon. It permits dependable arc initiation and guards against the erosion of the tungsten electrode and anode orifice. However, for austenitic stainless steel, additions of up to 8% hydrogen may be applied to improve arc constriction, fusion properties, and travel speed. The shielding gas may be argon.

Gases For Fcaw Welding Of Steel

The types of consumables used in the FCAW process determine the gases that are used, i.e.gases appropriate for basic consumer goods, carbon and low-alloy steels, and rutile.gases appropriate for steels, both carbon and low alloy, and consumables with metal cores.gases appropriate for FCAW in stainless steel.

The majority of rutile and basic flux-cored wires are designed to have acceptable mechanical qualities and operational characteristics with CO2 shielding. Arc stability often improves somewhat with the use of argon/20% CO2 and three-part argon/12-15% CO2/2-3% O2 mixtures, as does the recovery of alloying elements that are rapidly oxidised. The three-part argon/oxygen/carbon dioxide mixtures above produce good transfer qualities and somewhat better fusion. Metal-cored wires were first intended to give smooth spray transfer in argon/5% CO2 mixtures. Additionally, metal-cored wires that function well with CO2 shielding have been introduced.

Although the three-part mixes mentioned above have also been shown to be suitable, most stainless-steel flux-cored wires are intended to work in argon/ 20% CO2 solutions. According to recent research, using argon/CO2 gas mixtures with lower CO2 levels enhances the recovery of alloying elements, lowers the amounts of oxygen in the weld metal, and boosts yield and ultimate tensile strength. The same as with solid carbon steel wires, the best toughness was found with particular mixes, and this is due to a combination of changing the welding chemistry and the thermal cycle's reaction to the gas. It's crucial to make sure that any deviation from the intended gas mixture won't negatively impact the operating performance or weld properties when it comes to flux-cored wires because the flux formulation will be created under the assumption that a specific range of shielding gas mixtures will be used.

Gases For Miab Welding

Although it has been claimed that using CO2 can somewhat enhance joint quality, MIAB welding can be carried out without shielding gas.

Special mixtures

A few unique gas combinations have been created for particular uses.
For instance:

- argon/chlorine, argon/Freon mixtures
- argon/sulphur dioxide
- argon/nitric oxide gas mixtures
- gases for high-deposition GMAW.

To reduce porosity and enhance process tolerances in the GMA welding of aluminium, combinations of argon and chlorine have been studied. Despite some observed advantages, chlorine's severe toxicity makes the deployment of these mixes doubtful. Certain argon/Freon mixes are non-toxic, and it has been shown that substituting Freon for chlorine can have comparable effects. Arc stability and weld bead shape, in particular, were found to be enhanced. Despite being non-toxic, environmental considerations prevent the economic utilisation of these mixes. Despite the restrictions placed on the usage of both of these types of mixes, it is still plausible that they might be advantageous in completely enclosed controlled-environment chambers for applications that need automation.

sulphate of dioxide. In GTA welding of austenitic stainless steel, cast-to-cast variance has been reduced using argon/SO2 combinations. The trials provide a valuable indicator of the beneficial effect that sulphur has on these materials' weldability, but since the gas is hazardous, it cannot be used in actual applications.

Nitric oxidase. To reduce ozone levels around GMAW and GTAW arcs, a variety of gas combinations including a minor quantity of nitric oxide (nitrogen monoxide, NO) have been devised. By exposing the oxygen in the air around and immediately around the arc to UV light, ozone is created. To promote ozone production, radiation with a wavelength between 130 and 170 nm is highly effective. Ozone is harmful, and the welder's breathing zone's maximum recommended level is incredibly low. Fortunately, the ozone will combine with other airborne chemicals and gases to create oxygen and oxides, and Additionally, the rate of ozone generation is low at low currents or in the presence of a respectable quantity of particulate smoke, and the possibility of its recombination before reaching the welder's breathing zone is considerable. But extremely high quantities of ozone are produced in some applications using high-current GTAW arcs, notably when welding aluminium with GMA. Nitric oxide will mix with free ozone to create oxygen and nitrogen dioxide when it is introduced to the shielding gas. Nitric oxide is substantially less harmful than ozone.It has been demonstrated that adding 0.03% NO to an argon/20%. Freons, such as Freon 12 (CCl2F2), are gaseous mixtures of the elements carbon, chlorine, fluorine, and brominewhile welding steel with GMA, CO2 mixture may greatly minimise ozone generation. It also works well to control ozone while welding aluminium using GMAW and GTAW. To guarantee that all remnants of harmful gases have been eliminated from the welding environment, these gas mixes are often advised in conjunction with local ventilation.

GMAW with high deposition. With the use of the argon/O2/CO2 gas combinations mentioned above, the electrode-negative operation can provide high deposition rates. Alternately, specialised gas mixes based on argon/helium/CO2 have been created, which are targeted for automated applications and offer very high deposition rates (up to 15 kg h-1) when employed with prolonged electrical stick-out. To guarantee proper shielding with the increased electrical extension, a unique torch design is necessary.

Gases For Laser Welding

Gases are necessary for the laser's functioning, shielding, and plasma management during the laser welding process. A gas mixture is utilised to support the electrical discharge and produce the laser beam in gas or CO2 lasers. The precise combination will vary depending on the laser's model and maker, but typical gas mixes include:

1. 80% helium/15% nitrogen/5% carbon dioxide
2. 61% helium/4% carbon dioxide/31.5% nitrogen/3.5% oxygen

The type of gas laser being utilised will also determine whether these gases are provided separately or premixed. For shielding and plasma management in YAG lasers, both gas and solid state, extra gases are needed. While ionisation of the gas or metal vapour to generate plasma is undesired in laser welding (see Chapter 8), gases with a high ionisation potential, such as helium, are preferred. The most frequently utilised gas mixes for shielding are:

1. In addition to steel and the reactive metals titanium and zirconium, argon, helium, and argon/helium mixes are employed for the majority of materials.
2. Nitrogen can be used for less demanding applications on austenitic stainless steel.

A jet of gas can be used to disrupt or displace a plasma if it does develop; helium is typically employed for this purpose [8]–[10].

CONCLUSION

A great overview of the variety of welding methods available to structural and mechanical engineers is provided by advanced welding techniques. The first section of the book covers broad subjects such as power sources, filler materials, and welding gases. The primary welding methods, including gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), high energy density procedures, and narrow-gap welding techniques, are then evaluated in a central set of chapters.Gas metal arc welding (GMAW) is frequently used in chassis parts because it ensures the joint's strength and stiffness. Additionally, the method is flexible enough to link components with different forms to structural components like pipes and brackets. The weld joint must have a long fatigue life. In components created during welding, concerns with spatter, fit-up, and gaps need to be addressed. Resistance spot welding is prohibited by some component designs. Additionally, there are closed components that resistance spot welding guns cannot access. It is recommended to use the GMAW technique for these applications.

REFERENCES

[1] P. Kah, R. Suoranta, and J. Martikainen, “Advanced gas metal arc welding processes,” *Int. J. Adv. Manuf. Technol.*, 2013, doi: 10.1007/s00170-012-4513-5.

[2] B. Mvola, P. Kah, J. Martikainen, and R. Suoranta, “State-of-the-art of advanced gas metal arc welding processes: Dissimilar metal welding,” *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 2015. doi: 10.1177/0954405414538630.

[3] B. Mvola, P. Kah, and J. Martikainen, “Dissimilar ferrous metal welding using advanced gas metal arc welding processes,” *Rev. Adv. Mater. Sci.*, 2014.

[4] J. Norrish, “Recent gas metal arc welding (GMAW) process developments: the implications related to international fabrication standards,” *Weld. World*, 2017, doi: 10.1007/s40194-017-0463-8.

[5] Y. Cheng, R. Yu, Q. Zhou, H. Chen, W. Yuan, and Y. M. Zhang, “Real-time sensing of gas metal arc welding process – A literature review and analysis,” *Journal of Manufacturing Processes*. 2021. doi: 10.1016/j.jmapro.2021.08.058.

[6] Y. M. Zhang, Y. P. Yang, W. Zhang, and S. J. Na, "Advanced Welding Manufacturing: A Brief Analysis and Review of Challenges and Solutions," *J. Manuf. Sci. Eng. Trans. ASME*, 2020, doi: 10.1115/1.4047947.

[7] B. Mvola and P. Kah, "Effects of shielding gas control: welded joint properties in GMAW process optimization," *International Journal of Advanced Manufacturing Technology*. 2017. doi: 10.1007/s00170-016-8936-2.

[8] R. Chinnasamy, S. J. S. Chelladurai, and T. Sonar, "Investigation on Microstructure and Tensile Properties of High-Strength AA2014 Aluminium Alloy Welds Joined by Pulsed CMT Welding Process," *Adv. Mater. Sci. Eng.*, 2021, doi: 10.1155/2021/8163164.

[9] J. Norrish, "Gases for advanced welding processes," in *Advanced Welding Processes*, 2006. doi: 10.1533/9781845691707.58.

[10] B. Mvola, P. Kah, and J. Martikainen, "Welding of dissimilar non-ferrous metals by GMAW processes," *International Journal of Mechanical and Materials Engineering*. 2014. doi: 10.1186/s40712-014-0021-8.

CHAPTER 13

EXPLORING THE FEATURES OF PLASMA ARC WELDING

Mr. Sandeep Ganesh Mukunda, Assistant Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: sandeepgm@presidencyuniversity.in

ABSTRACT:

Plasma arc welding (PAW) is an arc welding procedure similar to gas tungsten arc welding, in which an electric arc is created between a non-consumable tungsten electrode and the workpiece. Similar to gas tungsten arc welding (GTAW), plasma arc welding (PAW) is a form of arc welding. An electrode, which is typically but not always built of sintered tungsten, and the workpiece come together to form the electric arc. The fundamental distinction between PAW and GTAW is the positioning of the electrode within the torch's body, which separates the plasma arc from the shielding gas envelope. This chapter explained plasma arc welding Key whole and non-key entire welds are both formed utilizing plasma welding. Making non-keyhole welds the process can make non-keyhole welds on work items that are 2.4 mm in thickness and under. The process of plasma arc welding is typically utilized for tools, dies, molds, etc. Many industries, including the marine and aerospace industries, use plasma arc welding. Welding stainless steel pipes and tubes with plasma arc welding is another possibility. It is applied for turbine blade welding.

KEYWORDS:

Plasma Arc, Arc Welding, Shielding Gas, Argon Hydrogen, Weld Pool, Shielding Gas Envelope.

INTRODUCTION

Plasma arc welding is an arc welding process wherein coalescence is produced by the heat obtained from a constricted arc setup between a tungsten/alloy tungsten electrode and the water-cooled (constricting) nozzle (non-transferred arc) or between a tungsten/alloy tungsten electrode and the job (transferred arc). An electric plasma arc and a non-consumable electrode are used in the plasma arc welding (PAW) procedure to fuse metals. The electrode is commonly formed of throated tungsten, just like TIG. It is an excellent alternative for welding both thin metals and making deep, narrow welds because of its unusual torch design, which delivers a more focused beam than TIG welding. Compared to conventional processes, plasma welding is usually used to join difficult metals including stainless steel, aluminum, and others. This technology can cut metal using plasma (like oxy-fuel welding), making it a flexible tool for fabricators and manufacturers [1]–[3].

Plasma arc welding (PAW) is an arc welding technology similar to gas tungsten arc welding (GTAW). The electric arc is created between an electrode (which is usually but not always constructed of sintered tungsten) and the workpiece. The fundamental distinction from GTAW is that with PAW, the electrode is positioned within the body of the torch, thus the plasma arc is separated from the shielding gas envelope. The plasma is then driven through a fine-bore copper nozzle which constricts the arc and the plasma exits the orifice at high velocities (nearing the speed of sound) and a temperature approaching 28,000 °C (50,000 °F) or higher.Arc plasma is a transient condition of a gas. The gas gets ionized by an electric current running through it and it becomes a conductor of electricity. In an ionized state, atoms are broken into electrons (−) and cations (+) and the system comprise a mixture of ions, electrons, and highly excited atoms. The degree of ionization may be between 1% and greater than 100% (possible with double and triple degrees of ionization). Such states exist as more electrons are dragged off their orbits. The energy of the plasma jet and consequently the temperature relies upon the electrical power applied to create arc plasma. A typical value of temperature obtained in a plasma jet torch is on the order of 28,000 °C (50,400 °F)), compared to roughly 5,500 °C (9,930 °F)) in a regular electric welding arc. All welding arcs are (partially ionized) plasmas, but the one in plasma arc welding is a restricted arc plasma.

The PAW (Plasma Arc Welding), which is a cutting technology, was discovered in the year 1953 by "Robert Merrell Gage" and recognized in the year 1957. This process was unusual as it can accomplish accuracy cutting on both thin and thick metal. This form of welding is also competent for spray coating hard metal on new metals. This welding process is used in the welding sectors for offering greater control towards the arc welding method in small current ranges. At present, plasma contains distinct features and is used across the business by providing a superior control level & accuracy for generating high-worth joins in micro applications to supply a long life for high production supplies. This page offers brief information about what is plasma arc welding, its working principle, different types, equipment, advantages, limitations, and applications.

Plasma arc Welding Process

The aim behind plasma arc welding is to establish an arc between a non-consumable tungsten electrode and the workpiece. The electrode for the plasma nozzle is positioned inside the torch's body, which is a distinguishing design aspect. As a result, the shielding gas envelope and arc plasma can escape the torch separately. In addition, the nozzle's constricted opening speeds up the flow of plasma gas, enabling deeper penetration. While the leading edge of the weld pool is normally where filler metal is supplied, this is not the case when making root pass welds. Compared to gas tungsten arc welding, the plasma welding torch is more sophisticated. It is vital for plasma welding torches to always be water-cooled as they operate at extremely high temperatures that risk melting away their nozzle. Although these flames can be handled by hand, the bulk of contemporary plasma welding guns is made for automatic welding. Tungsten inclusions and undercutting are the two plasma welding faults that occur most frequently. When the welding current exceeds the tungsten electrode's capability, tiny tungsten droplets become stuck in the weld metal and produce tungsten inclusions. Keyhole mode PAW welding is generally associated with undercuts, which can be mitigated by applying active fluxes. Plasma arc welding is a method of welding in which the temperature that arises from the setup between a tungsten alloy electrode and the workpiece is used to create a coalescence [4]–[6].

There are three different types of gas sources utilized in plasma arc welding, including:

1. **Plasma Gas:** As it flows through the nozzle, plasma gas becomes ionized.
2. **Shielding Gas:** This gas serves the exterior nozzle and shields the weld from ambient pollution.
3. **Back Purge Gas:** The back purge gas is mostly utilized when welding certain types of materials. To produce an additional pilot arc and separate the plasma and shielding gases, the equipment can be purchased as an add-on unit to traditional TIG equipment. The plasma arc is generated by the specific torch arrangement and system controller. Alternately, specialty plasma equipment is accessible.

DISCUSSION

In plasma arc welding (PAW), an electric arc is formed between an electrode and the workpiece during the welding process. In most situations, but not always, the electrode for plasma arc welding is constructed of sintered tungsten. Robert Merrell Gauge discovered plasma arc welding in 1957. The plasma arc can be separated from the shielding gas envelope by positioning the electrode inside the welding torch's body. The arc is then restricted when the plasma is driven through a fine-bore copper nozzle, and the plasma exits the nozzle orifice at high speeds and a temperature close to 2000 °C. A non-consumable tungsten electrode is utilized in plasma arc welding, and an electric arc is restricted through a fine-bore copper nozzle. The majority of industrial metals and alloys can be welded using a plasma arc [7]–[9].The plasma arc welding process can be varied in several ways by altering the welding current, plasma gas flow rate, and nozzle orifice width, including:

1. When the welding current is less than 15 A, micro plasma is used.
2. Melt-in Mode (15 to 400 A for welding current)
3. For welding currents more than 100 A, use keyhole mode.

Principle of Operation

Plasma arc welding is an advanced kind of tungsten inert gas (TIG) welding. In the case of TIG, it is an open arc shielded by argon or helium, whereas plasma employs a specific torch where the nozzle is utilized to restrict the arc while the shielding gas is separately supplied by the torch. The arc is constricted with the help of a water-cooled tiny diameter nozzle which squeezes the arc, raises its pressure, temperature, and heat intensity, and therefore improves arc stability, arc form, and heat transmission properties. Plasma arcs are created utilizing gas in two types; laminar (low pressure and low flow) and turbulent (high pressure and high flow). The gases used are argon, helium, hydrogen, or a mixture of these. In the case of plasma welding, laminar flow (low pressure and low flow of plasma gas) is utilized to ensure that the molten metal is not blasted out of the weld zone.

The non-transferred arc (pilot arc) is utilized during plasma welding to commence the welding process. The arc is produced between the electrode(-) and the water-cooled constricting nozzle (+). A non-transferred arc is initiated by using a high-frequency unit in the circuit. After the initial high-frequency start, the pilot arc (low current) is generated between the circuits by applying a low current. After the main arc is struck, the nozzle is neutral or in the case of welding-mesh employing microplasma, there can be an option offered to have a continuous pilot arc. A transferred arc possesses high energy density and plasma jet velocity. Depending on the current user and the flow of gas, it can be employed to cut and melt metals. Microplasma employs current between 0.1 and 10 amps and is used in foils, bellow, and thin sheets. This is an autogenous process and generally does not utilize filler wire or powder. Medium plasma employs current between 10 and 100 amps and is used for higher-thickness plate welding with filler wire or autogenous up to 6 mm (0.24 in) plates and metal deposition (hard facing) utilizing specialized torches and powder feeders (PTA) employing metal powders.

High-current plasma above 100 amps is utilized with filler wires welding at high travel rates.

Other applications of plasma are plasma-cutting, heating, deposition of diamond films (Kurihara et al. 1989), material processing, metallurgy (creation of metals and ceramics), plasma-spraying, and underwater cutting.Tungsten inert gas (TIG) welding has evolved into plasma arc welding. While plasma employs a special torch with the nozzle employed to limit the arc while the shielding gas is supplied separately by the torch, TIG uses an open arc shielded by argon or helium. A water-cooled small-diameter nozzle is used to constrict the arc, which squeezes it and intensifies its pressure, temperature, and heat to increase its stability, shape, and heat transfer qualities. Laminar (low pressure and low flow) and turbulent (high pressure and high flow) gases are employed to form plasma arcs. Argon, helium, hydrogen, or a mixture of these gases are utilized. To prevent the molten metal from being blasted beyond the weld zone when plasma welding, laminar flow (low pressure and low flow of plasma gas) is used. When plasma welding, the non-transferred arc (pilot arc) is employed to initiate the welding process. The electrode (-) and the water-cooled constricting nozzle (+) are where the arc is formed. By inserting a high-frequency unit into the circuit, a non-transferred arc is triggered.

After the first high-frequency start, a little current is employed to form the pilot arc between the elect. The nozzle is neutral after the main arc is struck, or in the case of welding mesh employing microplasma, an option to have a continuous pilot arc may be offered. A transferred arc features a rapid plasma jet and high energy density. It can be used to cut and melt metals depending on the current used and gas flow. Foils, bellows, and thin sheets can be utilized with microplasma,The melt-in mode and the keyhole mode, which are the two separate operating modes for the PAW process, are frequently used terms. The term "melt-in-mode" describes a weld pool that resembles the one that frequently forms during gas-tungsten arc welding (GTAW), in which a bowl-shaped section of the workpiece material that is under the arc is melted.

Gases for shielding and plasma (orifice):

The shielding gas is used to protect the weld metal pool while it cools and hardens, whereas the plasma gas is utilized to create the arc. Argon is often the plasma gas. For microplasma welding, the flow rate can range from 0.1 L/min to 10 L/min for keyhole plasma welding.

Gas Plasma

In more than 90% of all applications, argon is employed as the primary plasma gas. It is completely inert, which means that it won't interact with other substances at any temperature or pressure. Its low ionization potential ensures a dependable pilot arc and arc initiation.

Argon: Argon supplies the tungsten electrode with exceptional protection and arc stability.

The flow rates are between.25 SCFH (.18 lpm) and 5.0 SCFH (2.4 lpm).

Argon/Hydrogen: (Up to 3% Hydrogen) Argon/Hydrogen

There are occasions where adding a little hydrogen to argon is advisable. This raises the weld puddle's heat input. A hotter arc created by argon/hydrogen will help with weld penetration and weld puddle fluidity. When compared to argon, employing Argon/Hydrogen blends will lower the life of torch parts. Tip Using a hydrogen gas mixture leads to a 50% drop in current ratings. The flow rates range between.25 SCFH (.18 lpm) and 5.0 SCFH (2.4 lpm).

Shielding Gas

Argon:

All metals can be exploited with argon. At lower current levels (less than 20 amps), it delivers good arc stability and efficient cleaning. Additionally, it is indicated for utilization while welding reactive metals, copper alloys, titanium, and aluminium. Due to the greater arc voltages required in plasma welding (18–32V), Argon could occasionally perform less than satisfactorily. A weld may endure slight undercutting or show evidence of surface oxidation when the weld puddle is not flowing. It can be needed to employ argon/hydrogen, helium, or argon/helium blends.

Hydrogen/argon (95/5%)

Argon/hydrogen blends are exploited to increase the weld's heat input. Increased travel speeds occur from the lowering of surface tension in the molten pool produced by the addition of hydrogen to argon. Degassing of the weld pool is made easier by lowering the surface tension of the molten metal, which also decreases the possibility of gas inclusions in the form of porosity. Undercutting is also prevented and a better weld surface is produced at quicker welding speeds. Hydrogen has a fluxing function that minimizes the number of oxides formed when joining stainless steels, nickel, and high nickel alloys in addition to enhancing arc heating efficiency.

The presence of hydrogen benefits welding nickel or nickel alloys by preventing porosity. The hydrogen decreases the nickel oxides that are generated when oxygen from the air enters the system. Any stray oxygen is "attacked" by the hydrogen before it can create nickel oxides.

The maximum amount of hydrogen that is allowed is 15%. It is tangentially related to the thickness of the welding material. The hydrogen can get trapped in the weld with greater current welding and slower transit rates on thicker materials. The weld becomes embrittled as a result of this. In general, the higher the permissible amount of hydrogen in a gas combination that can be employed, the thinner the workpiece must be. In automated welding, employing thinner materials (.062", 1.6 mm or less), a larger hydrogen content can speed up travel.

Helium

The weld heat is enhanced by roughly 25% when helium is used instead of argon. This is produced by helium's enhanced ionization potential, which also enhances the arc voltage. When welding aluminum alloys, copper alloys, and thicker sections of titanium, helium is typically utilized. These materials will lose heat more quickly and require the help of helium. The range of flow rates varies from 15 SCFH (7.1 ppm) to 40 SCFH (18.8 pm).

Argon/Helium (75/25%)

For a given welding current, an arc gets hotter when helium is added to argon. Before a significant shift in heat can be felt, a mixture must have at least 40% helium in it. The arc tends to be stabilized by the argon. Results from mixtures containing more than 75% helium will be fairly comparable to those from pure helium. Thicker sections of titanium or copper alloys are employed in applications where a combination of 75% helium and 25% argon is utilized.

Equipment Used in plasma arc welding:

The following is a list of the tools required for plasma arc welding and their respective roles:

Current: Control of current and gas decay is necessary to adequately seal the keyhole and finish the weld in the structure.

Fixture: Important to keep the molten metal inside the bead from being contaminated by the atmosphere.

Materials: Materials include aluminum, steel, and other substances.

High-frequency: Arc igniting is performed utilizing a high-frequency generator and current limiting resistors. Arc-starting systems can be freestanding or integrated into bigger systems. Used for a transferred arc or non-transferred arc type, the plasma torch. It can be mechanized or operated by hand. Almost all applications today call for an automated system. To prolong the life of the nozzle and electrode, the torch is water-cooled. Depending on the metal to be welded, the shape of the weld, and the required penetration depth, the size and type of the nozzle tip are chosen.

Power source: Plasma arc welding requires a direct-current power supply (generator or rectifier) with drooping characteristics and an open circuit voltage of at least 70 volts. In general, rectifiers are preferred over DC generators. An open circuit voltage over 70 volts is necessary when employing helium as an inert gas. The arc can be ignited using argon at the standard open-circuit voltage and then helium can be turned on. This larger voltage can also be achieved by using two power sources in series.The following are typical welding parameters for plasma arc welding. Direct current electrode negative (DCEN) is typically used for plasma arc welding, except for when welding aluminum, in which case water-cooled electrodes, or direct-current electrode positive (DCEP), are preferred. Other parameters for plasma arc welding include currents of 50 to 350 amps, voltages of 27 to 31 volts, and gas flow rates of 2 to 40 liters/minute (lower range for orifice gas and higher range for outer shielding gas) [10], [11].

Shielding gas: Two inert gases or gas mixes are employed as shielding gases. The plasma arc is formed by orifice gas flowing at a lower pressure and flow rate. Although the orifice gas pressure is purposely kept low to reduce weld metal turbulence, this low pressure cannot sufficiently protect the weld pool. The same or another inert gas is pumped through the outer shielding ring of the torch at substantially greater flow rates to have enough shielding protection. The majority of materials can be bonded together using inert gases or gas combinations such as argon, helium, argon hydrogen, and argon helium. It's common to use argon. Where a broad heat input pattern and flatter cover pass are required without a key-hole mode weld, helium is preferable. Keyhole mode welding in nickel-base alloys, copper-base alloys, and stainless steels is conceivable when argon and hydrogen are coupled because the thermal energy produced is higher than when argon is used alone. A mixture of argon and hydrogen (10–30%) or nitrogen may be utilized for cutting. Due to its atomic dissociation and subsequent recombination, hydrogen creates temperatures higher than those attained by utilizing argon or helium alone. Furthermore, hydrogen provides a reducing atmosphere that aids in preventing oxidation of the weld and its surrounds. Attention must be paid since some metals and steel can get embrittled as a result of hydrogen leaking into the metal.

Voltage control: Voltage regulation is necessary for contour welding. Voltage control is not thought to be necessary for standard key-hole welding because an arc length change of up to 1.5 mm has no discernible impact on weld bead penetration or bead form.

Application of plasma arc welding

The following list includes several plasma arc welding applications.

1. The procedure of plasma arc welding is mostly utilized for tools, dies, molds, etc.
2. Many industries, including the marine and aerospace industries, use plasma arc welding.
3. Welding stainless steel pipes and tubes with plasma arc welding is another option.
4. It is utilized for turbine blade welding.
5. Additionally suitable for the electrical sectors is plasma arc welding.

Advantages of Plasma arc welding

The following are the main benefits of plasma arc welding:

1. Compared to other arc welding procedures, plasma arc welding has a higher energy concentration.
2. Depending on the material, a maximum depth of 12 to 18 mm can be reached using the plasma arc welding process.
3. Greater arc stability in plasma arc welding enables significantly longer arc lengths and a much higher tolerance for arc length variations.
4. Plasma arc welding uses very little power.
5. Plasma arc welding allows for rapid welding.
6. When compared to other procedures, such as GTAW, thicker metal can be pierced in a single pass.
7. Less joint preparation is necessary due to the higher penetration.
8. The method can result in good weld integrity (similar to GTAW), reducing the number of welding passes and, consequently, the number of welding hours and labor costs.
9. Better visibility of the weld pool is made possible by the longer arc length, which is crucial for manual welding.

Disadvantages of plasma arc welding

The following are some drawbacks of plasma arc welding.

1. It's noisy when plasma arc welding.
2. Welders with advanced skills are necessary.
3. The orifice needs to be replaced for plasma arc welding.
4. The complicated and expensive plasma arc welding equipment is employed.
5. There is more radiation produced.
6. The welding processes used in plasma arc welding are typically more intricate and less forgiving of fit-up variances, etc.
7. The cost of the equipment is higher than with the GTAW method.
8. Compared to the wider, conical arc of the GTAW process, high arc constriction yields higher penetration but also limits the method's tolerance to joint gaps and misalignment.
9. The PAW torch design is more complex and has more parts, necessitating more periodic maintenance [12], [13].

CONCLUSION

This chapter described the plasma arc welding technology that is used to fuse the metal workpiece. The procedure of plasma arc welding is usually utilized for tools, dies, and molds, among other things. Plasma arc welding is employed in several industries, including the marine and aerospace sectors. Plasma arc welding stainless steel pipes and tubes is an extra option. It is used to solder turbine blades. Plasma arc welding is also useful for the electrical industry. Plasma arc welding is a versatile and precise welding process that has many applications in various sectors. While it has certain limitations, its positives vastly exceed them. If you require a welding technique for your next project, try employing PAW.

REFERENCES

[1] J. Qiao, C. Wu, and Y. Li, "Numerical analysis of keyhole and weld pool behaviors in ultrasonic-assisted plasma arc welding process," *Materials (Basel).*, 2021, doi: 10.3390/MA14030703.

[2] C. S. Wu, L. Wang, W. J. Ren, and X. Y. Zhang, “Plasma arc welding: Process, sensing, control and modeling,” *J. Manuf. Process.*, 2014, doi: 10.1016/j.jmapro.2013.06.004.

[3] Z. M. Liu, S. L. Cui, Z. Luo, C. Z. Zhang, Z. M. Wang, and Y. C. Zhang, “Plasma arc welding: Process variants and its recent developments of sensing, controlling and modeling,” *Journal of Manufacturing Processes*. 2016. doi: 10.1016/j.jmapro.2016.04.004.

[4] T. Q. Li, L. Chen, Y. Zhang, X. M. Yang, and Y. C. Lei, “Metal flow of weld pool and keyhole evolution in gas focusing plasma arc welding,” *Int. J. Heat Mass Transf.*, 2020, doi: 10.1016/j.ijheatmasstransfer.2019.119296.

[5] C. S. Rao and K. S. Prasad, “Advances in Plasma Arc Welding□: A Review,” *J. Mech. Eng. Technol.*, 2012.

[6] Y. Li, C. Wu, and M. Chen, “Numerical analysis of the ultrasound induced arc pressure increment in plasma arc welding,” *J. Phys. D. Appl. Phys.*, 2019, doi: 10.1088/1361-6463/aae96d.

[7] A. V. Nguyen, D. Wu, S. Tashiro, and M. Tanaka, “Undercut formation mechanism in keyhole plasma arc welding,” *Weld. J.*, 2019, doi: 10.29391/2019.98.018.

[8] R. Zhang, F. Jiang, and S. Chen, “Comparison of energy acted on workpiece among Twin-body Plasma Arc Welding, Non-transferred Plasma Arc Welding and Plasma Arc Welding,” *J. Manuf. Process.*, 2016, doi: 10.1016/j.jmapro.2016.08.009.

[9] D. Wu, S. Tashiro, X. Hua, and M. Tanaka, “Numerical study of keyhole behaviors and thermal fluid flow in high current plasma arc welding,” *Yosetsu Gakkai Ronbunshu/Quarterly J. Japan Weld. Soc.*, 2021, doi: 10.2207/QJJWS.38.40S.

[10] Z. Lu, W. Zhang, F. Jiang, S. Chen, and Z. Yan, “A primary study of variable polarity plasma arc welding using a pulsed plasma gas,” *Materials (Basel).*, 2019, doi: 10.3390/MA12101666.

[11] A. Sahoo and S. Tripathy, “Development in plasma arc welding process: A review,” 2019. doi: 10.1016/j.matpr.2020.09.562.

[12] T. Qing Li, X. M. Yang, L. Chen, Y. Zhang, Y. Cheng Lei, and J. Chun Yan, “Arc behaviour and weld formation in gas focusing plasma arc welding,” *Sci. Technol. Weld. Join.*, 2020, doi: 10.1080/13621718.2019.1702284.

[13] H. L. Nguyen, A. Van Nguyen, H. Le Duy, T. H. Nguyen, S. Tashiro, and M. Tanaka, “Relationship among welding defects with convection and material flow dynamic considering principal forces in plasma arc welding,” *Metals (Basel).*, 2021, doi: 10.3390/met11091444.

CHAPTER 14

WELDING METALWORKING'S METALLURGY: AN ANALYSIS

Mr. Vijaykumar Lingaiah, Assistant Professor
Department of Mechanical Engineering, Presidency University, Bangalore, India
Email Id: vijaykumarsl@presidencyuniversity.in

ABSTRACT:
The study of welding's effects on metals' physical, mechanical, and chemical properties is known as welding metallurgy. Generally speaking, alloys melt and resolidify during welding, completely eradicating the intended microstructure and changing the mechanical and corrosion properties. This abstract provides a synopsis of welding metallurgy. It talks about how understanding welding metallurgy is essential to creating high-quality welded joints. It discusses several welding methods and how metallurgical changes are impacted by them. Additionally, it highlights crucial factors that have an impact on the metallurgical modifications made during welding. The science and technology of metalworking involve economically extracting metals from their ores, purifying them, and getting them ready for use. It investigates a metal's microstructure or the structural elements that are visible under a microscope. Welding metallurgy refers to the complex microcosm of metallurgical processes that can occur inside and around a weld during the rapid heating and cooling cycles associated with the majority of welding methods.

KEYWORDS:

Liquid, Fusion, Metal, Phase, Zone, Welding.

INTRODUCTION

Since welding always occurs in non-equilibrium settings and diffusion is frequently limited, many of the existing fundamental metallurgical principles can only approximate metallurgical behavior when utilized in welding. A branch of materials science and engineering called metallurgy examines the physical and chemical properties of metallic elements, their intermetallic compounds, and the mixes of these elements that are referred to as alloys. The science and technology of metals, or how science is applied to the manufacturing of metals, as well as the engineering of metal components utilized in products for both customers and manufacturers, are all included in the field of metallurgy. The art of metalworking is distinct from metallurgy. Similar to how medicine depends on medical science for technical advancement, metalworking depends on metallurgy. A metallurgist is an expert in the practice of metalworking [1]–[3].

Chemical metallurgy and physical metallurgy are two further divisions of the science of metallurgy. The reduction, oxidation, and chemical behavior of metals are the main topics of study in chemical metallurgy. Mineral processing, metal extraction, thermodynamics, electrochemistry, and chemical deterioration (corrosion) are among the topics covered in chemical metallurgy. Physical metallurgy, on the other hand, is concerned with the mechanical, physical, and performance characteristics of metals. Crystallography, material characterization, mechanical metallurgy, phase transitions, and failure mechanisms are among the subjects covered in physical metallurgy. Metal production has always been the main emphasis of metallurgy. The process of extracting metal from ores is the first step in the manufacture of metal, which also involves mixing different metals to create alloys. Melting and solidification are crucial processes when employing fusion welding techniques since they are necessary to achieve a good connection. Local compositional changes result from dendrite nucleation, growth, segregation, and diffusion processes, all of which are related to solidification. Such compositional alterations may have an impact on welding performance.

Phase transitions, diffusion, precipitation reactions, recrystallization, and grain formation are just a few of the metallurgical processes that occur in the solid state. Liquidation processes, in which liquid films may form outside the fusion zone, may cause cracking problems. Depending on the metal being welded, some or all of these processes may help create the weld heat-affected zone (HAZ). Concerning the base metal, the intensity of these reactions may significantly alter the microstructure and welding characteristics.

Numerous of these occurrences or combinations of occurrences have the potential to result in weld embrittlement. To forecast and understand the mechanical properties of a weldment and how it will operate in service, it is essential to first understand the microstructure created during welding. Before one can properly comprehend the microstructure, it is essential to understand the base metal's microstructure, how it was processed, and the type of welding method being used. For instance, transformation hardening, which involves intentionally creating martensite, a hard microstructure, can strengthen steel by changing its properties through tempering heat treatment. Untempered martensite will likely develop when the steel is being welded, which could lead to cracking and/or a decrease in ductility and toughness. When using high energy density welding techniques like laser welding as compared to submerged arc welding, which is known for its high heat input and slow cooling rates, martensite may develop more frequently. An averaging response could make a precipitation-hardening-enhanced aluminum alloy susceptible to substantial softening in the HAZ. A high energy density welding technique like laser welding, with its low heat input, may be helpful in this case.

The heat-affected zone (HAZ), which includes the partially melted and true heat-affected zone, and the fusion zone, which includes the composite zone (CZ) and unmixed zone (UMZ), are words used to describe the areas of a fusion weld. Since 1976, there hasn't been much change in the nomenclature used to describe them, but a lot of effort has been done to verify the accuracy of these regions using a variety of alloy systems. Additional terminology has been added to the original. For instance, the actual HAZ in steels has been divided into several sub-regions, such as the coarse-grained HAZ, the fine-grained HAZ, and the region (occurs when peak temperatures are higher than the alpha ferrite + austenite phase field). For instance, martensite may form in the transition zone of a weld between stainless steel and low alloy steel even when it does not occur elsewhere in the weld [4].

History of Welding Metallurgy

The discovery of ways to join metals by early civilizations resulted in the creation of welding metallurgy. However, welding metallurgy was not systematically investigated as a scientific discipline until the 19th century. The following information provides a detailed account of welding metallurgy's history. From the Cretaceous Period through the Eighteenth Century, Early Development of Ingot Welding The earliest known method of joining metals was by heating and pressing them together. This method was employed by blacksmiths in ancient civilizations such as the Egyptian, Greek, and Roman. Metals can be joined together using the brazing and soldering processes that were developed. Both of them employ a filler substance with a lower melting point. preliminary scientific research Researchers like Benjamin Franklin and Alessandro Volta made the first observations of how metals acted during welding procedures in the 18th century. The study of welding's effects on metals' physical, mechanical, and chemical properties is known as welding metallurgy. Generally speaking, alloys melt and resolidify during welding, completely eradicating the intended microstructure and changing the mechanical and corrosion properties. The goal of studying welding metallurgy is to produce high-quality weldments that can preserve the same properties of the alloys before welding. Chemical composition, grain size, cooling rate, and the mechanical properties of the alloys are the primary factors that must be taken into account to produce weldments of high quality.

The temperature distribution in the fusion and HAZ of the welded alloys, and therefore the metallurgical changes, connected with the welding process, can be correlated using the thermal equilibrium phase diagrams. On the other hand, because welding processes cool at relatively quick rates, such diagrams are constructed under sluggish cooling. As a result, these representations cannot adequately depict the changes that take place during welding. The Development of Science in the Nineteenth Century: At the beginning of the 19th century, Sir Humphry Davy conducted experiments with electric arc welding that laid the foundation for modern arc welding techniques. Developments in metalworking: The discovery of new metals and alloys, such as steel and aluminum, prompted the development of welding procedures and the need to understand their metallurgical behavior.

Studies on the effects of heat on materials: Scientists like James Joule and Michael Faraday looked at the temperature gradients, phase changes, and microstructural changes that heat on metals causes.The 20th Century's industrial development and world wars: World War I: Welding technology developed during the fight as a result of the requirement for quick and efficient joining techniques. Understanding how welding affects the properties of materials was the aim of the metallurgical study. The production of weaponry during World War II relied heavily on welding. The study of novel welding processes, materials, and quality assurance methods grew. Post-war industrial growth: As a result of the enormous post-war industrial growth, there was an increasing need for welding metallurgical research. Universities, research centers, and private businesses began conducting extensive studies in the area. The development of new welding processes is one of the most recent modern developments. Advanced welding processes like gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), and laser welding were developed in the latter part of the 20th century. These processes spawned brand-new metallurgical issues and research possibilities. microstructural the advancement of electron microscopy and other cutting-edge characterization techniques allowed a comprehensive analysis of the microstructural changes that occur during welding.

DISCUSSION

The Fusion Zone

The fusion zone is the region of a fusion weld where full melting and solidification take place during the welding process. Usually, it differs metallographically from the base metal and HAZ in its vicinity. The microstructure in the fusion zone is impacted by the alloy composition and solidification conditions. For instance, rapid solidification and finer fusion zone microstructure will result from high cooling rates. When the base metal and filler metal are welded together, three potential problems could conceivably occur. The largest of these is the CZ, which is created by fusing base metal with filler metal to dilute it. Near the fusion border, there can be two additional zones. The only part of the material that has undergone melting is the fusion zone. The heat-affected zone (the material that has been changed by the welding heat but hasn't melted) is not regarded as the fusion zone.

The molten base metal used to construct the UMZ was momentarily combined with filler metal before it was resolidified. Between the UMZ and CZ, there must be a transition zone with a composition gradient from the base metal to the CZ. As was previously mentioned, a transition zone may be especially important in a dissimilar metal weld. The three types are autonomous, homogeneous, and heterogeneous fusion zones. Both the presence or absence of filler and the filler's relative composition to the base material determine these classifications. Autogenous (no filler added) fusion zones are typical when section thicknesses are thin and penetration is easily accomplished by the technique selected. Autogenous welding can be carried out quickly and typically requires little to no joint preparation. Edge welds for autogenous welding are commonly preferred over butt joints, despite the latter being an alternative. Even though several welding processes, including electron beam and resistance welding, do not utilize a filler metal, the term "autogenous" is exclusively used to describe welds made using the Gas Tungsten and Plasma Arc procedures. The fusion zone's composition is almost identical to that of the base metal, except for any losses caused by metal evaporation or gas absorption from the shielding atmosphere. All materials cannot be joined automatically due to weldability issues like solidification cracking, which will be discussed later [5]–[7].

The Partially Melted Zone

Between the 100% melting in the fusion zone of the weld and its 100% solid component (the true HAZ), the partially melted zone serves as a transitional phase. A partially melted zone can develop as a result of various metallurgical processes. In many commercial alloys, segregation of alloying and impurity elements to the grain boundaries is possible. occur as processing goes on. Overall, this results in variations in regional composition that could lower the melting temperature near grain boundaries.Grain boundary (GB) liquation can take place in the area right outside the weld metal, which is known as the partially melted zone (PMZ), which can lead to intergranular cracking. It is well known that aluminum alloys are prone to liquation and liquation cracking. A study was done on the PMZ of alloy 2219, which is essentially Al-6.3Cu. Eutectically initiating the liquidation. The temperature variations across the PMZ caused the GB liquid to solidify in a specific path, up and towards the weld. In a low-strength, low-ductility structure made up of a solute-depleted ductile phase and a solute-rich brittle eutectic, the liquid material solidifies with severe segregation. The maximum load and displacement before failure in the tensile test were both much lower than those of the basic metal. While the nearby Cu-depleted and easily deformed under tension, the GB eutectic cracked.

The grain boundary liquid solidified primarily in a flat manner. Although temperature differences were least at the bottom of partial-penetration welds, cellular solidification was also noticed there. Additionally, the mechanisms of liquidation in welded multicomponent aluminum alloys were investigated. There were found to be three mechanisms. They include most wrought aluminum alloys if not all of them. Investigations into liquid cracking in full-penetration aluminum welds in the PMZ. Because a weld metal that is stronger than the PMZ is pulling on the hardening PMZ, causing it to contract and induce liquid cracking. If there is sufficient liquefication in the PMZ, there is no solidification cracking in the nearby weld metal, and the PMZ loses strength during terminal solidification relative to the solidifying weld metal, liquid cracking may develop. A study of liquid cracking in aluminum welds with partial penetration looked at the PMZ. Regardless of the filler metal used, the papillary (nipple) type penetration prevalent in welding with spray transfer of the filler wire oscillates throughout the weld and encourages cracking. Regardless of the nature of the weld metal, cracking can happen if there is significant PMZ liquation because the rapidly solidifying weld metal immediately behind the penetration tip shrinks and pulls the PMZ close to the tip.

The temperatures related to the thermal gradient of the welding process are higher than these regional temperatures. There will be grain boundary liquation, a process related to melting temperatures. Whether or whether this occurs depends, among other things, on the size and slope of the temperature differential. of alloy and impurity separation. It is expected that welding techniques that use more heat input and have a smoother temperature gradient will produce a bigger partially melted zone. A key region in welding metallurgy is the fusion zone, often known as the partially melted zone. This word describes the area of the base metal that partially melts during the welding process. Here, the heat from the welding process causes the base metal to melt, creating a molten pool in the process. The weld metal, which is created when the molten pool hardens, joins the two metal pieces that are being welded. The rapid heating and cooling cycles that take place during welding significantly alter the metallurgy of the partially melted zone. Grain enlargement, the creation of dendritic solidification structures, and the probable emergence of undesirable phases are a few of these modifications. The characteristics of the partially melted zone are influenced by the welding process, welding parameters (such as heat input and travel speed), base metal composition, and heat treatment conditions. To obtain the proper weld quality and mechanical properties, the partially melted zone must be understood and handled. The size and geometry of the partially melted zone affect several properties, such as joint strength, toughness, and resistance to faults such as solidification cracks and porosity. By maximizing welding conditions and heat treatments, the characteristics of the partially melted zone can be managed, resulting in welds with the required attributes and adherence to the required standards and specifications. In conclusion, a critical region in welding metallurgy is the partially melted zone, where the base metal partially melts during welding. Its characteristics and attributes are essential to the general efficiency and caliber of welded joints.

Constitutional liquation is a different phenomenon that can also lead to liquated grain boundaries. In this case, when particles like carbides begin to disintegrate near the HAZ, they may introduce material into the matrix surrounding it, thus lowering its melting point. If the HAZ A pool of liquid will form when the temperature around a particle is higher than the localized melting temperatures. form. If the particle is at a grain boundary, the liquid may wet the grain barrier, resulting in a grain border that is liquid. Liquidized grain boundaries have no strength and are easily pulled. As the weld cools and residual tensions grow, liquid fractures are produced.

Affected by heat zone (HAZ)

The genuine HAZ is the area between the undamaged base metal and the partially melted zone, even though the HAZ frequently includes the partially melted region. In a real HAZ, all metallurgical reactions take place in the solid form. Depending on the nature of the alloy, previous processing history, and thermal variables related to the welding process, the evolution of the microstructure in the real HAZ can be rather complex. The reactions in this area will be influenced by peak temperatures, heating and cooling rates, and can frequently have significant microstructural consequences within the same alloy or alloy system.

Within the same HAZ, a broad variety of microstructures are possible, and local variances might be significant. The most distinct HAZ microstructures are seen in materials that change phases when heated and cooled. Steels, for instance, change from a bcc ferrite phase to austenite (fcc) when heated above a critical temperature. Steel has a significantly different HAZ microstructure than base metals, in general. Equilibrium binary phase diagrams are one tool for comprehending the microstructural characteristics of the HAZ. However, due to the nonequilibrium cooling circumstances that are typical of welds, metal alloys that undergo phase transformations, such as steels, may generate weld microstructures that are not predicted by equilibrium phase diagrams. Other diagrams that take into account non-equilibrium cooling in this situation have been produced and will be discussed in the following chapter on the welding metallurgy of carbon steels.

The HAZ may or may not be present in solid-state welding. A HAZ will be created during procedures like friction welding and resistance flash welding that depend on the production of a considerable amount of heat. However, because they rely more on pressure and/or time than intense heat, such as in the case of Diffusion Welding, Explosion Welding, and Ultrasonic Welding, these procedures either don't form a HAZ altogether or produce one that is very small and difficult to detect.

Overview of Phase Diagrams

Phase diagrams are commonly used in teaching and understanding welding metallurgical techniques. A phase diagram describes the equilibrium phases that emerge from temperature and composition in a metal alloy. The most common and fundamental type of phase diagram is the binary phase diagram, which explains the stability of phases between just two metals (or elements). Phase diagrams can be very intricate. Binary phase diagrams of the two basic metal alloy components are widely used to forecast and comprehend the solidification process and subsequent microstructure of a weld. The fundamental binary eutectic phase diagram of elements A and B (Figure 9.7) contains examples. In phase diagrams, liquidus, solidus, and solvs lines are always present. The liquidus lines distinguish pure liquid from a mixture of pure liquid and solid. The solidus lines distinguish between a completely solid material and a mixture of liquid and solid. The solves lines also show the amount of one element that can completely dissolve in the other. A weld fusion zone of composition 1 would first go through a liquid and solid phase as it cooled from the liquid phase. This stage is sometimes described as "mushy" since there is a mixture of liquid and solid at these temperatures. The "liquidus" is the point at which a substance begins to solidify after cooling from a liquid. The "solidus" line indicates that the leftover liquid solidifies upon further cooling. The liquid transforms into the "alpha" phase at composition 1. Additional cooling causes the "solves" line to cross, proving that the (beta) phase should arise in the solid state provided cooling rates are slow enough. It is important to understand that while the "phase" represents element "A" with some element "B" dissolved, the "solves" line depicts the maximum amount of element "B" that may dissolve in metal "A" at a certain temperature. In conclusion, the solidification of a metal with composition 1 should produce a microstructure with some phases.

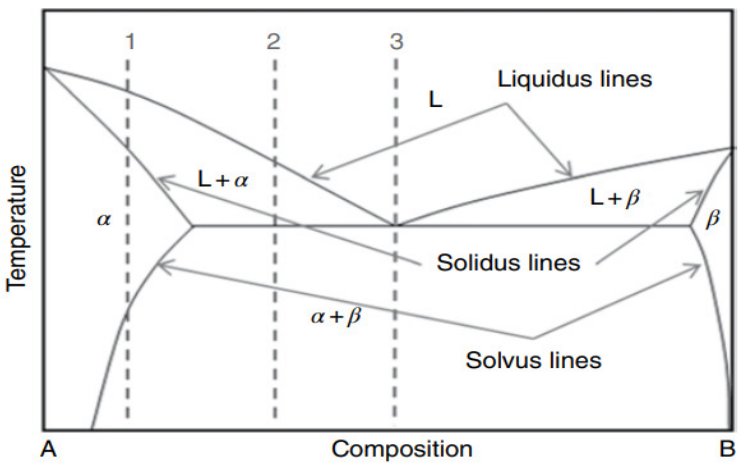


Figure 1 Phase Diagrams.

After solidification begins to occur at a lower temperature, the horizontal line indicating the eutectic temperature is reached at composition 2. At the eutectic temperature, all liquid that is still present solidifies into its eutectic composition. This is very different from component 1, which crystallized to 100%. As a result, it would be expected that Composition 2's weld fusion zone will have a very different microstructure from Composition 1's. The primary phase islands in the composition 2 microstructure would be surrounded by the eutectic phase and indicate solidification up to the eutectic temperature. The phase diagram dictates the ratios of each component, which are then combined to generate the eutectic phase. The final composition is the eutectic composition. All of the liquid immediately turns into the eutectic phase when it reaches the eutectic temperature. The eutectic phase, a mixture of and, would make up the entire microstructure in this case. Conclusion: According to the phase diagram, the three different proportions of an element A and B mixture should each produce notably different weld microstructures. Real binary phase diagrams can range substantially in complexity.

Three-dimensional ternary diagrams, which show the phase equilibrium of a mixture of three components, are even more challenging. These equilibrium diagrams should only be used for theoretical understanding and forecasting purposes since weld solidification seldom occurs under the equilibrium circumstances that the diagrams depict and because very few metal alloys include only two components. Robust modeling techniques like ThermoCalcTM are increasingly being used to predict weld microstructures. These software programs give the user the ability to create phase diagrams based on different alloying components and no equilibrium solidification circumstances to more accurately show the solidification of actual weld metals [8]–[10].

CONCLUSION

Metalworking by welding has a long history that dates back to the Bronze Age and continues to the present. Since the beginning of time, innovations in technology and welding techniques have improved the strength and quality of welds, making welding a crucial part of many industries. The significance of accurate and exact measuring and inspection of welds increases as welding technology develops. To guarantee the quality and safety of welded products and structures, welding metrology, or the measuring and analysis of welded structures, is crucial. Welding metrology is essential for preserving the integrity of welded structures due to the growing need for high-quality welds in sectors including aerospace, automotive, and construction. Making sure that welds adhere to the necessary standards and requirements, entails the use of cutting-edge tools and methods, such as non-destructive testing. An important field that studies the properties and behavior of metals during welding is called welding metallurgy. The science of welding metallurgy has evolved throughout time, moving from prehistoric forging techniques to modern, cutting-edge welding techniques. One needs to have a thorough understanding of welding metallurgy to ensure the quality and integrity of welded joints. Continual advancements in materials science and technology are still being made in this field with the hopes of speeding welding processes, improving weldability, and increasing the efficacy of welded structures.

REFERENCES

[1] A. L. Insley *et al.*, “Occupational survey of airborne metal exposures to welders, metalworkers, and bystanders in small fabrication shops,” *J. Occup. Environ. Hyg.*, 2019, doi: 10.1080/15459624.2019.1603389.

[2] D. G. Marrugo, D. León-Méndez, J. P. Silva, C. Granados-Conde, and G. León-Méndez, “Metal fumes: Exposure to heavy metals, their relationship with oxidative stress and their effect on health1,” *Prod. y Limpia*, 2020, doi: 10.22507/PML.V14N2A1.

[3] W. J. Arbegast, “A flow-partitioned deformation zone model for defect formation during friction stir welding,” *Scr. Mater.*, 2008, doi: 10.1016/j.scriptamat.2007.10.031.

[4] J. C. Conte Solano, A. I. Domínguez, A. I. García Felipe, E. Rubio, and A. Pérez Prados, “Cox regression model of hearing loss in workers exposed to noise and metalworking fluids or welding fumes,” *An. Sist. Sanit. Navar.*, 2010.

[5] D. Jiang, A. S. Alsagri, M. Akbari, M. Afrand, and A. A. Alrobaian, “Numerical and experimental studies on the effect of varied beam diameter, average power and pulse energy in Nd: YAG laser welding of Ti6Al4V,” *Infrared Phys. Technol.*, 2019, doi: 10.1016/j.infrared.2019.06.006.

[6] C. Wippich, J. Rissler, D. Koppisch, and D. Breuer, “Estimating Respirable Dust Exposure from Inhalable Dust Exposure,” *Ann. Work Expo. Heal.*, 2020, doi: 10.1093/ANNWEH/WXAA016.

[7] V. V. Moskvichev and N. A. Chernyakova, “Problems and Perspective Technologies of the Machinery Complex in the Format of Regional Development,” *J. Sib. Fed. Univ. Eng. Technol.*, 2019, doi: 10.17516/1999-494x-0189.

[8] P. Lacki, W. Wieckowski, G. Luty, P. Wieczorek, and M. Motyka, “Evaluation of usefulness of AlCrN coatings for increased life of tools used in friction stir welding (FSW) of sheet aluminum alloy,” *Materials (Basel).*, 2020, doi: 10.3390/ma13184124.

[9] Z. Y. Ma, “Friction stir processing technology: A review,” *Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science*. 2008. doi: 10.1007/s11661-007-9459-0.

[10] A. Vivek, M. Presley, K. M. Flores, N. H. Hutchinson, and G. S. Daehn, “Solid state impact welding of BMG and copper by vaporizing foil actuator welding,” *Mater. Sci. Eng. A*, 2015, doi: 10.1016/j.msea.2015.03.012.

CHAPTER 15

COMPREHENSIVE REVIEW OF SAFE PRACTICES

Dr. Suman Paul, Associate Professor
Department of Petroleum Engineering, Presidency University, Bangalore, India
Email Id: sumanpaul@presidencyuniversity.in

ABSTRACT:
The protection of resources, the environment, and the health of employees all depend on safe practises. This summary offers a succinct overview of safe practises, highlighting their significance, essential components, and effects on workplace security. It draws attention to the significance of risk analysis, hazard detection, effective communication, proper training, and safety leadership. Following safe procedures decreases accidents, boosts production, and protects the reputation of the organization. Establishing safe workplaces and adhering to industry norms and standards require the implementation of safe practises. The Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labour estimates that over 30 million American workers may be exposed to one or more chemical risks at work from over 650,000 hazardous chemical items. This circumstance poses a severe concern for exposed workers and their employers as these numbers rise with the expanding workforce and the launch of hundreds of new items each year.

KEYWORDS:

Electrical Safety, Eye Protection, Equipment Inspection, Maintenance, FireExtinguishers, FirePrevention, Personal Protective Equipment.

INTRODUCTION

All welding, cutting, brazing, and associated processes must take health and safety into account. Any activity that results in property damage or personal injury is not satisfactorily accomplished. This chapter provides an overview of the policies, procedures, and methods used to reduce the risks to workers' safety connected with welding, cutting, and related processes. It looks at safety management, safeguarding workers and the workspace, taking safety into account during specific processes, and robotic safety [1]–[3].The discussion's constrained scope prevents an extensive analysis of the health and safety issues surrounding every welding operation, especially those employing advanced technology. The American National Standard Safety in Welding, Cutting, and Allied Processesand Safety and Health Fact Sheets, the latter of which is available electronically at http://www.aws.org, provide additional safety and health information pertaining to the various welding processes. Welding Processes, Volume 2 of the 8th edition of the American Welding Society (AWS) Welding Handbook, contains more process-specific material. The reader is urged to consult these sources as well as those in the Bibliography and Supplementary Reading List at the chapter's conclusion.

In general, there are three types for procedures. Operations that often entail manufacturing a product are governed by operating procedures, as explained. In general, testing, inspecting, calibrating, maintaining, or repairing equipment are all part of maintenance procedures, as explained. The space between the other two sets of processes is filled by safe work procedures, which are frequently augmented with permits (i.e., a checklist that includes an authorisation step). Safe work procedures aid in reducing risks and controlling hazards in non-routine employment. Any activity that is not entirely detailed in an operating procedure is considered a nonroutine activity in this context. Nonroutine refers to whether an activity is a part of the regular process of transforming raw materials into finished goods rather than how frequently it occurs. While breaking a connection to remove and calibrate a pressure transmitter would be regarded as a nonroutine work activity and fall under the purview of the safe work practises (safe work) element, making and breaking connections to unload a railcar would likely be covered by an operating procedure. Take a look at an example work order for calibrating a pressure transmitter while the procedure is running. Accidents and process disruptions can be avoided with the use of an integrated set of operating, maintenance, and safe work procedures.

Safety Management:

An estimated 562,000 of these workers are at risk of being exposed to chemical and physical risks from welding, cutting, brazing, and related activities. The risks of welding and related activities include those of explosion, asphyxiation, electrocution, falling and crushing, and weld flash (burn to the eyes), as well as those of overexposure to the fumes, gases, or radiation they create or release. These include, among others, metal fume fever, heavy metal poisoning, and lung illness.In order to guarantee safe and healthy working conditions for all employees, the Occupational Safety and Health Act of 19707 was passed. It includes provisions for the dissemination of knowledge, training, education, and research in the area of occupational health and safety.Based on the 1967 American National rules Institute (ANSI) standard Z49.1 and the National Fire Protection Association (NFPA) code, OSHA's current rules for welding, cutting, and brazing in general industry and building.

Management Support

Management must show its dedication to employee safety and health in accordance with the requirements of Title 29 CFR 1910 by supplying guidance and support for a successful safety and health programme. Management must establish clear safety rules and demand that everyone, including management, adhere to them consistently.Additionally, management must identify acceptable areas where welding and cutting operations can be carried out safely in accordance with the guidelines initially set in ANSI Z49.1:1967 and NFPA 51B:1962. Management must ensure that the appropriate safety measures are established and followed to protect people and property when welding operations must be performed elsewhere.

The use of only authorized welding, cutting, and related equipment in the workplace is another duty of management. Torches, regulators, welding machines, electrode holders, and personal protective equipment are all included in this machinery. In order to guarantee that all equipment is used and maintained correctly, management must offer sufficient supervision.Contractors that the management uses to carry out welding operations must use qualified, trained individuals. Contractors must be made aware of any potential dangers in the work environment by management.

DISCUSSION

Hazard Communications

Employers are required under the Occupational Safety and Health Act's Hazard Communication Standard, 29 CFR 1910.1200,13 to notify staff of possible dangers at work and to give training on how to handle hazardous items safely. This standard considers both immediate and long-term health risks in addition to physical risks including flammability and explosive potential [4]–[6].The Hazard Communication Standard mandates that all chemicals created, imported, or used in U.S. workplaces be evaluated and that hazard information be distributed to impacted employers and exposed employees via material safety data sheets (MSDSs), training, and warnings on container labels. Numerous consumables used in welding are classified as hazardous compounds under the Hazard Communication Standard.

Weldersand other equipment operators operate more safely and have fewer mishaps when they are adequately instructed in safe practises. Before work starts, users must get training on how to read and comprehend all safety paperwork. This paperwork provides safety instructions from the manufacturers for using materials and equipment, including MSDSs, as well as preventative information.

The Hazard Communication Standard, 29 CFR 1910.120016, requires manufacturers, suppliers, and importers to give customers material safety data sheets that list products that could pose health risks and give details on each hazardous chemical, including its physical and chemical properties, potential effects, and suggested countermeasures. The permissible exposure limit (PEL®) set by OSHA, another exposure limit like the threshold limit value (TLV®) set by the American Conference of Governmental Industrial Hygienists (ACGIH), or any other limit suggested by the manufacturer are all included in the material safety data sheets.

All companies, including those that use welding consumables, are required to provide their staff with pertinent material safety data sheets and provide training on how to read and comprehend them. Important details on the components of welding electrodes, rods, and fluxes, the makeup of any gases that may be released during usage, and ways to safeguard the welder and others from possible risks are all included in the material safety data sheets used in the welding industry. maintenance of all equipment. An example material safety data sheet. For instance, while undertaking welding or cutting activities, staff must be taught to position themselves away from gases or fume plumes.

Additionally, employees need to be educated to spot safety risks in all contexts and settings. They must get a full briefing on any possible risks before working in an unusual setting or environment. For instance, welders working in poorly ventilated confined spaces must have extensive training in correct ventilation techniques and be aware of the negative effects of doing so (see the section below labelled "Confined Spaces" for more information). Additionally, workers should be taught to challenge their superiors before beginning any kind of welding or cutting operation if they feel that the safety measures for a particular activity are insufficient or unclear.In conclusion, training is necessary to make sure that all staff members (1) are aware of the safety regulations that apply to welding practises and any potential workplace situations, and (2) are aware of the risks and potential repercussions should these regulations be disregarded or broken.

Security of The Work Area

Making sure that working conditions are secure and healthful requires good housekeeping. Supervisors and welders are responsible for maintaining the cleanliness and accessibility of all work spaces, including stairways, ladders, and hallways. The eyesight of people passing by a welding station is restricted because they must cover their eyes from the flame or arc radiation, which limits the vision of welders who are wearing the proper eye protection. Welders and onlookers may easily tumble over items on the floor since eye protection obstructs their view. Therefore, management must arrange the production space so that mechanical components, cables, gas hoses, and other equipment do not cross pathways or obstruct regular operations.Whether work is being done at floor level or at an elevated site, safety rails, harnesses, or lines must be available to keep employees out of constrained, potentially dangerous areas and avoid falls.

Safeguards For Machines

All employees must be shielded from harm that might come from both the machinery and equipment they utilize and other machinery running in the workspace. Welders may be more vulnerable than other employees to harm from invisible, unprotected equipment since welding helmets and dark filter lenses impair eyesight. To avoid physical touch, guards must be installed on drive belts and moving parts. Rotating, automated welding equipment, fixtures, and welding robots must also be protected with the proper protections or sensors to stop working when people are around a danger.To avoid accidental activation and damage, the power supply to the equipment must be disconnected, locked out, and labelled out20 while welding or brazing is being done on it. The risks involved and the precautions that must be taken to prevent unintentional damage should be clearly understood by welders who are assigned to operate on equipment with disengaged safety systems.

Resistance welding machines, robots, automated arc welding machines, fixtures, and other mechanical equipment all have pinch points that, if not adequately guarded, might cause significant harm. When using such machinery, a machine should only be turned on when the user's hands are in a secure position. Otherwise, the pinch points must be mechanically well protected. In order to avoid pinch points from shutting in the event of equipment failure, pinch points should be blocked during equipment maintenance. An observer should be stationed in very dangerous circumstances to prevent the power from being switched on while maintenance is being done.

Conservative Booths

Workers and others near welding and cutting areas must be protected from radiant radiation and hot spatter by (1) flame-resistant screens or shields or (2) sufficient eye and facial protection and protective gear, as per the requirements of ANSI Z49.1:1999. Semitransparent, radiation-protective materials are acceptable. Workstations should be separated by noncombustible screens or shields, if operations permit. epicts protective booths with semitransparent shielding. Booths and screens should allow airflow above and below the screen.

Wall Reflection

Walls and other reflective surfaces must be painted in places where arc welding or cutting is often done with a finish that has a low reflection of ultraviolet (UV) light, such as those made with titanium dioxide or zinc oxide.23 Colour pigments may be applied as long as they don't make the surface more reflective. It is not advised to use pigments based on powdered or flaked metals since they reflect a lot of UV light. To reduce reflection, welding curtains may be used as an alternative.

Exhibitions And Demonstrations In Public

The audience's safety as well as the safety of the demonstrators is the responsibility of those organising exhibitions and public demonstrations of arc or oxyfuel gas welding or cutting procedures. A site that is situated and constructed to guarantee viewing safety is required for the installation of all welding and welding-related equipment used at trade fairs and other open events. To prevent potential electric shock or trip dangers, electric wires and hoses must be routed away from the audience. Additionally, exhibitors are required to provide fire safety against fuel, flammable, and overheated equipment and electrical fires. Combustible goods must be removed from the area or protected from flames, sparks, and molten metal. Fire extinguishers must also be nearby. It is necessary to provide demonstrators, observers, and bystanders with the proper protection. By using the proper ventilation, welding fume and gas overexposure must be prevented. Additionally, people need to be protected against dangerous radiation, molten metal, sparks, and flames. The audience can see a welding operation while being safe to do so by using a protected, mobile, transparent screen. The audience can view the finished weld by moving the screen when welding is finished.

Eye, Face, and Head Protection

Employees who perform tasks that could result in dust, flying debris, or molten metal must wear protective eyewear, face shields, and helmets. They must also wear protective gear if they are exposed to extreme heat, physical or chemical irritants, intense radiation, or light, such as that produced by welding arcs and lasers, or if they are at risk of being struck on the head by tools or falling objects.

Figure 1: Typical Protective Clothing for Welding (research gate)

PPE for the head, face, and eyes comprises welding goggles, welding helmets, face shields, and eyeglasses.30 The body of welding helmets and shields must be made of a material that is noncombustible, thermally and electrically insulating, and opaque to radiation in accordance with ANSI Z49.1:1 requirement. To shelter the user from welding spatter, the lenses of helmets, shields, and goggles must have protective outer coverings. Lift-front helmets must include inner impact-resistant safety plates or lenses to guard against flying debris.The UV, bright, and infrared transmittance criteria listed in Practise for Occupational and Educational Eye and Face Protection, ANSI Z87.1.32 must be followed when choosing filter lenses. It is required that the shade chosen adhere to Lens Shade Selector, ANSI/AWS F2.2.33. For different welding, brazing, soldering, and thermal cutting procedures, Table 17.1 offers optimum shade numbers of filter lenses.For more information on the usage of protective equipment, those with particular eye disorders should speak with their doctor. Wearing contact lenses is acceptable as long as they are worn in tandem with the proper safety eyewear, with the exception of industrial settings where there is a chance of exposure to extreme heat, significant chemical splash, an extremely particulate atmosphere, or situations where such use is expressly prohibited by regulation.

Audience Protection

One of the most common occupational ailments in the US is hearing loss. Overly noisy environments at work are known stressors that may have an impact on behaviour and physical health. Excessive noise, especially continuous noise at loud levels, may result in hypertension as well as temporary or permanent complete or partial hearing loss. OSHA controls acceptable noise exposure limits in General Industry Standards, Title 29 CFR 1910.95, to protect employees from exposure to excessive noise.Noise in welding, cutting, and related processes may be produced by the equipment, the process, or both. Plasma and air carbon arc cutting often produce loud noises. High-frequency and induction welding power sources, as well as certain engine-driven generators, may produce loud noises. Therefore, it is important to employ the proper noise-limiting equipment to guard against potential hearing damage. When sparks or hot splatter potentially hit the ears, flame-resistant earplugs should also be used [7]–[9].

Respirational Protection

Respiratory protection equipment must be worn in places where natural or mechanical ventilation is insufficient (see the section below on "Ventilation"). A programmed must be set up to identify and utilize the right equipment when using respiratory protection equipment is mandated by the work. If the appropriate respirator type (e.g., half-mask, full-face, or powered air respiratory protection [PARP]) is chosen based on the calculated hazard ratio for the contaminant of concern, either dust/mist/fume respirators or any of the new series of respirators approved by the National Institute for Occupational Safety and Health (NIOSH) can be used to protect against metal fumes. A powered respirator that purifies the air Filter respirators may not provide enough protection from certain welding products, such as fluxes, welding rods, and leftover cleaning and degreasing solutions, which may contain hazardous substances or produce fumes and vapours. A chemical cartridge/particulate, gas mask/particulate or aircraft respirator should be used in these circumstances. When the pollutants themselves or their concentrations have not been established, the sole option for effective protection should generally be an air-supplied respirator that has been authorised by NIOSH.

It is also crucial to remember that respirators cannot be transferred from one worker to another without first having been sanitised in accordance with OSHA's Respiratory Protection Standard, 29 CFR 1910.134.45 All filters' service lives are limited, according to NIOSH, by factors including breathing resistance, deterioration, and cleanliness. Any time a filter is damaged, dirty, or significantly increases breathing resistance, it has to be changed. Given that gas and fume protection is crucial in the area of welding and its related operations, this subject is covered in more detail in the next section.

Protection From Gas and Fumes

There are several welding techniques that produce potentially dangerous gases and fumes. Fumes are made up of airborne metal particles from the base metal, welding supplies, or any coatings that may be on the workpiece. Therefore, it is important to safeguard against overexposure to the fumes and gases created during welding, brazing, soldering, and cutting activities for welders, welding operators, and everyone else in the work area. A government agency such as OSHA in Title 29 CFR 1910.1000 or another recognised authority such as the American Conference of Governmental Industrial Hygienists (ACGIH) in its publication 1999 TLVs® and BEIs®: Threshold Limit Values for Chemical Substances and Physical

Agents, Biological Exposure Indices define overexposure as exposure that may present a health risk and exceeds the permissible limits.Overexposure to welding fumes and gases may have both immediate and long-term negative health consequences, such as nausea, headaches, dizziness, dermatitis, chronic or acute systemic poisoning, metal fume fever, pneumoconiosis, respiratory tract irritation, and even cancer. In most cases, adequate ventilation (see the section below under "Ventilation") protects against excessive exposure. Respiratory protection must be used when exposure would be too great with the current ventilation. It is necessary to safeguard individuals around from fumes in addition to the welding and cutting employees. It is important to highlight that people with certain health issues can have unique sensitivity, necessitating even more protection than that recommended by a recognized authority.

Exposure Results

The quantity of fume exposure that may occur during arc welding depends on a variety of parameters. The welder's head position in relation to the fume plume is the most crucial element. Exposure levels may be quite high if the head is positioned such that the fume surrounds the face or helmet. Welders need to be taught to keep their heads to one side of the fume cloud as a result. The job may sometimes be set up such that the smoke plume rises to one side.

Employees who do welding may also limit their exposure to fumes by using the right welding helmet. The quantity of fume exposure depends on how much the helmet bends beneath the chin towards the chest. It's crucial to remember that the welding helmet isn't seen to be a sufficient respiratory protection tool on its own.The kind of ventilation employed affects how much fume exposure there is. A portion of the shop's air may be changed or filtered as part of general ventilation, which involves extracting fumes and gases close to the welding area. Depending on the welding process, the material being welded, and other shop circumstances, the right sort of ventilation should be used. To keep the staff's exposure to fumes and gases below the advised limits, adequate ventilation is required.Another crucial factor is the work area size for cutting or welding. Generally speaking, fume exposure in a tank, pressure vessel, or other restricted space is greater than in a high-bay manufacturing area. The background fume level, which is influenced by the number and type of welding stations, the kind of ventilation, and the duty cycle for each station, also relies on the size of the work area. The components of the fume as well as its volume depend on the kind of base metal being welded. The potential fume dangers might be considerably increased by surface impurities or coatings. When welding and cutting, lead paints and cadmium-plated plating's release dangerous vapours. Zinc fume is released by galvanized material.

Fumes And Gases Sources:

These factors include the welding procedure used, the base metal's composition, the consumables used, the workpiece's coatings (such as paint, galvanising, or plating), and the contaminants in the air (such as halogenated hydrocarbon vapours produced by cleaning and degreasing activities).Fume is a byproduct of the vaporisation, oxidation, and condensation of the constituents in the consumable and, to a lesser extent, the base metal during welding and cutting. The electrode is often the main source of fume, not the base metal. However, if the base metal has alloying components or is coated with a material that is volatile at high temperatures, considerable fume constituents may come from there. Typically, the composition of the fume and the electrode or consumable are different. Components of fumes from base metals, coatings, and ambient pollutants are all fairly predicted, as are the byproducts of the volatilization, reactivity, or oxidation of the consumables [10].

CONCLUSION

To avoid accidents and provide a secure working environment, safe welding techniques are essential. The use of appropriate personal protection equipment (PPE), ensuring correct ventilation, routinely checking and maintaining equipment, adhering to proper electrical safety precautions, using acceptable welding procedures, and getting necessary training are among the key practices. By putting these procedures into practice, you may lower your risk of welding-related accidents, fires, and health problems.Arc welding often raises more fumes and gas concerns than oxyfuel gas welding, cutting, or brazing. Arc welding often involves a wider range of materials and may produce more smoke and gas than other types of welding. The next paragraphs go over specific issues pertaining to arc welding and cutting, resistance welding, and oxyfuel gas welding and cutting. Cutting and Arc Welding Gases and Fumes It is difficult to categories the vapours and fumes generated during arc welding and cutting processes. Their composition and amount are influenced by a variety of elements.

REFERENCES

[1] E. Kanal *et al.*, "ACR guidance document on MR safe practices: 2013," *J. Magn. Reson. Imaging*, 2013, doi: 10.1002/jmri.24011.

[2] I. Rodrigo Rincón *et al.*, "Patients and relatives as auditors of safe practices in oncology and hematology day hospitals," *BMC Health Serv. Res.*, 2021, doi: 10.1186/s12913-020-06018-3.

[3] D. Shivnani, E. V. Raman, and D. Amle, "The COVID TIDE Approach: A Protocol for Safe Tracheostomy Practice in COVID Patients," *Indian J. Otolaryngol. Head Neck Surg.*, 2021, doi: 10.1007/s12070-021-02370-w.

[4] A. Shankar *et al.*, "Level of awareness of cervical and breast cancer risk factors and safe practices among college teachers of different states in India: Do awareness programmes have an impact on adoption of safe practices?," *Asian Pacific J. Cancer Prev.*, 2015, doi: 10.7314/APJCP.2015.16.3.927.

[5] P. S. Dhagavkar, A. Dalal, A. Nilgar, and M. Angolkar, "Safe motherhood practices - Knowledge and behaviour among pregnant women in Belagavi, Karnataka. A descriptive study," *Clin. Epidemiol. Glob. Heal.*, 2021, doi: 10.1016/j.cegh.2021.100846.

[6] J. I. Boullata *et al.*, "ASPEN Safe Practices for Enteral Nutrition Therapy," *Journal of Parenteral and Enteral Nutrition*. 2017. doi: 10.1177/0148607116673053.

[7] A. J. Olak *et al.*, "The relationships between the use of smart mobile technology, safety knowledge and propensity to follow safe practices at work," *Int. J. Occup. Saf. Ergon.*, 2021, doi: 10.1080/10803548.2019.1658398.

[8] A. F. Nimmo *et al.*, "Guidelines for the safe practice of total intravenous anaesthesia (TIVA)," *Anaesthesia*, 2019, doi: 10.1111/anae.14428.

[9] L. James, P. Butterfield, and E. Tuell, "Nursing Students' Sleep Patterns and Perceptions of Safe Practice During Their Entrée to Shift Work," *Work. Heal. Saf.*, 2019, doi: 10.1177/2165079919867714.

[10] T. D. Greenberg *et al.*, "ACR guidance document on MR safe practices: Updates and critical information 2019," *J. Magn. Reson. Imaging*, 2020, doi: 10.1002/jmri.26880.

CHAPTER 16

WELDING METALLURGY OF NONFERROUS ALLOYS

Mr. Sanjeet Kumar, Assistant Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id:sanjeet.kumar@jnujaipur.ac.in

ABSTRACT:

The broad review includes the fundamentals of welding alloys based on aluminium, copper, magnesium, and nickel. Alloy characteristics that affect weldability, general weldability, welding techniques, and potential process problems are all discussed. When nonferrous alloys are welded, the base metal, heat-affected zone (HAZ), and fusion zone all undergo metalworking alterations. These modifications are brought on by welding variables including heat input and cooling rate, which have an effect on the weld's final microstructure and properties. The study of the metallurgical changes that take place during welding materials including aluminium, copper, titanium, and nickel alloys is known as welding metallurgy of nonferrous alloys. Nonferrous alloys are frequently employed in a variety of industries because of their special qualities and uses. In order to produce welds of excellent quality with desired mechanical and physical qualities, it is crucial to understand the welding metallurgy of these alloys.

KEYWORDS:

Auxiliary Metals, Fusion Area, Impacted By Heat (HAZ), Non-Ferrous Alloys,Protecting Gases.

INTRODUCTION

The fusion of base metals during the welding of nonferrous alloys creates a fusion zone and an adjacent heat-affected zone (HAZ). The weld's final microstructure and characteristics are greatly influenced by welding factors including heat input and cooling rate. For successful welds in nonferrous alloys, the right welding procedures, filler metals, and shielding gases must be chosen [1]–[3].Nonferrous alloys provide difficulties when being welded because of problems including hot cracking, deformation, and porosity development. In order to reduce the creation of flaws and enhance the mechanical properties of the welds, adequate cleaning, preheating, and post-weld heat treatment are frequently required.The goal of nonferrous alloy welding metallurgy is to comprehend and regulate the metallurgical changes that take place during welding processes in order to produce high-quality welds with desired qualities. This information is essential for a variety of sectors whose applications depend on the effective welding of nonferrous alloys.

Aluminum Alloys

In applications where low density (light weight) and corrosion resistance are typically required, aluminium alloys comprise a family of frequently used engineering materials. These alloys' ability to resist corrosion is due to the aluminium oxide (Al_2O_3) that forms quickly and is reasonably stable at room temperature. Applications employing aluminium often do not require protective paint or coatings due to this advantageous property of the oxide.Since the early 1990s, the use of aluminium has dramatically expanded. The majority of alloys can be formed into a variety of shapes and are often simple to roll, extrude, and draw. The potential for the extensive use of aluminium alloys in the automobile sector has prompted a renewed interest in welding them, especially with the recent push towards lighter, more fuel-efficient vehicles.They don't show a ductile-to-brittle transition at low temperatures, in contrast to steels.

The Aluminium Association has established eight classifications of wrought aluminium alloys. A four-digit number is used to identify each alloy, with the first digit designating the basic class. The major alloying element(s) and the method of strengtheningeither cold work (strain hardening) or a precipitation-strengthening heat treatmentdistinguish these classes. The designation's additional digits have no specific meaning. According to the table, cold work is used to strengthen the 1xxx, 3xxx, 4xxx, and 5xxx alloys whereas precipitation heat treatment is used to strengthen the 2xxx, 6xxx, 7xxx, and 8xxx alloys. Prior to welding, it is crucial to understand how the alloy will be strengthened.The tensile strength will significantly decrease after welding in both situations, however in alloys that have undergone heat treatment, these losses may be made up.

A heat treatment, processing, or temper designation code is frequently written after the four-digit alloy code. The specifics of how the particular alloy is reinforced are described in this code. For instance, the "T6" in 6061T6 stands for a solution heat treatment, followed by an ageing process that increases precipitation strength, while the "H3" in 5754H3 stands for a strain hardening, then a low-temperature stabilisation process. These are only two of the numerous potential temper designation codes. With aluminium alloys, the term "temper" is used very loosely because, in some circumstances, no heat treatment is necessary at all. It is important to distinguish between this word's meaning and the heat treatment used to soften martensite in steels.

Aluminium alloys are utilised in a variety of structural and aesthetic applications. The 2XXX and 7XXX series alloys are widely employed in aeronautical applications because to their comparatively high strength. Commercial aircraft use alloys from the 7XXX series for the majority of the wing and fuselage "skin". The "workhorse" alloys from the 5XXX and 6XXX family are those that are employed most frequently for structural purposes.The majority of aluminium used today for automotive purposes belongs to the 5XXX or 6XXX alloy family. Lithium is added to the relatively new 8XXX series alloys to decrease density and increase strength. They have outstanding strength-to-weight ratios as a result of their lower density, which clearly benefits aircraft applications. Since they are utilised for aluminium foil and beverage cans, respectively, the 1XXX and 3XXX series alloys are the aluminium alloys with the highest tonnage production. As electrical conductors, the 1XXX alloys are also widely employed in high-voltage transmission lines, for example.

As previously noted, significant hardness and tensile strength deterioration in the HAZ is to be anticipated when welding all aluminium alloys (Figure 12.1). There will frequently be a loss in characteristics of up to 50%. Due to recrystallization and grain development, the HAZ of cold treated aluminium alloys softens. The only method to restore these lost qualities is to cold work the material again, which is rarely a workable option. Because of the dramatic loss in irrecoverable qualities, cold wrought aluminium alloys are frequently regarded as being unweldable—not because they cannot be welded—but rather because of this. The optimum strategy is to weld while the metal is fully annealed or to keep the heat input very low to reduce the loss in strength.

When precipitation-strengthened alloys are welded, the weld HAZ softens as a result of over-aging or the dissolving of the strengthening precipitates that were created during the precipitation hardening process. However, post-weld heat treatments allow for the recovery of part or all of the characteristics when welding these alloys. One method is to solutionize the entire weldment in order to completely dissolve the precipitates, and then to age the material thereafter. Although time-consuming, expensive, and occasionally impractical, this strategy is effective. A different strategy is to weld at "T4" conditions. This circumstance entails a "natural" ageing process that only partially strengthens the alloy. The amount of precipitate overaging is decreased but not entirely removed when a metal alloy in the "T4" condition is welded. The weld can then be aged to attain strengths close to those of base metal.Weld metal porosity is a well-known tendency of aluminium (Figure 12.2). This is because, especially at higher temperatures, molten aluminium can dissolve a sizable amount of hydrogen. As seen in Figure 12.3, aluminium becomes significantly more soluble in hydrogen once it melts at 660°C/1220°F. Further heating causes the solubility to rapidly increase. When welding, the weld metal's hot, molten aluminium rapidly loses its ability to saturate hydrogen as it starts to cool. As a result, gas bubbles made of hydrogen emerge from solution. The bubbles are trapped during additional cooling and after the solidification, which leads to porosity [4]–[6]Aluminium is the second most preferred metal for welding due to its exceptional mix of light weight and relatively high strength. Although joining aluminium is not difficult, welding aluminium is not the same as welding steel.There are several characteristics of welding aluminium that set it apart from welding steel. Which are:

1. Surface coating made of aluminium oxide.
2. Substantial thermal conductivity.
3. High coefficient of thermal expansion.
4. A low melting point.
5. The absence of color shift as a substance gets closer to melting.

DISCUSSION

Nickel□Based Alloys

Alloys based on nickel have several desirable characteristics that make them the perfect choice for many high-performance applications. In particular at high temperatures, they are frequently chosen for their exceptional corrosion resistance or their combination of strength and corrosion resistance. They have an austenitic (FCC) microstructure, and solid solution or precipitation strengthening techniques can be used to strengthen them. Compared to steels, they are more challenging to machine. They are exceedingly expensive (10–20 times more expensive than carbon steel and 3–4 times more expensive than stainless steel) due to their high alloy content and complicated processing procedures, and are typically only chosen for specialised applications where other metals would not hold up. For instance, they perform significantly better than stainless steels in terms of their outstanding elevated temperature corrosion resistance [7]–[9].

Alloys classified as nickel-based are those in which nickel serves as the main component. In some circumstances, the sum of all alloying additions may reach 50%, yet the alloy is still regarded as nickel-based if the Ni content represents the largest percentage of a single element. Despite having a high iron content, several alloys fall within the category of nickel-based alloys. Examples are the iron-based Incoloy alloys 800 and 825.

There are many different nickel-based alloys available, and many of them are highly complex in terms of the quantity and variety of alloying additives. A number of these and other alloys are, along with the alloy families to which they belong as a function of the Ni content. Numerous alloys made of nickel are referred to by their brand names, such as Inconel, Nimonic, René, Sanicro, and so on.

Based on the process used to strengthen them, nickel-based alloys are often divided into one of two categories: solid solution strengthened or precipitation hardened. Alloys that have been reinforced by solid solution include significant additions of Cr, Mo, Fe, and occasionally W. Additionally, the Cr and Mo offer more corrosion protection. The power generation and chemical processing sectors make extensive use of the solid solution reinforced alloys 600 and 625. Because of their remarkable strength and ability to keep it at extremely high temperatures, precipitation hardened alloys are frequently referred to as "superalloys". Because of this, they are frequently utilised in gas turbine engine applications at temperatures above 650 °C (1200 °F) (Figure 12.7). Numerous precipitates can be used to fortify superalloys, but the most used is gamma prime, or Ni3 (Ti,Al).

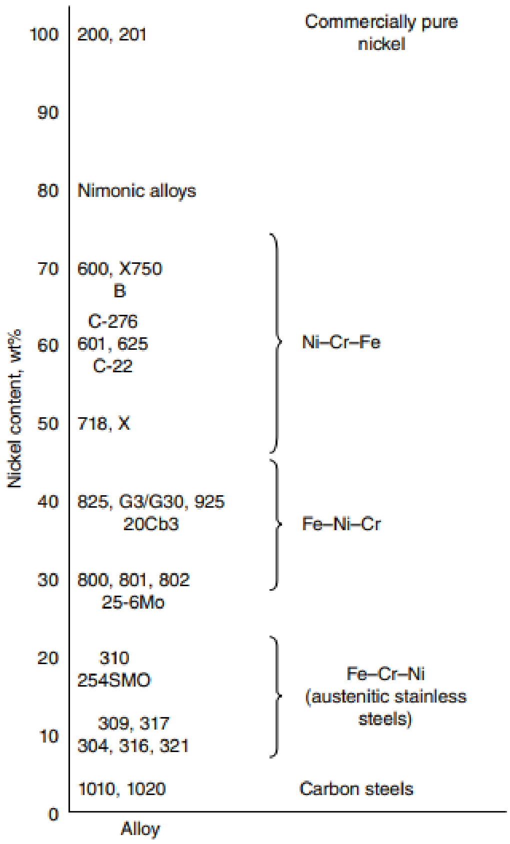


Figure 1: Classes of alloys as a function of nickel content (research gate)

Applications for nickel-based alloys outside of gas turbine engines include nuclear pressure vessels and pipelines, heat exchangers, chemical processing, petrochemical, marine, and pulp-and-paper industries. They are frequently used as cladding, especially to safeguard carbon steels against corrosive conditions. When compared to fabrications constructed entirely of nickel-based material, cladding procedures can provide fabrications with good corrosion resistance at a lower cost. Additionally, alloys based on nickel display a CTE that lies halfway between that of carbon steels and that of stainless steels. As a result, they are occasionally utilised as a "buffer" for CTE mismatches to lower stresses during elevated temperature exposure of dissimilar metal carbon-to-stainless steel weldments. They are often only used to a limited extent in mass production industries, including the automotive industry, due to their high cost.

Although nickel-based alloys can have a number of weldability issues, strain-age cracking, solidification cracking, and HAZ liquation cracking are the most frequent.Some of the high chromium solid solution reinforced alloys have also shown evidence of ductility-dip cracking. Porosity is a rare issue, but it can typically be managed by using the right cleaning techniques before welding.The precipitation enhanced alloys (superalloys), which are strengthened to high levels by the rapidly developing gamma-prime precipitates, are particularly susceptible to strain-age cracking. The simultaneous development of the strengthening precipitates and relaxation of residual stresses causes this type of cracking, which often happens after a postweld heat treatment. Because the strengthening precipitates in the superalloys dissolve in the HAZ during welding, a postweld heat treatment is required. A postweld solution heat treatment followed by ageing is necessary to restore the strength and eliminate residual stresses.

Precipitation can start too earlyif the solutionizing heating rates during the postweld heat treatment are too sluggish. As the grains' interiors become precipitated, they become stronger compared to the grain boundaries. Residual stress relaxation happens in the same temperature range. This can lead to concentrated strains at or near the grain boundaries since the grain boundaries are weaker than the grain interiors. A strain-age crack will develop if these strains are high enough to cause grain boundary collapse.

Thus, the simultaneous existence of a strong precipitation (ageing) reaction and a relaxing strain gives strainage cracking its name.The quick development of the Ni3 (Ti,Al) precipitate after welding causes strain-age cracking, which is why titanium and aluminium have a significant impact on cracking susceptibility. The rate of gamma-prime precipitation is decreased by lowering these elements, which effectively shifts the precipitation curve's snout to longer durations. The relative strain-age cracking effects of aluminium and titanium for several nickel-based alloys are depicted.

It is nearly hard to apply postweld heat treatment to alloys with high titanium+aluminum compositions, such IN100 and IN713C, without generating strain-age cracking. Depending on welding and restraint conditions, alloys with intermediate titanium+aluminum concentrations like Waspaloy have varying susceptibilities to cracking. Because it is alloyed with niobium to create a gamma double prime, Ni3 Nb precipitate, alloy 718 (IN718) is essentially impervious to strain-age cracking. Gamma double prime forms far more slowly than gamma prime, which enables stress relaxation to happen even in the absence of precipitation, eliminating the likelihood of strain-age cracking with this alloy.

Titanium Alloys:

Titanium alloys are low density materials that can be combined with transformation hardening to increase their strength to high levels. They are hence renowned for having an exceptional strength-to-weight ratio, or particular strength. They also provide exceptional corrosion resistance in the majority of conditions, including seawater. At temperatures as high as 540°C (1000°F), some of the alloys can be employed. Due to the lengthy and expensive chemical extraction procedure required to remove titanium from its ore (rutile), titanium alloys are exceedingly expensive.

Based on their microstructure, titanium alloys can be divided into four main categories: commercially pure (CP), alpha, alpha-beta, and metastable beta alloys. The allotropic behaviour of titanium, like that of iron, enables transformation hardening. The crystal structure is hexagonally close packed (HCP) at low temperatures and changes to bi-crystal close packed (BCC) at high temperatures. The BCC phase is referred to as beta, and the HCP phase as alpha. The beta phase may be kept stable at room temperature and mixes of these phases are achievable by regulating the ratio of alpha-stabilizing elements (examples include aluminium, tin, and zirconium) to beta-stabilizing elements (examples include vanadium, molybdenum, and chromium). Rapid cooling can cause hard martensitic microstructures to develop, which frequently calls for postweld heat treatments. When opposed to concerns about steels, the weldability issue related to martensite development is minimal.Titanium alloys are typically chosen for either their unique strength or corrosion resistance.

Heat exchangers, pressure vessels, waste storage, tube and piping, and other applications rely on their corrosion resistance. They function well in marine conditions and are stress corrosion crack resistant. Additionally, they are biocompatible, which makes them a viable option for medical implants like hips, knees, and fasteners. The high specific strength of titanium alloys is nearly entirely responsible for their widespread application in the aerospace sector. In example, titanium alloys are frequently used in both the airframe and skin of high-performance military aircraft. When utilised in sporting equipment like bicycle frames, tennis rackets, and golf clubs, their high specific strength can also result in a performance advantage.

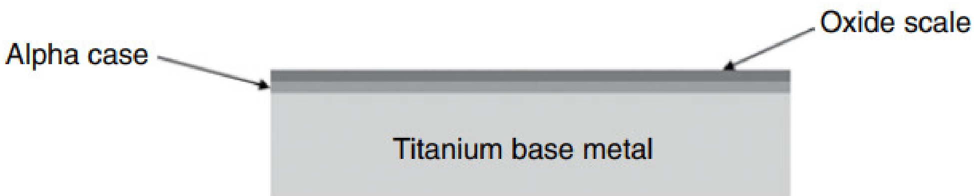


Figure 2: Coloured oxide scale.

If the right safeguards are taken, titanium alloys can be welded using the majority of procedures (apart from shielded metal arc welding, or SMAW). Interstitial embrittlement (or contamination cracking) and excessive HAZ and weld metal grain size are two of the main welding issues. Oxygen, nitrogen, and hydrogen are interstitial elements that titanium easily absorbs and dissolves. These substances significantly strengthen titanium when present in modest amounts. For instance, the modest changes in oxygen and nitrogen concentration are mostly responsible for the differences in tensile strengths among the CP titanium grades. However, considerable embrittlement happens at higher absorption rates. Above 500°C (930°F), embrittlement can happen quite quickly, making even areas of the part that are relatively far from the fusion zone susceptible during welding. Since all of the components that cause brittleness are present in the ambient atmosphere, welding protection (shielding) is crucial.

Copper Alloys:

Although copper alloys are employed in a wide range of engineering applications, they are often chosen for their corrosion resistance, electrical conductivity, and thermal conductivity. In general, copper alloys have low to moderate strength but good ductility and toughness, with the exception of alloys containing beryllium (which are strengthened through precipitation hardening). Copper alloys are strengthened by solid solution and cold work. They either have single phase FCC or dual phase FCC+BCC microstructures. Brass, a copper alloy with zinc and perhaps some tin or lead, and bronze, a copper alloy with tin, aluminium, or silicon, are two members of the family of copper alloys.

They are a fantastic option for marine applications like tubing, boilers, and decorative fittings on boats and ships because of their resilience to salt water corrosion. Their exceptional resistance to corrosion is also used in caskets and storage containers for nuclear fuel, among other things. They are quickly castable and easily manufactured into a range of shapes. For instance, early guns were made from castings of copper alloy.

Additionally, a multitude of architectural and artistic uses exist for copper alloys. In order to achieve various aesthetic effects, the copper oxide that forms in the environment can take on a range of colours, ranging from gold to red to brown (depending on the alloying elements added). Many of the copper alloys will eventually develop a greenish oxide when exposed to typical atmospheric conditions, just like copper-roofed structures do over time. These alloys' physical characteristics also make them attractive in the market for musical instruments and for the creation of bells and chimes. The majority of internationally renowned bells are cast from brass or bronze alloys.

Since cold work is the main technique used to strengthen copper alloys, welding will cause grain growth and HAZ recrystallization, resulting in a zone that is significantly softer than the surrounding base metal. This loss of strength can be substantial in alloys that have undergone extensive cold working, which will significantly reduce the structure's ability to support loads. Reducing heat input is typically the best way to minimise HAZ softening, but because copper has such high thermal conductivity and diffusivity, heat is extracted during welding so quickly that high heat input is typically required. Weld preheating is very frequently necessary to produce adequate penetration with many alloys, especially as component thicknesses rise above approximately 0.25in. Weld penetration can also be considerably increased by using helium shielding gas. Figure 12.15 illustrates how preheat and the type of shielding gas can affect the depth of fusion.

Porosity development may occur in alloys containing Zn, Cd, or P. This is typically manageable by employing a filler metal that resists porosity, but it can cause issues with autogenous welds with vulnerable alloys. It is advised to use chemical or mechanical procedures to remove the oxide before welding. Even though most copper alloys form in a single-phase FCC structure, they are nonetheless regarded as being resistant to solidification and liquation cracking. Tin and nickel-containing alloys may shatter when subjected to intense pressure.

Magnesium Alloys

Although magnesium alloys are even less dense (lighter weight), they nevertheless have advantages over aluminium alloys. Heat treatment can be used to strengthen them, resulting in good strength-to-weight (specific strength) ratios. In the transportation sector, where a move towards lighter, more fuel-efficient vehicles is encouraged, interest in magnesium is rising quickly. These materials are susceptible to solidification cracking because they have a high CTE and a wide solidification range, just like aluminium alloys do. They are also vulnerable to substantial weld distortion because of the high CTE. The majority of magnesium alloys are meant to be used at room temperature, however some of them may withstand prolonged exposure to temperatures as high as 350°C (660°F).

The bulk of magnesium components now in use are cast, but as interest in magnesium alloys as prospective structural components for automobiles grows, the trend towards wrought goods is on the rise. Ladders, hand-held tool and computer housings, automotive and aerospace gear boxes, and other applications are examples of current uses. Welding knowledge for these alloys is scarce because historically castings have been used for the majority of magnesium applications.But the emphasis on welding has grown significantly as more wrought items have entered the automotive and transportation sectors.An HCP alpha phase, like the alpha phase in titanium alloys, is the main microstructural phase (crystal structure) of the magnesium alloy system. Although they can also be used to strengthen precipitations, aluminium and zinc are added to solid solutions to strengthen them. Precipitation strengthening techniques also employ the additions of thorium, silver, and rare earth elements.

Thorium is very helpful for preserving strength at high temperatures since the magnesium-thorium precipitates can withstand temperatures of up to 350°C without becoming coarse. Numerous alloys incorporate zirconium as a grain-refining agent because the coarsening of the grains during the casting of magnesium alloys might affect their mechanical properties.The American Society for Testing and Materials (ASTM) was the organisation that initially created the alloy identification scheme (see an illustration in Figure 12.16) for magnesium alloys. It is based on the amounts of the two main alloying additions, rounded to the nearest single digit. Aluminium, manganese, zinc, and zirconium are some common alloying additives, although there are many others as the chart demonstrates. The MgAlZn and MgZrZn systems serve as the fundamental foundation for the wrought alloys, and manganese is added for corrosion resistance [10]–[12].

CONCLUSION

To sum up, non-ferrous alloy welding metallurgy is a vital discipline that enables the successful joining of materials like aluminium, copper, titanium, and nickel alloys. To produce welds of the highest quality with the appropriate mechanical and physical properties, it is crucial to comprehend the metallurgical changes that take place during the welding process. The choice of suitable welding procedures, filler metals, and shielding gases are important factors to take into account when welding nonferrous alloys. Through adequate cleaning, preheating, and post-weld heat treatment, issues including hot cracking, deformation, and porosity formation must be addressed. Overall, nonferrous alloy welding metallurgy is essential to many industries, ensuring the performance and integrity of welded connections in a variety of applications, from aerospace and automotive to electronics and beyond.

REFERENCES

[1] K. Saida, Y. Fujiya, and T. Obana, "Welding metallurgy of nonferrous alloys," *Yosetsu Gakkai Shi/Journal of the Japan Welding Society*. 2015. doi: 10.1002/9781119191407.ch12.

[2] K. Saida, Y. Fujiya, and T. Obana, "Welding metallurgy of nonferrous alloys," *Yosetsu Gakkai Shi/Journal Japan Weld. Soc.*, 2011, doi: 10.2207/jjws.80.426.

[3] K. Saida, S. Tsukamoto, Y. Fujiya, and E. Ashida, "Welding metallurgy of nonferrous alloys," *Yosetsu Gakkai Shi/Journal Japan Weld. Soc.*, 2009, doi: 10.2207/jjws.78.418.

[4] K. Saida, K. Nishio, Y. Fujiya, and E. Ashida, "Welding metallurgy of nonferrous alloys," *Yosetsu Gakkai Shi/Journal Japan Weld. Soc.*, 2007.

[5] K. Nishio, S. Kawaguchi, and K. Saida, "Welding metallurgy of nonferrous alloys," *Yosetsu Gakkai Shi/Journal Japan Weld. Soc.*, 2005.

[6] M. Balasubramanian, V. Jayabalan, and V. Balasubramanian, "Modeling corrosion behavior of gas tungsten arc welded titanium alloy," *Trans. Nonferrous Met. Soc. China (English Ed.*, 2007, doi: 10.1016/S1003-6326(07)60155-1.

[7] ASM International Handbook Committee, "ASM Handbook: Materials Characterization, Volume 10," *Book*, 1998.

[8] T. Lienert, *Welding Fundamentals and Processes*. 2018. doi: 10.31399/asm.hb.v06a.9781627081740.

[9] F. Hardesty, "Metals handbook, ninth edition. Volume 3, Properties and selection: Stainless steels, tool materials and special-purpose metals," *J. Mech. Work. Technol.*, 1982, doi: 10.1016/0378-3804(82)90039-0.

[10] ASM International. Handbook Committee, "ASM Handbook, Volume 15," *Frict. Lubr. Wear Technol.*, 2008.

[11] H. Baker, *ASM Handbook: Alloy Phase Diagrams Volume 3*. 1998.

[12] ASM International, *ASM handbook volume 3: Alloy phase diagrams*. 1998.

CHAPTER 17

WELDING METALLURGY OF CARBON STEELS

Mr. Dipendra Kumar, Associate Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id:dipendra1987@jnujaipur.ac.in

ABSTRACT:

This abstract offers a succinct summary of welding metallurgy with a particular emphasis on carbon steels. It includes the important elements involved in welding carbon steels, such as metallurgical adjustments, difficulties, and considerations.The significance of carbon steels as widely utilized materials in numerous industries and their significance in welding applications are highlighted in the abstract's opening paragraph.The formation of the fusion zone, the heat-affected zone (HAZ), and base metal transformations are some of the metallurgical changes that take place during the welding of carbon steels. It emphasizes the impact of welding factors on the final microstructure and characteristics, such as heat input and cooling rate.

KEYWORDS:

Consolidation, Heat-Affected Zone, Phase Transitions, Welding Specifications, Welding Flaws.

INTRODUCTION

The most popular metal alloy manufactured commercially is still steel. Over 90% of the metals produced and used on Earth are composed of these ferrous alloys, often known as iron and carbon alloys. When little amounts of carbon are added to iron, it transforms into steel and has a significant interstitial strengthening effect. Carbon content in steels typically ranges from 0.05 to 0.8% by weight. Other alloying additions and phase transformation strengthening, which makes use of the allotropic properties of iron, can further strengthen materials [1], [2].

Steels can be as basic as iron alloys that are mostly composed of carbon and manganese, or they can be far more complicated alloys with numerous alloying additives. According to their composition, structural steels can be broadly divided into four groups: plain carbon steels, low alloy steels, high strength low alloy (HSLA) steels, and high alloy steels. Simple Fe–C alloys with modest additions of Mn and Si make up plain carbon steels. Low carbon (0.2%), medium carbon (0.2-0.4%), high carbon (0.4-1.0%), and ultra-high carbon (1.0-2.0%) are often used to distinguish them. Low alloy steels can have low or medium carbon levels and up to 8% total alloy additions. To obtain high strength, many of these steels are quenched and tempered. Steels with high strength and low alloy content come in a variety of compositions. These steels typically contain less carbon and are strengthened using specialised processing methods like controlled rolling or micro-alloying additions that encourage small grain size and/or precipitation processes. High temperatures are the main use for high alloy steels, where strength and corrosion resistance are crucial. The alloying component often used to impart corrosion resistance is chromium. Stainless steels are high alloy steels that include at least 12% chromium (more on this in the following chapter).

In the US, there are numerous classification schemes used for steel. The most popular system, which is based on a four-digit classification system, is the American Iron and Steel Institute (AISI)/Society of Automotive Engineers (SAE) system. The main alloying element(s) are indicated by the first digit, while further details about the alloying elements or their amounts are revealed by the second number. When divided by 100, the weight percentage of carbon is revealed. Examples of two typical ones are 1018 and 4340.

First example (1018): This is a carbon steel, as indicated by the first digit, which is a "1". This steel is a carbon steel with no notable extra alloying, as indicated by the "0" that follows. After multiplying by 100, the "18" denotes steel with a nominal carbon content of 0.18 weight percent.

Examples 2 and 4340 In this instance, the first number "4" indicates that the steel in question is a molybdenum steel, and the number "3" that follows shows that chromium and nickel have also been added. This steel has 0.40 weight percent carbon.

Steels are specified by the American Society for Testing and Materials (ASTM) based on mechanical characteristics rather than composition restrictions. General standards for large families of steel products, including bar, plate, sheet, and others, are contained in the different ASTM specifications. Since they are defined by their mechanical characteristics, a wide range of chemical compositions is typically permitted. Under this system, steels are designated by a letter that refers to the ASTM specification to which they were produced, followed by a random number. For instance, the term A322 describes hot-rolled alloy steel bars. The number "322" is the specification number for this steel product, while the letter "A" denotes a ferrous alloy.

The American Society for Mechanical Engineers (ASME) Boiler and Pressure Vessel code uses a system known as "P□Numbers" which assigns metal alloys such as steels in broad groups based on their weldability properties. The weldability group that the specific alloy falls under is indicated by the letter P, which is followed by a number. For instance, the "1" in designation P-Number 1 designates a collection of steels that share a common set of weldability traits.

The range of P numbers for ferrous alloys is 1 through 11, albeit the number 2 is not utilised. As long as the change is to an alloy type that is in the same weldability group (P Number), this method of welding a fabrication allows for a change in the base metal alloy type without the need to requalify the welding technique.

History of Welding Metallurgy of Carbon Steels

Thegrowth and development of the welding industry are connected with the history of welding metallurgy of carbon steels. A timeline of significant events and advancements in the development of welding metallurgy for carbon steels is shown below:The advent of arc welding in 1800s: Arc welding was made possible by Sir Humphry Davy's research with electric arcs and carbon electrodes. However, rather than researching the metallurgical elements, the emphasis at this time was on showcasing the possibilities of electric arcs.

World War I saw considerable advancements in arc welding as a result of the need for quick and effective joining techniques. Although the metallurgical modifications in carbon steels during welding were detected, nothing was known about them. During World War II, the development of arc welding techniques such as shielded metal arc welding (SMAW) and gas metal arc welding (GMAW) was significantly advanced. More in-depth research was done on the metallurgical impacts on carbon steels, including heat-affected zone (HAZ) and fusion zone properties.

The Post-War Period and Industrial Development: - 1950s–1960s: The need for carbon steel structures in the construction, shipbuilding, and automobile industries sparked more welding metallurgy research. Weldability, welding parameter optimization and comprehension of the microstructural changes in carbon steels during welding were the main research areas. From the 1970s to the 1990s, improvements in welding techniques such as submerged arc welding (SAW) and gas tungsten arc welding (GTAW) allowed for better control of metallurgical changes in carbon steels. Investigated were the impact of alloying components like manganese on the characteristics of carbon steel welds [3]–[5].

DISCUSSION

Steel Microstructures and the Iron□Iron Carbide Diagram

The well-known iron–iron carbide diagram depicted in serves as the foundation for the physical metallurgy of steels. With a maximum carbon content of 6.67wt%, this picture only depicts a minor section of the iron carbon diagram. This mixture (6.67%) corresponds to the mixture of cementite, sometimes referred to as iron carbide, an intermetallic phase having a stoichiometry of Fe3 C. The picture is not drawn to scale in order to better highlight the significant phase fields in the diagram's iron-rich side, which is where the majority of steel compositions may be found.On the left side of this picture, you can observe the three phases of iron. Although fascinating, the high temperature bcc delta () ferrite has little bearing on steels. The change from the higher temperature bcc alpha ferrite to the lower temperature fcc austenite is particularly significant for the manufacturing of steels. Observe how far to the right the austenite phase field extends; this indicates that it has a high carbon dissolution rate (up to 2.11%). The highest quantity of carbon that can dissolve in alpha ferrite is 0.02%, on the other hand. Since almost all steels contain more than 0.02% carbon, this discrepancy has the effect of causing cementite to form after equilibrium cooling from austenite when the carbon content is beyond the solubility limit of ferrite [6]–[8].

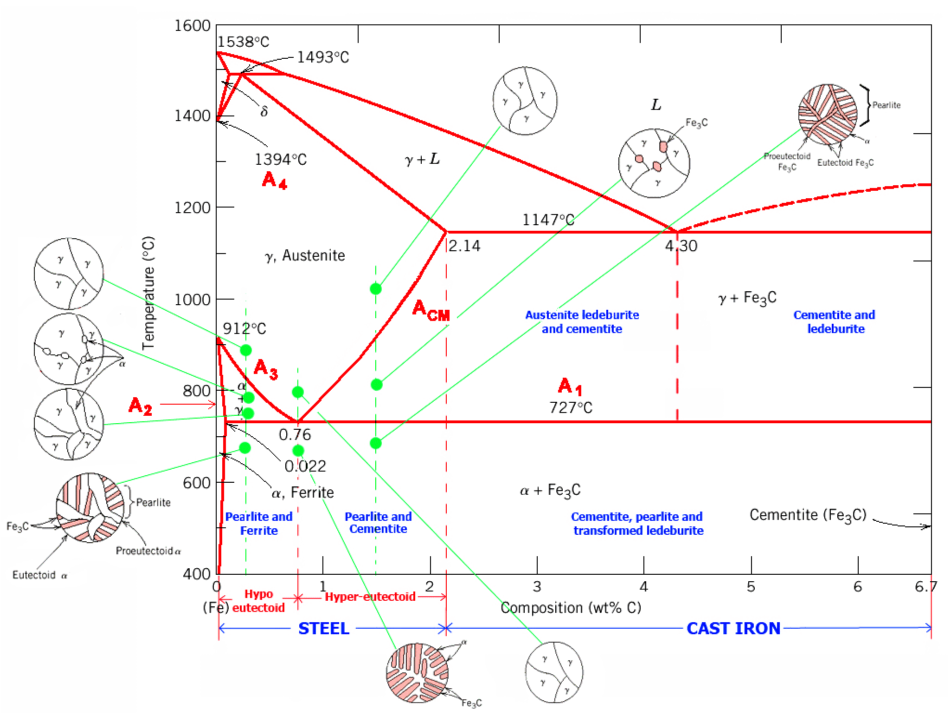


Figure 1: Steel Microstructures and the Iron□Iron Carbide Diagram (research gate)

The Fe3 C cementite can take on a variety of shapes depending on how quickly austenite cools. Round Fe3C particles should form in a ferrite matrix if cooling rates are exceedingly slow, allowing for substantial diffusion. This is the spheroidite equilibrium morphology. In reality, cooling rates during welding or processing are never slow enough to for spheroidite to develop.The element that often occurs is a layered structure known as pearlite when cooling rates are fast enough to produce nonequilibrium conditions but are still relatively sluggish. The fact that pearlite frequently resembles mother-of-pearl when seen under a microscope is reflected in the name. Upon cooling from austenite, colonies of thin layers of ferrite (0.02% carbon) and Fe3 C (6.67% carbon) develop. Because of the structure's low diffusion distances, which provide the "easiest" route for extra carbon (beyond the 0.02% maximum amount ferrite can dissolve) to diffuse from the austenite into the high carbon Fe3 C cementite, layering morphology develops. Martensite and bainite, which will be covered later, are transformation products that may be created at even faster cooling rates from austenite temperatures.

A variation of the iron–iron carbide diagram is frequently used to highlight the fact that pearlite is a common ingredient that develops in steels following cooling from austenite. This graphic highlight other crucial aspects related to the machining and welding of steels, in addition to elements like pearlite. A heat treatment or welding operation may cause the steel to cool from austenite at the A3 and A1 temperatures, which are significant temperatures. At compositions lower than the eutectoid composition, ferrite will start to form from austenite at the A3 temperature. All remaining austenite will become pearlite upon further cooling to the A1 temperature. Again, slow cooling rates are in line with this.

Another significant aspect of this equilibrium phase diagram is the A1 temperature, commonly referred to as the eutectoid temperature, which is 727°C (1341°F). Similar to a eutectic reaction, a eutectoid reaction occurs when a single liquid phase changes into a two-phase solid at a particular temperature. A single phase solid (austenite) changes into a two-phase solid (ferrite+Fe3 C, or pearlite), but there is no liquid involved in the eutectoid reaction. The microstructure of a carbon steel with a carbon content less than the eutectoid composition (0.77%) would be composed of an alpha phase (or ferrite) microstructure that starts to form at the A3 temperature, surrounded by pearlite that forms from the remaining austenite once it reaches the A1 temperature. All of the austenite undergoes direct transformation to pearlite at the eutectoid composition of 0.77%, resulting in a microstructure that is entirely made of pearlite. Iron ceases to be ferromagnetic at the A2 temperature, also referred to as the curie temperature.

According to the diagram, after cooling from austenite, steels with carbon contents above the eutectoid composition would first form Fe3 C cementite. All remaining austenite would change to pearlite at the eutectoid temperature. A microstructure of primary cementite and pearlite is the end outcome. The term "hypereutectoid" refers to these extremely high carbon steels, whereas the term "hypoeutectoid" refers to steels with compositions below the eutectoid composition. Additionally, this graphic demonstrates that cast irons are made with iron that contains significantly more carbon than 2%."Hypoeutectoid" steels are the most common type. These steels will have a microstructure of ferrite and pearlite if cooling rates from austenite temperatures are again assumed to be reasonably slow. larger carbon "hypoeutectoid" steels will have a larger ratio of pearlite to ferrite because pearlite contains the high carbon cementitecontrasts the microstructures of an A36 steel with a substantially lower carbon content and a comparatively high carbon hypoeutectoid steel (1060) on the left.

The dark gray/black component is the pearlite, and the white phase in these microstructures is known as primary ferrite (the word primary separates it from the layers of ferrite in the pearlite). Layers of cementite and ferrite make up the pearlite, as previously The ferrite layers found within pearlite are made up of the same materials as primary ferrite; however, they form through a distinct process. Ferrite (the main ferrite) is the first phase to form after austenite cools, as shown on the iron-iron carbide diagram. Any austenite that is still present at the eutectoid temperature will change into pearlite with further cooling. The layering of cementite and ferrite in pearlite is often visible as solid dark grey or black, as shown in the photomicrographs, because it is too finely layered for optical microscopy to distinguish.

Primary ferrite is extremely brittle, ductile, and weak while cementite is hard and robust. A microstructure with usually favourable overall properties results from the combination of the two features that make up pearlite's characteristics. When welding low alloy and low carbon steels, as well as when utilising high heat input welding procedures that result in slow cooling rates (such submerged arc welding), pearlite/ferrite development in the weld HAZ will be more likely. In both scenarios, it is easier for the fcc austenite atoms to rearrange into bcc ferrite and pearlite and for the carbon to completely diffuse from austenite into these minerals However, for a particular steel, when cooling rates are relatively quick, there might not be enough time for the carbon to diffuse out of the austenite to produce ferrite and pearlite and for the fcc austenite atoms to rearrange to form bcc ferrite. Martensite, a diffusionless body centred tetragonal (BCT) structure, may form as a result of this

The extra carbon (over the 0.02% that the bcc ferrite can dissolve) is trapped and causes a shearing mechanism that extends the structure in one direction, resulting in the "stretched" bcc structure that makes up the BCT crystal structure. Martensite generally displays a needle-like shape under an optical microscope. It is well recognised for being brittle and hard, with the hardness of the material rising with the amount of carbon present. Hard martensite is known to be vulnerable to hydrogen cracking, a potentially disastrous cracking mechanism.

Martensite often undergoes a relatively low temperature heat treatment process called tempering in order to regain some ductility. Tempering reduces the amount of trapped carbon in the BCT matrix by softening the martensite through the production of tiny carbides. Additionally, some ferrite production may take place depending on the tempering duration and temperature, which also aids in the softening. When welding high alloy steels with more carbon, such as 4340, and low heat input techniques that produce quick cooling rates, such as laser welding, martensite production will be more likely to occur in the weld HAZ.

Continuous Cooling Transformation (CCT) Diagrams

Therefore, even while equilibrium conditions of very slow cooling can be used to use the iron–iron carbide phase diagram to estimate the phase balance in steels, these conditions are typically not present during welding, where high cooling rates occur. A different kind of diagram that takes cooling rates into account is therefore required. The terms Time Temperature Transformation (TTT) and Continuous Cooling Transformation (CCT) diagrams are used to describe these types of diagrams. Steel microstructures can be predicted using TTT and CCT diagrams as a function of rate of cooling from austenite temperatures. Every diagram only applies to one type of steel composition.

Given that they are both plots of temperature versus log time, these diagrams are comparable. The method by which they are produced is the only tiny distinction. To create TTT diagrams, steel is heated to the austenite temperature range, quickly cooled to a variety of temperatures, and then held at each of these temperatures to allow austenite to convert.They are frequently referred to as Isothermal Transformation Diagrams since they depend on isothermal transformation. CCT diagrams are produced by constantly letting the steel to cool from austenite at varied cooling rates rather than by maintaining the specimen at a single temperature. CCT diagrams are therefore frequently employed for forecasting weld microstructures since they are more accurate representations of actual welding circumstances.

Differential thermal analysis (DTA), among other techniques, is used to identify the timing of the change. DTA employs the heat of transformation as a gauge for the temperature of the transformation. When austenite converts into ferrite, pearlite, and other transition products in steels, a significant amount of latent heat is released. Individual points can be shown on the diagram as a result of this heat being detected using the DTA measuring technique. Each isothermal hold or cooling rate will provide a different set of points (TTT diagrams or CCT diagrams). A set of transformation curves that show the beginning and end of the transformation can be produced by repeating this procedure at various temperatures and cooling speeds. A very basic example of a TTT diagram stacked with different cooling rates is. This diagram must be applicable to a eutectoid steel (0.77% carbon) because it only depicts one transformation start curve and one transformation end curve. If the cooling rates are not quick enough to produce martensite, such a steel can only cool from austenite to 100% pearlite (no ferrite). An extra ferrite transition curve will be present at compositions lower than the eutectoid composition, which is characteristic of most steels.

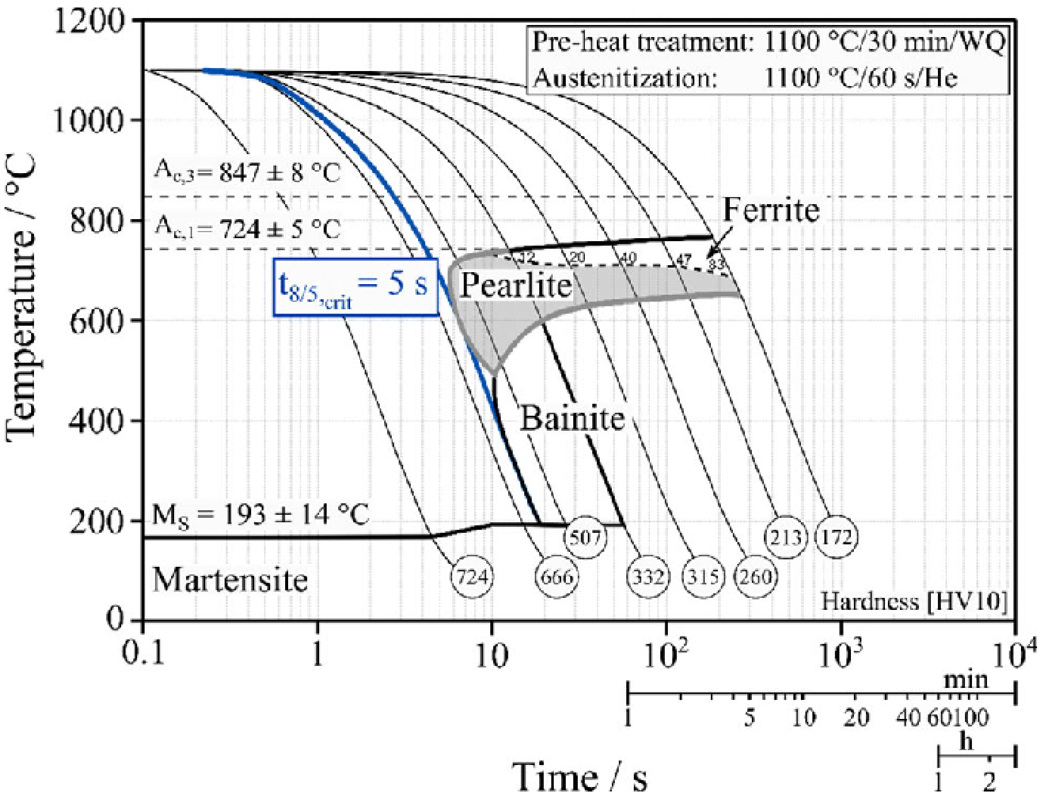


Figure 2 Continuous Cooling Transformation (CCT) Diagrams (research gate)

Ferrite and pearlite transformation curves, as well as martensite start (Ms) and martensite finish (Mf) temperatures, are often included in TTT and CCT diagrams. The Mf is the temperature at which martensite transformation is complete, while the Ms represents the temperature at which martensite creation starts. The ferrite/pearlite transformation curves show the onset and termination of the process. No further microstructures, including martensite, can occur after the austenite to ferrite/pearlite transformation is finished. Alternatively, austenite is the only material from which martensite may develop.

Various cooling rates that might be anticipated during a normal heat treatment procedure or during a weld are also included in the particular diagram that is being displayed. In this situation, 100% martensite would be produced with a cooling rate as rapid as curve "A". All of the austenite converts to martensite when the curve's snout is avoided (as with cooling rate "A"). Because the pearlite transformation is incomplete and some austenite remains to be changed into martensite upon reaching the martensite start temperature, cooling curve "B" would result in a pearlite+martensite (or bainite, which is not depicted in this picture) microstructure.

Since the pearlite trans-formation is complete, a cooling rate like "C" should result in the creation of 100% pearlite. As previously mentioned, no more transformation products can emerge until all of the austenite has been converted to pearlite. The fact that the TTT and CCT diagrams are always based on cooling from temperatures in the austenite phase field should also be highlighted. These diagrams can only be used to forecast what will happen when austenite cools; they cannot anticipate what will happen while it is heated. The pace of cooling between 800°C (1472°F) and 500°C (932°F) is crucial because this is the temperature range when austenite undergoes its changes.

Due to the fact that includes pearlite transformation curves, it is rather straightforward. These diagrams are typically more intricate, a CCT diagram for 1040 steel. This graphic illustrates the enormous diversity of microstructures that can form even with a straightforward steel like 1040 depending on the rate at which austenite temperatures are cooled.

A highly significant microstructural component of steels, martensite has both positive and negative meanings. Numerous steels, including 4340, rely on its creation during processing due to its high strength. Since it occurs during the transition from austenite to martensite, this type of strengthening is sometimes referred to as phase transformation strengthening. As was previously indicated, a later heat treatment called tempering enables the manufacturer of steel to "customise" certain characteristics to achieve a balance between strength and ductility. More ductility will be produced via longer tempering times and/or hotter tempering temperatures, but at the sacrifice of strength [9], [10].This type of steel processing is also known as "quenched and tempered" steels.

Steels that have been quenched and tempered are made to form martensite relatively easily. This is accomplished by including alloying components including chromium, nickel, and molybdenum.When these and other steels are welded, martensite poses a challenge. It is extremely simple for weld fusion zone and HAZ martensite to form, which is exceedingly hard in its untempered state, has low toughness and ductility, and is vulnerable to hydrogen cracking.The majority of the time, postweld temper treatments for steels that produce hard martensite during welding are expensive and time-consuming. For instance, whereas tempering a tiny plate in a furnace can be quite simple, it might be necessary to use resistance heaters or localised heating blankets for larger fabrications such pipe lines or massive assemblies. Complicated geometry, difficult access, and the presence of close heat-sensitive attachments are a few field implementation difficulties that might make it challenging to apply a tempering treatment [11]–[13].

CONCLUSION

In conclusion, the requirement for effective joining techniques and developments in welding technology have spurred centuries of development in the welding metallurgy of carbon steel. The development of diverse welding procedures and techniques, as well as a deeper comprehension of the metallurgical changes that take place during welding, can be witnessed throughout the history of welding metallurgy of carbon steel. The discipline has increased our understanding of weldability, microstructural changes, and the optimization of welding parameters for carbon steels from the early use of forge welding to the introduction of arc welding and contemporary advancements in computational modelling and materials science. These skills are currently used across sectors to guarantee the excellence and integrity of welded connections in carbon steel structures. Our grasp of welding metallurgy is being enhanced by ongoing research, which has resulted in better welding procedures and the creation of superior carbon steel alloys for certain uses.

REFERENCES

[1] D. H. Phillips, "Welding Metallurgy of Carbon Steels," in *Welding Engineering*, 2015. doi: 10.1002/9781119191407.ch10.

[2] R. Neystani, B. Beidokhti, and M. Amelzadeh, "Fabrication of dissimilar Fe-Cu-C powder metallurgy compact/steel joint using the optimized resistance spot welding," *J. Manuf. Process.*, 2019, doi: 10.1016/j.jmapro.2019.05.014.

[3] R. D. Ramdan *et al.*, "Metallurgy and mechanical properties variation with heat input,during dissimilar metal welding between stainless and carbon steel," 2018. doi: 10.1088/1757-899X/307/1/012056.

[4] P. Puschner, M. Klein, and G. Kölzer, "Fully automatic spot welding system for application in automotive industry," *Soldag. e Insp.*, 2015, doi: 10.1590/0104-9224/SI2003.07.

[5] D. Peckner, "Handbook of Stainless Steels," *Br. Corros. J.*, 1978, doi: 10.1179/000705978798318774.

[6] S. Qiao and W. Qian, "Replication experiments and microstructural evolution of the ancient co-fusion steelmaking process," *Metals (Basel).*, 2020, doi: 10.3390/met10091261.

[7] O. Sherepenko, O. Kazemi, P. Rosemann, M. Wilke, T. Halle, and S. Jüttner, "Transient softening at the fusion boundary of resistance spot welds: A phase field simulation and experimental investigations for al–si-coated 22mnb5," *Metals (Basel).*, 2020, doi: 10.3390/met10010010.

[8] J. R. Deepak, J. Jeya Jeevahan, D. Ramachandran, S. V. Sai Suhas, and P. V. Praneethkumar Reddy, "XRD investigation of GTAW, GMAW, LBW and AGTAW Corten A588 grade steel weldments," 2021. doi: 10.1016/j.matpr.2021.06.081.

[9] K. J. Singh, "Multi-objective optimization of high carbon steel (EN-31) and low carbon steel (SAE-1020) using Grey Taguchi method in rotary friction stir welding," *Grey Syst.*, 2019, doi: 10.1108/GS-10-2018-0047.

[10] Q. Lu *et al.*, "Revolutionizing car body manufacturing using a unified steel metallurgy concept," *Sci. Adv.*, 2021, doi: 10.1126/sciadv.abk0176.

[11] C. DiGiovanni, L. Li, R. Driver, and L. Callele, "Cracking in welded steel platform structures during hot-dip galvanization," *Eng. Fail. Anal.*, 2017, doi: 10.1016/j.engfailanal.2017.06.021.

[12] A. Santillan Esquivel, S. S. Nayak, M. S. Xia, and Y. Zhou, "Microstructure, hardness and tensile properties of fusion zone in laser welding of advanced high strength steels," *Can. Metall. Q.*, 2012, doi: 10.1179/1879139512Y.0000000002.

[13] J. R. Davis, "Corrosion of Carbon Steel and Low-Alloy Steel Weldments," in *Corrosion of Weldments*, 2021. doi: 10.31399/asm.tb.cw.t51820013.

CHAPTER 18

A REVIEW STUDY ON SOLID-STATE WELDING PROCESSES

Mr. Ashok Singh Gour, Assistant Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id:asgour@jnujaipur.ac.in

ABSTRACT:

A collection of joining methods known as solid-state welding technologies create welds without melting the workpieces. The advantages, difficulties, and uses of solid-state welding methods are briefly discussed in this abstract.In addition to allowing the joining of different materials, solid-state welding methods also provide low heat input requirements, less distortion, and excellent mechanical qualities in the welded joints. In the abstract, several of the most widely utilised solid-state welding techniques are highlighted, including friction welding, explosive welding, diffusion bonding, and ultrasonic welding.The necessity for precise control of process parameters, surface preparation, and contamination removal are difficulties in solid-state welding procedures. In order to produce good solid-state welding, the abstract emphasises the significance of workpiece alignment and thorough surface cleaning.

KEYWORDS:

Bonding Through Diffusion, Electrical Explosions, Nuclear Diffusion, Rolling Bonding, Solid-State Fusion.

INTRODUCTION

A collection of joining methods known as "solid-state welding processes" make it possible to create welds without completely melting the workpieces. Solid-state welding technologies produce welds by a mix of heat, pressure, and plastic deformation as opposed to traditional fusion welding techniques, which need the complete liquefaction of the base metals.Atoms diffusing between the adjacent surfaces of the workpieces is the main idea of solid-state welding. The atoms at the material interface move and establish metallurgical bonds as pressure and heat are applied, creating a strong and cohesive connection. In comparison to fusion welding techniques, solid-state welding technologies have a number of benefits, including the ability to weld disparate materials together, less distortion, a small heat-affected zone, and superior mechanical qualities of the weld [1], [2].

Industrial applications use a variety of solid-state welding techniques, each with unique properties and uses. Friction welding, explosive welding, diffusion bonding, ultrasonic welding, and roll bonding are a few of the frequently used methods. Materials including metals, alloys, composites, and even incompatible materials can be joined using these methods, giving designers more options when choosing materials for particular applications.The need for precise control of process parameters is one of the main difficulties in solid-state welding procedures. In order to achieve successful solid-state welds, variables including pressure, temperature, deformation rate, and surface preparation are crucial. For close contact and effective atomic diffusion at the interface, proper workpiece cleanliness and alignment are also necessary.Many different industries, including aerospace, automotive, electronics, power generation, and more, use solid-state welding techniques. These procedures are very useful for fusing lightweight materials like titanium alloys and aluminium, as well as for forging high-strength joints in vital parts.

Fundamentals and Principles of Solid State Welding

A series of procedures known as "solid-state welding" creates welds without the need of molten metal. The solid-state welding hypothesis emphasises that if the barriers (oxides, impurities, and surface roughness) to welding can be removed, the driving power for two pieces of metal to spontaneously weld (or establish a metallic link) to each other exists. This idea serves as the foundation for all solid-state welding methods, which use some combination of heat, pressure, and time to break down the barriers. Resistance, friction, diffusion, explosion, and ultrasonic welding are all methods.

Since there is no melting, there is no potential for the production of defects such porosity, slag inclusions, and solidification cracking, which are only present in fusion welding techniques. Additionally, since solid-state welding technologies don't need filler materials, they are sometimes highly successful at joining dissimilar metals that conventional welding methods can't because to metallurgical incompatibilities. The equipment is frequently highly expensive, and some procedures necessitate extensive prepping of the welding materials. Some of these methods can't be used in a production setting, and the majority are restricted to specific joint designs. Because it might be challenging to tell if a solid-state welding procedure has created a real metallurgical bond when there is no solidification, nondestructive testing techniques are not always effective.

Theory of Solid-State Welding

Ionic, covalent, or metallic atomic bonds are the three types of atomic bonding most frequently found in materials. The final result is that the traits and attributes of any material directly correspond to how the substance's atoms are bound, despite the fact that the distinctions in the types of atomic bonds relate to how valence electrons are shared. As a "cloud" of free-drifting electrons, the valence electrons in metallic bonds are unusual in that they are not attached to a single atom. The attraction interactions between the positively charged nuclei or ions and the negatively charged electron cloud are what hold the metal atoms together. Many of the qualities that metals are renowned for, such as electrical conductivity, are produced through this kind of bonding. It also implies that if their atoms are placed near enough together, all metals ought to spontaneously fuse. The idea of adhesion, which refers to the spontaneous welding that should take place due to the atomic attraction forces if two metals are brought close enough together, is the foundation of solid-state welding theory [3]–[5].

The force of attraction between the ions and electrons required for adhesion only manifests itself when the interatomic distance is less than 10. This would necessitate a surface that was nearly flawlessly smooth and spotless. A surface roughness of less than 10 (the distance between asperity peaks and troughs) cannot be produced using a typical industrial procedure.Even after being polished to a mirror sheen, a metal would still have a tiny surface roughness well above 10. Metals are also known to develop surface oxides quickly, which further prevents the formation of interatomic proximity between two metal surfaces. Additionally, pollutants like oils are frequently present. In conclusion, these obstacles of surface roughness, oxides, and other impurities must be removed in order to establish adhesion or metallic bonding (welding) between two metals without melting. Every solid-state welding procedure aims to get over these obstacles.

Theory of Roll Bonding

To overcome bonding obstacles and achieve metal-to-metal contact is the common objective of all solid-state welding procedures, according to the roll bonding hypothesis. An application for the solid-state welding technique known as roll bonding (or welding) ranges from clad refrigerator components to coins like the US cent. It also offers a helpful technique to describe the idea of developing nascent surfaces.

Depicts the results of forcing two metal pieces through rigid rollers that are spaced apart by less than the combined thickness of the two metal pieces. The lengths of the parts will increase while the metal thicknesses will be decreased. The length of the interfacial zone between the two components will also automatically grow as their length does. In essence, the interfacial region is stretched and compressed, resulting in the disintegration of oxides and the collapse of surface asperities. What's left are what are known as nascent surfaces, which are new metal surfaces that are in contact with one another. These regions between these regions reflect the original surfaces. To establish metallic bonding or a solid-state weld, an adequate number of nascent surfaces must be created.

DISCUSSION

Friction Welding Processes

To get beyond the limitations of solid-state welding, this class of techniques relies on frictional heating and considerable plastic deformation or forging action. There are several ways to produce frictional heating, but Inertia and Continuous (or Direct) Drive Friction Welding are two friction welding technologies that do so by rotating one part against another. These friction welding techniques are the most popular and are perfect for round components, bars, or tubes.

Both inertia and continuous drive friction welding involve rotating one piece rapidly while leaving the other piece still Then, with considerable force, the rotating part is brought into contact with the stationary part, causing frictional heating that softens (decreases the yield strength) the material at and close to the joint. As the softened material is forced out of the joint area, heating caused by plastic deformation takes over and frictional heating gradually decreases. The residual softened hot metal and any pollutants are frequently squeezed out into the "flash" once the necessary amount of time has passed to thoroughly heat the pieces. After welding, the flash is often removed while it is still hot and simple to remove.It is evident that more heating will take place towards the outside diameter of the items being heated since the radial velocity will be the largest there. This is because the initial heating is caused by friction heating. Therefore, the amount of time needed for heat to transfer from the heated material in the outer diameter to the inner diameter is what determines whether the part is properly heated over its whole thickness. Lack of bonding in the centre may be caused by parameters that are set in a way that prevents proper heating of the material along the inner diameter. For instance, excessive pressures could prematurely squeeze heated material from the outer diameter before the centre has heated up enough. The distinctive hourglass shape of these welds is a result of this nonuniform heating as well [6]–[8].

Other friction welding techniques include linear friction welding, which permits the welding of rectangular geometries, and friction stir welding (FSW), which uses an extra pin tool to allow the welding of conventional joint designs such butt joints. These strategies will be covered in more detail later in this chapter. But friction welding's basic principles apply in any situation.

Welding by Inertia Friction

A flywheel is used in inertia friction welding to supply the energy necessary to spin two parts against one another and generate the warmth necessary to form a weld. The flywheel is accelerated to the correct speed by a motor, which then releases it, allowing it to spin freely. After that, it is positioned against the stationary component and a force is applied, a typical weld sequence is displayed. The flywheel's energy is used in the forging process at the weld, and when the weld zone starts to cool and restore strength, the flywheel's speed drops. To produce the right level of upset, a second forging force may be used at the end of the cycle. The size and beginning velocity of the flywheel are two crucial factors in this process. Large components, like those used in jet engines, are an excellent candidate for inertia welding since the process may rely more on the size of the flywheel than it can on an incredibly strong (and pricy) motor. An ordinary illustration is the titanium compressor rotor seen in jet engines. Welding by Continuous Drive Friction. In comparison to inertia welding, continuous drive friction welding, also known as direct drive friction welding is quicker and provides more exact control of the rotating portion. When welding two components with features that require alignment after the weld is complete, the capacity to control rotational velocity can be very crucial. The procedure normally makes use of a hydraulic system and is motor-driven. As with inertia welding, frictional speed is maintained constant, and a forge force may be used at the conclusion of the procedure to produce the right amount of upset Although this method is more adaptable and more suited to a production setting than inertia welding, it is typically not the best option for welding components with particularly high cross-sectional areas. Strut rods, which are used in automobile suspension systems, are one type of production-welded part that uses this technique

Linear Friction Welding

To provide the necessary frictional warmth for welding, the Linear Friction Welding procedure moves two components in a straight line or linear fashion. Friction welding is possible on parts with a square or rectangular shape because to the linear motion. Due to the high equipment requirements and small item sizes that may be welded with this process (up to 2-3 square inches of surface), it is not a widely used method. The principal use of this method is the installation of jet engine blades on specific contemporary aircraft engines. Another name for it is Translational Friction Welding. An orbital motion is used in another variant.An solid-state welding technique called linear friction welding involves applying mechanical pressure and frictional heat to unite two workpieces. An overview of linear friction welding is provided below:

Process Overview

1. Preparation: The surfaces of the workpieces that will be joined are cleaned before being pressed into contact.
2. Heating Phase: Under a particular pressure, one workpiece is rapidly oscillated in relation to the other. The rubbing motion causes frictional heat to be produced at the interface between the workpieces.
3. Plastic Deformation: As a result of the heat-induced softening of the material at the interface, plastic deformation might take place.
4. Forge Phase: The oscillation is stopped, and the applied pressure is raised, after the desired temperature and plasticity have been reached. This results in additional distortion and helps the workpieces' metallurgical bonding.
5. Solidification and Cooling: The weld cools and solidifies after the pressure is released, completing the desired connection.

Linear Friction Welding Benefits

1. High Strength: Linear Friction Welding results in joints with outstanding mechanical qualities and high strength.
2. Quick and efficient welding procedure: This technique enables quick production cycles.
3. The combining of incompatible materials is made possible by linear friction welding, which broadens the range of design options.
4. Lessened Distortion: When compared to fusion welding techniques, the approach reduces distortion and residual strains.
5. Linear Friction Welding is Eco-Friendly

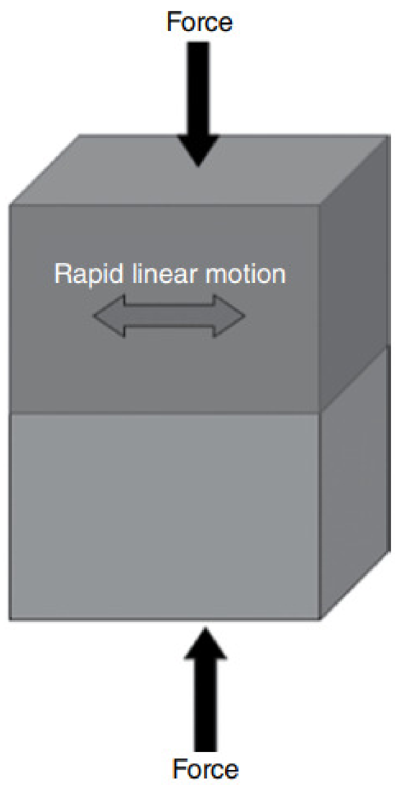


Figure 1: Linear Friction Welding (research gate)

Friction Stir Welding

The British Welding Institute (TWI) invented the innovative new friction welding technique known as friction stir welding (FSW) in the early 1990s. While FSW creates solid-state friction welds using traditional arc weld joint designs like butt joints, processes like Inertia and Continuous Drive Friction Welding are generally restricted to spherical objects. When a specially made non-consumable pin tool is spun along the joint against the top of the two components being welded, frictional heat is produced as a result. Frictional heating causes the metal at the joint to soften (or plasticize) at the start of the process, making it easier for the plasticized metal to be stirred. As the weld progresses, additional heat produced by the plastic deformation takes over as the primary source of heating.The shoulder and pin that make up the FSW pin tool. The majority of the frictional heating is produced by the shoulder, which is resting on the plates' surface. The pin partially pierces the weldment between the plates. The plasticized hot metal flows around the pin to create a weld within the stir zone itself. The pin's main function is to regulate the stirring process.

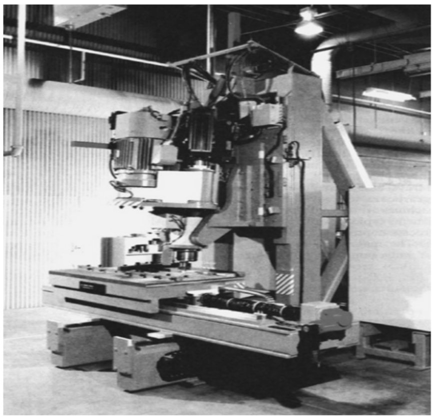


Figure 2: Friction Stir Welding.

The usage of tungsten-based materials, threaded pins, and cupped shoulders are just a few of the pin tool designs and materials that have been researched. Travel speeds are substantially slower than usual arc welding speeds, and a very tiny push angle (5°) is occasionally utilized. huge and extremely rigidly constructed, FSW machines typically have a huge size. The number of applications for this method is expanding; one well-known example is the welded seam of the primary fuel tank of aluminium alloy on the Space Shuttle. Rockets (launch vehicles) and automobile sheet connectors are among further uses.

The stir zone designates the area where there is a significant amount of metal flow or stirring as a result of tool rotation. Dynamic recrystallization, a process where heating and plastic deformation combine to continuously produce very thin grains, is how this happens. The stir zone's related fine grain structure produces exceptional mechanical characteristics. Better as-welded tensile characteristics of aluminium weldments compared to arc welding are one of the main benefits of this method, principally because the fine-grained stir zone is produced. Since the relative velocity of the stirring material will be higher in the direction of weld travel, the stir zone microstructure is likely to differ from one side to the other. The major stir zone is surrounded by a narrow region known as the heat and deformation-affected zone (HDAZ), which shows minor deformation that happens at high welding temperatures. Only the heat flow out of the weld has an impact on the heat-affected zone (HAZ). This region experiences metallurgical reactions that are nearly equivalent to those in a fusion weld.

This method requires a material to flow at a high temperature in order to successfully weld a material. Consequently, it is possible to determine a material's FSW properties using the flow stress as a function of temperature. In general, FSW can weld materials more readily the faster the flow stress decreases with rising temperature. Due to its reduced flow stress in the stir zone temperature range, Alloy A should be significantly simpler to weld in the case than Alloy B. Increased stirring temperatures also have an impact on tool wear, a crucial factor in this process.For adequate metal flow to happen while welding aluminium alloys, temperatures above 450°C (840°F) are required. Temperatures more than 1200°C (2190°F) are necessary for steels. The use of tool steels for the pin tool during the early stages of FSW development prevented it from being used on metals other than aluminium. But because to recent advancements in higher temperature pin tools, metals like steel and titanium may now be successfully welded while maintaining a respectable tool life.The benefits and drawbacks of friction welding procedures are listed in conclusion.

Advantages

1. No melting means no chance for solidification‐related defects
2. Filler materials are not needed

3. Very few process variables result in a very repeatable process
4. Can be used in a production environment (mainly the Continuous Drive Friction Welding process)
5. Fine grain structure of friction welds typically exhibits excellent mechanical properties relative to the base metal, especially when welding aluminum
6. No special joint preparation or welding skill required

Limitations

1. Equipment is very expensive
2. Limited joint designs, and in the case of Continuous Drive and Inertia Friction Welding, part, must be symmetric
3. FSW is very slow, and not conducive to high□speed production

Diffusion Welding

Diffusion welding is a solid-state welding technique that uses pressure and heat in conjunction with diffusion to forge welds. It typically takes a lot of time (up to an hour) and high temperatures, and it's normally done in a protective environment,to keep the welding interface from oxidising. A significant enough pressure is applied to the interface to result in some local deformation. During this procedure, a vacuum hot press is frequently employed.Due to the fact that the maximum temperatures are frequently much lower than typical fusion welding temperatures, this method has the advantage of little deterioration of the base metal microstructure. Surface preparation is a key component of diffusion welding, which removes obstacles to solid-state welding. Due to its propensity to easily dissolve its own oxide, titanium is a good candidate for this technique. As a result, titanium aircraft parts used in military aircraft are a typical application for Diffusion Welding.

Heat treatment lowers the material's yield strength, and moderate general pressure will produce local pressures that are high enough to plastically bend the asperity peaks and produce the necessary close contact. After the initial contact is formed, according to AWS, the complete diffusion welding procedure entails three steps. A border between the asperities arises as personal touch is made possible. Similar to a grain boundary, the interfacial boundary reduces its free energy throughout the Diffusion Welding cycle by migrating into the surrounding microstructure. Although the formation of pores is a potential, there will typically be little sign of a bond line after the weld is finished. Diffusion welding can be challenging for some metals, like nickel, hence a related technique called diffusion brazing is frequently employed [9]–[11].

CONCLUSION

To sum up, solid-state welding techniques offer important benefits for attaching materials without completely melting them. Friction welding, diffusion bonding, and ultrasonic welding are just a few of the procedures that make it possible to unite materials that aren't compatible with one another while also minimizing distortion and enhancing mechanical characteristics. They are used in a variety of sectors, including as electronics, automotive, and aerospace. Solid-state welding techniques are constantly improving, allowing for the creation of welds that are dependable, high-quality, and environmentally sustainable. Intimate contact between the pieces is necessary to obtain enough dispersion to produce a weld. Prior to welding, smooth surfaces are created and the majority of the oxides and impurities are eliminated using surface preparation processes, which commonly combine metal machining or grinding with chemical etching. But as no industrial machining method can produce complete smoothness and cleanliness, there will still be some localised asperity peaks and valleys and oxides to get rid of when the pieces are put together.

REFERENCES

[1] A. Nassiri, T. Abke, and G. Daehn, "Investigation of melting phenomena in solid-state welding processes," *Scr. Mater.*, 2019, doi: 10.1016/j.scriptamat.2019.04.021.

[2] A. Verma, B. Kotteswaran, A. C. Abhyankar, and T. Shanmugasundaram, "Microstructure and Mechanical Properties of AA7005 Alloy Joint by Fusion and Solid-State Welding Processes," *Trans. Indian Inst. Met.*, 2020, doi: 10.1007/s12666-020-01917-9.

[3] J. Guo, "solid state welding processes in manufacturing," in *HandBook of Manufacturing Engineering and Technology*, 2015. doi: 10.1007/978-1-4471-4670-4_55.

[4] D. R. Cooper and J. M. Allwood, "Influence of diffusion mechanisms in aluminium solid-state welding processes," 2014. doi: 10.1016/j.proeng.2014.10.300.

[5] S. Ragu Nathan, V. Balasubramanian, S. Malarvizhi, and A. G. Rao, "Effect of welding processes on mechanical and microstructural characteristics of high strength low alloy naval grade steel joints," *Def. Technol.*, 2015, doi: 10.1016/j.dt.2015.06.001.

[6] H. Wang and Y. Wang, "High-velocity impact welding process: A review," *Metals*. 2019. doi: 10.3390/met9020144.

[7] T. F. Kong, L. C. Chan, and T. C. Lee, "Qualitative study of bimetallic joints produced by solid state welding process," *Sci. Technol. Weld. Join.*, 2008, doi: 10.1179/174329308X383757.

[8] R. Sivasubramani, A. Verma, G. Rithvik, U. Chadha, and S. Senthil Kumaran, "Influence on nonhomogeneous microstructure formation and its role on tensile and fatigue performance of duplex stainless steel by a solid-state welding process," 2021. doi: 10.1016/j.matpr.2020.12.983.

[9] L. Peng, Z. Xu, and X. Lai, "An investigation of electrical-assisted solid-state welding/bonding process for thin metallic sheets: Experiments and modeling," *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, 2014, doi: 10.1177/0954405413506193.

[10] H. Kreye, "Melting Phenomena In Solid State Welding Processes," *Weld. J. (Miami, Fla)*, 1977.

[11] E. Hoyos and M. C. Serna, "Basic tool design guidelines for friction stir welding of aluminum alloys," *Metals (Basel).*, 2021, doi: 10.3390/met11122042.

CHAPTER 19

WELDING METALLURGY OF STAINLESS STEELS

Mr. Ranveer Singh, Associate Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id: ranveer@jnujaipur.ac.in

ABSTRACT:
An outline of welding metallurgy with an emphasis on stainless steels is given in this abstract. It discusses important issues surrounding welding stainless steels, such as metallurgical modifications, difficulties, and considerations.The introduction of the abstract emphasizes the value of stainless steels as widely utilized materials in numerous industries because of their superior corrosion resistance qualities.The creation of the fusion zone, the heat-affected zone (HAZ), and base metal conversions are some of the metallurgical changes that take place during the welding of stainless steels. It places a strong emphasis on how welding parameters, such heat input and cooling rate, might affect the final microstructure and characteristics, with a focus on preventing chromium carbide precipitation and maintaining corrosion resistance.

KEYWORDS

Stainless Steel Material, Fusion Area, Phases of Intermetallic, Sensitization, Cooling Speed.

INTRODUCTION

A large family of iron-based alloys with at least 12% chromium by volume are known as stainless steels. These alloys get their stainless and corrosion-resistant properties from the chromium addition, which creates an incredibly thin but stable and continuous chromium-rich oxide coating. Qualities that resist rusting. Although they may contain additional alloying additives that change their microstructures or characteristics, they are based on the iron-chromium, iron-chromium-carbon, and iron-chromium-nickel systems. Depending on the alloy, they offer a variety of strength and ductility in addition to resistance to oxidation at high temperatures and discolouration. Stainless steels are employed in numerous settings and for a wide range of applications. These range from the pulp and paper industry and electricity generation to everyday domestic items like washing machines and kitchen sinks [1]–[3].

Generally speaking, stainless steels are divided into five different alloy families and are categorized based on the phase that predominates in the microstructure. Martensitic, ferritic, austenitic, duplex, and precipitation-hardened (sometimes known as "PH" stainless steels) are the five families of stainless steels. While PH stainless steels can be either martensitic or austenitic, Duplex stainless steels are composed of a roughly equal amount of ferrite and austenite. Stainless steels are identified by the American Iron and Steel Institute (AISI) using a system based on three digits, occasionally followed by a letter. 304, 304L, 410, and 430 are typical examples.

Since Cr is the main alloying element, the iron-chromium phase diagram (Figure 1) serves as the foundation for stainless steels. Keep in mind that all Fe–Cr alloys solidify as ferrite at high temperatures due to the total solubility of Cr in iron. The "gamma loop" is a "loop" of austenite that forms at low chromium concentrations. At high temperatures, alloys containing more than around 13% Cr will be totally ferritic, whilst those containing less will develop austenite inside the gamma loop. This austenite can change into martensite after cooling. Strong austenite stabilising agents like carbon have the effect of enlarging the gamma loop in the iron-chromium diagram.

A key distinction between ferritic and martensitic stainless steels is represented by the gamma loop. Low carbon content in ferritic stainless steels prevents them from entering the gamma loop, leading to a microstructure that is mostly ferritic. Contrarily, martensitic stainless steels have increased carbon content, which widens the gamma loop and promotes the development of austenite, which readily converts to marten site when cooled.

The phase diagram shows that the Fe–Cr system also exhibits a low temperature equilibrium phase known as the sigma phase. Due to the FeCr stoichiometry of this phase, high Cr alloys are where it is most likely to occur. Sigma phase development typically occurs over a long period of time and at temperatures between 500 and 700 °C (930 and 1300 °F). Sigma phase is hard and brittle, hence it is typically undesirable to have it present in stainless steels. Since its development requires time, it typically isn't a welding issue and instead serves as a service temperature restriction. Another embrittling phase that arises at slightly lower temperatures is alpha prime [4]–[6].

History Of Welding Metallurgy Of Stainless Steels In Shortly:

Stainless steel welding technology has advanced significantly since its inception at the beginning of the 20th century. Here is a brief synopsis of the background:

Early Development: In the early 20th century, research on the weldability of stainless steels was sparked by the discovery of these materials and their exceptional abilities to resist corrosion. During welding, issues including hot cracking and embrittlement were noted.

World War II and the Post-War Era: - During World War II, the military's need for stainless steel boosted research into welding methods and metallurgical issues. The emphasis was on improving welding procedures and cutting down on flaws.In the post-World War II era, in-depth research was done on the metallurgical modifications that stainless steel welds underwent, such as the production of chromium carbides and sensitization. To address these problems, efforts were made to create appropriate welding consumables.

Development of advanced welding methods, such as gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW), in the late 20th century gave stainless steel welders better control over heat input and weld quality.The development of computational modelling, non-destructive testing, and characterization techniques allowed for a greater comprehension of the metallurgy of stainless steel welds and improved process optimisation. - Technology and Metallurgy Integration.

Contemporary Developments: - Research in Progress: The goal of ongoing research is to improve stainless steels' weldability and performance through alloy design, welding parameter optimisation, and the creation of novel welding processes. Sensitization reduction, intermetallic phase formation prevention, and corrosion resistance improvement in welded joints are all given special consideration.Along with improvements in welding technology and a greater understanding of metallurgical phenomena, the history of welding metallurgy of stainless steels has changed over time. The demand for high-quality stainless-steel welds with enhanced mechanical characteristics and corrosion resistance is now driving the field's advancement.

DISCUSSION

Constitution Diagrams

Stainless steels employ "constitution" diagrams, whereas carbon steels depend on the iron-iron carbide and CCT diagrams for forecasting weld microstructures. Based on the kind and quantity of different alloying components, a constitution diagram forecasts the microstructure of the stainless steel. There are many different constitution diagrams that have been created over the years, but the Schaeffler is one of the most widely used ones that is still in use today. Diagrams of the constitution are based on calculations for the stabilising components of austenite.

On the vertical axis, ferrite stabilising components are represented by (nickel equivalency formula) and on the horizontal axis, by (chromium equivalency formula). Because nickel is the predominate austenite stabiliser and chromium is the predominate ferrite stabiliser, these formulas are known as nickel and chromium equivalency formulas. The alloying components and appropriate multiplication factors used in the equivalency formulas make them "equivalent" to either nickel or chromium in terms of their ability to stabilise phases. The variety of stainless steel compositions they can be utilised for and their equivalency formulas are the key variations between the numerous constitution diagrams that are available [7], [8].

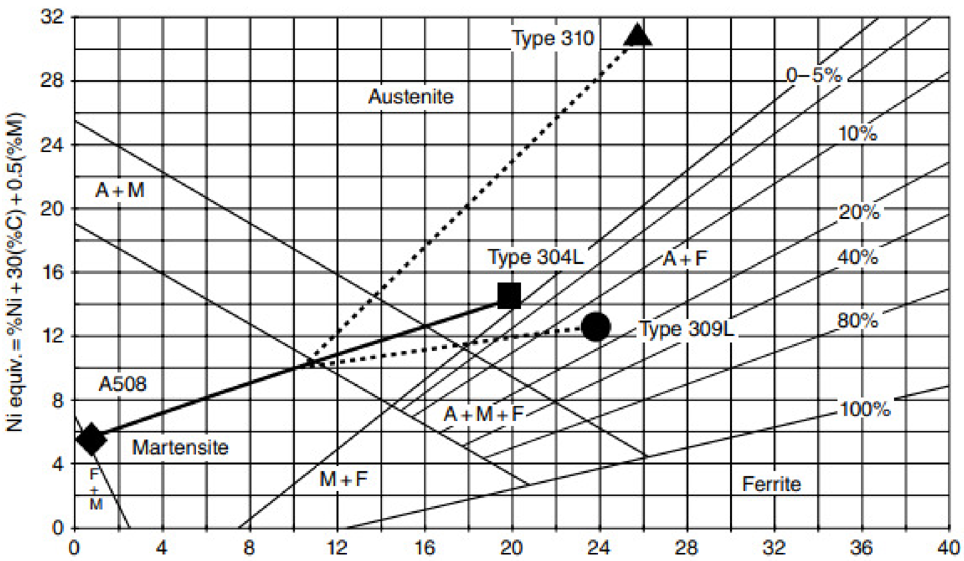


Figure 1: Constitution Diagrams (research gate)

Nickel and chromium equivalency calculations for the base metal and filler metal can be made, and the two points plotted on the diagram, in order to forecast weld microstructures. The expected weld metal microstructure will therefore lie somewhere along the line and will simply depend on how much the base metal has diluted the weld filler metal. A tie line is then drawn between the two spots. For instance, the predicted weld metal microstructure would lie along the tie line at a position 25% of the length of the line closest to the weld metal composition if the base metal dilution was 25%. When welding some stainless steels, the base metal's dilution of the filler metal is frequently a crucial factor to take into account. The sensitivity to solidification cracking, which is covered later in this chapter, is known to increase with high base metal dilution in austenitic stainless steels.

The Schaeffler diagram, in comparison to all other constitution diagrams, is helpful in figuring out the "big picture" for stainless steel weld microstructures since a wide range of nickel and chromium equivalency is covered. Since stainless steels and low alloy steels can both be plotted on the diagram, it is also the best diagram for predicting weld microstructures in a dissimilar metal weld between stainless and carbon steels. Tie lines can also be utilised to forecast the microstructures of different metal welds. In the illustration, either a Type 309L (round symbol) or Type 310 (triangular symbol) filler metal is being used to weld a low alloy steel, such as A508 (diamond symbol), to Type 304L (square symbols).

Tie lines can be drawn from the filler metals to the centre of the tie line between the two base metals, presuming equal mixing of the two base metals. The expected weld metal composition will then be distributed along the tie line that runs from the base metal's centre to each filler metal. Be aware that a two phase, austenite+ferrite structure will develop from a modest dilution of the filler metal by the base metal in the 309L composition. The weld deposit made with Type 310 filler metal will almost definitely be entirely austenitic.

The microstructure in the transition zone at the fusion boundary can also be predicted using the tie line between the filler metal composition and the base metal tie line. For instance, the martensite, austenite+martensite, and austenite+ferrite regions are all cut by the tie line to Type 309L. One can anticipate finding all of these microstructures in a little space between the base metal HAZ and the fully mixed weld metal. In conclusion, constitution diagrams are an effective tool for predicting the microstructure of stainless-steel welds and, consequently, for foreseeing future weldability issues. For instance, a totally austenitic microstructure will be far more vulnerable to weld solidification cracking than one that contains 5–10% ferrite, as will be detailed later in this chapter.

Martensitic Stainless Steels:

The Fe, Cr, and C ternary system is the foundation for martensitic stainless steels. They have high levels of carbon (0.1-0.25% for most alloys, but up to 1.2% for cutlery grades) and relatively low levels of chromium (12-18%). They go through an allotropic transformation into austenite, which they then use to create martensite. When analysing these alloys, CCT diagrams are not necessary since martensite occurs readily, even at relatively modest cooling rates. They could also have traces of ferrite and carbides in addition to the dominant martensite phase.

With martensitic stainless steels, a wide range of strengths are possible. Yield strengths are available for high carbon grades and can range from 40 ksi (275MPa) in an annealed condition to 280 ksi (1900MPa) in a quenched and tempered condition. In order to produce these steels with the necessary toughness and ductility for the majority of technical applications, tempering is necessary. It is also possible to reach high hardness levels, which helps with abrasion resistance.Due to the relatively low chromium content of the majority of alloys, martensitic stainless steels generally do not have as excellent corrosion resistance as the other grades. These alloys are typically chosen for uses where a balance between strength and corrosion resistance is needed.

The martensitic stainless steels are also less expensive than many other stainless steels due to their low chromium concentration (for most grades) and alloying element content.Steam pipes, gas and jet engine turbine blades, and martensitic stainless steel are just a few of the common uses for these materials. Knives, gears, and shafts are among the products made from the high chromium, high carbon grades. Martensitic stainless steels degrade in mechanical characteristics and corrosion resistance over 650°C (1200°F), hence they are not used above that temperature. At these temperatures, they will also start to revert to austenite. The postweld temper heat treatment is almost always necessary for martensitic stainless steels because cooling after welding causes the development of untempered martensite. They are therefore typically regarded as being the most challenging stainless steels to weld.

The martensitic stainless steels, especially those with higher carbon content, may be vulnerable to hydrogen-induced cracking because untempered martensite is prone to occur during welding. When welding these alloys, preheat, interpass temperature control, and low-hydrogen welding procedures are typically advised in addition to a postweld temper. Some of these steels have the potential to experience reheat cracking during a postweld heat treatment. When carbides develop within the grains following a postweld heat treatment, reheat cracking results. In comparison to the grain boundaries, this makes the grain interiors stronger. The simultaneous occurrence of stress relaxation and heating causes substantial strain concentration along grain boundaries, which encourages cracking. Reheat cracking may also happen during multipass welding as the earlier passes are heated into the temperature range for carbide precipitation. Impurities like sulphur, phosphorus, antimony, tin, boron, and copper, as well as molybdenum, have all been linked to reheat cracking in these steels.Iron-based stainless steels

Ferritic Stainless Steels

Fe–Cr alloys with enough chromium and minimal carbon to prevent much austenite from forming at high temperatures, leading to a microstructure that is predominantly ferrite. These alloys come in a wide range of chromium concentrations, and corrosion resistance rises as chromium content does. Typically, ferritic stainless steels are used when mechanical characteristics are less significant than corrosion resistance. The most affordable stainless steels are often those with low chromium content (11–12% by weight or less).

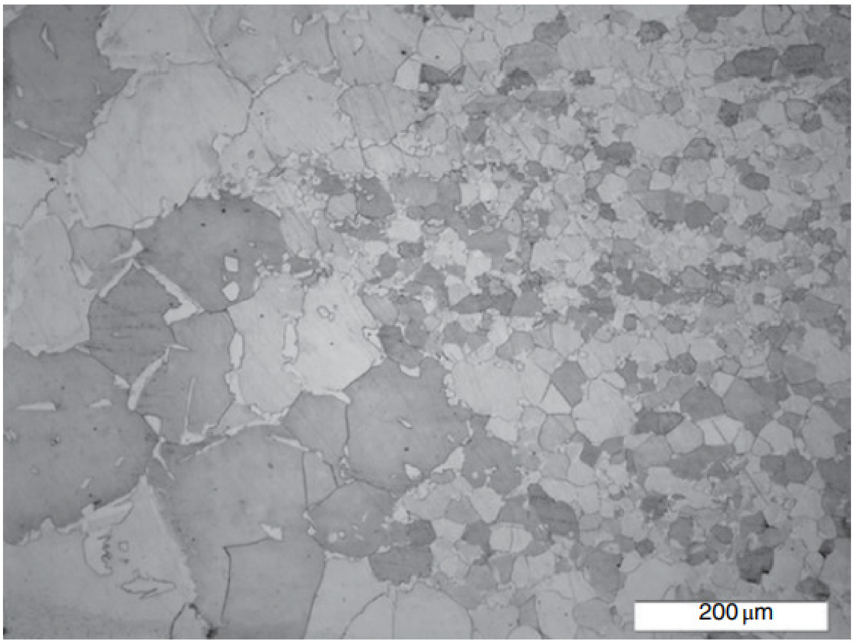


Figure 2: Ferritic Stainless Steels.

Ferritic stainless steels are not transformation hardenable because, up until the melting point, they are basically a single phase alloy. Due to their body-centered cubic crystal structure, they display a ductile-to-brittle transition temperature (DBTT), which is similar to that of carbon steels. They also have poor toughness at low temperatures. These steels cannot be used in low temperature service due to their transition behaviour, despite service temperatures reaching up to 400°C (750°F). These alloys may become brittle at temperatures above 400 °C as a result of the production of the alpha-prime or sigma phases (see the Fe-Cr diagram in Figure 2). However, these phases rarely present issues when welding since they form so slowly.

In non-welding applications, ferritic stainless steels have traditionally been employed in greater quantities. For instance, the medium chromium grades are widely employed in ornamental and architectural applications such as vehicle trim. The usage of low and medium chromium grades for welded vehicle exhaust systems has significantly increased over the last 20 years or so. As a result, it is no longer necessary to regularly repair automotive exhaust systems, which were previously made of carbon steel and deteriorated very quickly.Exhaust tube made of low-chromium 409 stainless steel, which is frequently welded employing high-frequency resistance welding, is a typical example of modern practise.

For usage in demanding environments like chemical plants, pulp and paper mills, and refineries, a number of high-Cr grades have been created. Comparing these alloys to the austenitic and martensitic grades, they have better corrosion resistance. However, they are challenging to make and relatively expensive. It has been extensively studied whether alloys with more than 25% chromium are weldable. Because ferritic stainless steels are single phase at high temperatures, grain development during welding can happen relatively quickly, causing ductility and toughness to decline. Ferritic stainless steels are known to lose ductility and hardness during welding as a result. The issue is exacerbated by rising levels of carbon, chromium, nitrogen, and impure elements. The use of minimal preheat temperatures and low heat input during welding are two welding techniques. Niobium and titanium may be added to regulate the nitrogen and carbon. Additionally, significant grain growth may occur in multipass weldments, causing the HAZ and weld metal's mechanical characteristics to deteriorate.Although the majority of these alloys are ferritic, some alloys (such 430) may generate a tiny amount of grain boundary martensite because the gamma loop (austenite) cannot be fully avoided during cooling. As a result, these alloys might be prone to hydrogen cracking, necessitating the adoption of low hydrogen procedures and perhaps the requirement for a postweld heat treatment.

Austenitic Stainless Steels

The most common type of stainless steel and the grade that is produced in the greatest volume is austenitic stainless steel. These steels have predominantly austenite microstructures with traces of ferrite. They have strengths comparable to mild steels and display excellent corrosion resistance in the majority of situations. Due to the higher alloy concentration of these alloys, austenitic stainless steels are more expensive than martensitic and the majority of ferritic grades while still offering a fair mix of toughness and ductility. They are not transformation hardenable because they contain metals like nickel that stabilise austenite at ambient temperature. Their low temperature impact properties are quite good due to a face-centered cubic crystal structure, making them suitable for cryogenic applications. High service temperatures of up to 760°C (1400°F) are possible. They are more expensive than other stainless steels, but they also have numerous significant engineering advantages over those steels, such as corrosion resistance, high temperature performance, formability, and weldability (where the right methods are followed).

These steels include significant amounts of nickel and other austenite-stabilizing elements. They have a nickel content of 8 to 20% and a chromium content of 16 to 25%. With carbon concentrations between 0.02 and 0.08%, they are comparatively low. The several nickel equivalency calculations show that, in addition to nickel, nitrogen and copper are potent austenite stabilising components. Additionally, nitrogen may be used to dramatically increase strength. Alloys that have been reinforced by nitrogen are typically identified by adding the suffix N to their AISI designation (for example, 304LN), or by different brand names like Nitronic. The variety of uses for austenitic stainless steels, which include pressure tanks, architectural, kitchen equipment, structural support, and containment. For applications like heat treatment baskets, some of the most heavily alloyed grades are employed in very high temperature usage. Although austenitic stainless steels are generally quite resistant to corrosion, it should be noted that they cannot be used in conditions with high concentrations of caustic or chloride, such as seawater. This is because base metal, HAZ, and weld metal are more susceptible to the process known as stress corrosion cracking. When choosing stainless steels that will be put under a lot of stress in these situations, caution should be used.

Even though austenitic alloys are typically thought to be very weldable, if necessary measures are not taken, they are susceptible to a number of weldability issues. One of the main issues is weld solidification cracking, especially with alloys that solidify as 100% austenite. Although these alloys have strong overall corrosion resistance, they may nevertheless be vulnerable to localised forms of corrosion along grain boundaries in the HAZ or at stress concentrations in and around the weld.Other weldability issues such reheat cracking, ductility dip cracking, HAZ liquid cracking, and copper contamination cracking are possible but less frequent. The use of filler metals that encourage the production of weld metal ferrite is a standard method for preventing solidification cracking, therefore intermediate temperature embrittlement caused by sigma phase formation is also a concern. The sigma phase precipitation reaction is generally slow, similar to ferritic stainless steels, and is typically a service issue rather than a welding one. Austenitic stainless steels are known to induce substantial distortion when welded because of their extremely high coefficient of thermal expansion.

Solidification cracking, which happens when liquid-containing solidification grain boundaries tear apart as the weld cools and shrinks during the latter stages of weld solidification, is one of the main weldability issues with austenitic stainless steels, as was previously discussed. According to the plot of cracking susceptibility vs Creq/Nieq ratio, the likelihood of solidification cracking is a significant effect of composition. The equivalency formulas used to generate this ratio, which establishes the proportions of ferrite (Creq) and austenite (Nieq) stabilising components, are the same formulas used for the constitution diagrams. The different letters on the map, which range from totally austenitic (A) to fully ferritic (F), reflect different weld solidification modes. It should be noted that the FA mode gives the most resistance to solidification cracking, whereas compositions that lead to primary austenite solidification (A and AF) are most vulnerable to it.The reason for this is because the presence of a two phase (ferrite+austenite) microstructure at the conclusion of solidification resists wetting along solidification grain boundaries, hence limiting the area of the liquified grain borders that are susceptible to cracking.With austenitic stainless steels, filler metal selection can be a very efficient method of reducing weld solidification cracking. Utilising filler metals with sufficient ferrite-stabilizing elements to support the FA solidification mode is a common strategy. Weld metal ferrite levels of at least 5–10% are typically thought to be considered to be resistant to cracking on a typical constitution diagram like the Schaeffler diagram previously showed.

The Welding Research Council has developed a more contemporary design known as the WRC1992 diagram since the release of the Schaeffler diagram, which covers a wide range of compositions.This diagram is substantially more reliable for forecasting the solidification modes of austenitic and duplex stainless steels (described next) since it covers a smaller range of compositions. It is now widely acknowledged on a global scale as a useful tool for estimating solidification cracking susceptibility. High levels of impurities including phosphorus, boron, and sulphur, quick travel rates that favour a teardrop-shaped weld rather than an elliptical one, and high weld constraint are additional characteristics that make solidification cracking more likely to occur.Sensitization is another typical weldability issue with austenitic stainless steels that is known to cause a considerable decrease in corrosion resistance in the HAZ. Chromium and carbon interact to generate carbides (Cr23C6) along grain boundaries in a small area of the HAZ heated to temperatures ranging from 600 to 850C (1110 to 1560F). The carbides produced during heating are dissolved at temperatures above this range, while precipitation of carbides is not possible at temperatures below this range. As a result, carbide formation occurs in a very small area [9]–[11].

CONCLUSION

In conclusion, the desire for high-quality welds with exceptional corrosion resistance has led to substantial advancements in the welding metallurgy of stainless steels over time. Early investigations into weldability, difficulties with hot cracking and embrittlement, and developments during and after World War II are all part of the history of welding metallurgy of stainless steels. Our understanding of the metallurgical processes taking place in stainless steel welds has been significantly improved by the integration of technology and metallurgy, such as computer modelling and characterization tools. Current research focuses on enhancing corrosion resistance in welded connections, regulating sensitization and intermetallic phase development, and optimising welding procedures. To fulfil the growing demand for dependable and long-lasting stainless-steel welding across a variety of industries, the field is still evolving.

REFERENCES

[1] P. Ferro and J. O. Nilsson, "Welding metallurgy of stainless steels," in *Handbook of Welding: Processes, Control and Simulation*, 2021. doi: 10.22486/iwj.v2i2.150282.

[2] J. Lippold, "Welding metallurgy and weldability of stainless steels," *Choice Rev. Online*, 2005, doi: 10.5860/choice.43-2230.

[3] W. Reitz, "A Review of: 'Welding Metallurgy and Weldability of Stainless Steel,'" *Mater. Manuf. Process.*, 2006, doi: 10.1080/10426910500476747.

[4] R. Fenn, "Welding Metallurgy Of Stainless Steel.," *Weld. Met. Fabr.*, 1987.

[5] M. Alizadeh-Sh, M. Pouranvari, and S. P. H. Marashi, "Welding metallurgy of stainless steels during resistance spot welding part II –heat affected zone and mechanical performance," *Sci. Technol. Weld. Join.*, 2015, doi: 10.1179/1362171815Y.0000000010.

[6] M. Pouranvari, M. Alizadeh-Sh, and S. P. H. Marashi, "Welding metallurgy of stainless steels during resistance spot welding part I: Fusion zone," *Sci. Technol. Weld. Join.*, 2015, doi: 10.1179/1362171815Y.0000000015.

[7] H. Ikawa, "Welding metallurgy of austenitic stainless steel," *Yosetsu Gakkai Shi/Journal Japan Weld. Soc.*, 1972, doi: 10.2207/qjjws1943.41.115.

[8] Subba Rao Ps, "Welding Metallurgy Of Stainless Steels," *Indian Weld J*, 1970.

[9] S. H. Arabi, M. Pouranvari, and M. Movahedi, "Welding metallurgy of duplex stainless steel during resistance spot welding," *Weld. J.*, 2017.

[10] G. R. Mohammed, M. Ishak, S. N. Aqida, and H. A. Abdulhadi, "Effects of heat input on microstructure, corrosion and mechanical characteristics of welded austenitic and duplex stainless steels: A review," *Metals*. 2017. doi: 10.3390/met7020039.

[11] M. Alizadeh-Sh, S. P. H. Marashi, and M. Pouranvari, "Resistance spot welding of AISI 430 ferritic stainless steel: Phase transformations and mechanical properties," *Mater. Des.*, 2014, doi: 10.1016/j.matdes.2013.11.022.

CHAPTER 20

APPLICATION OF THE WELDING METALLURGY

Mr. Robin Khandelwal, Assistant Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id:robinkh16@jnujaipur.ac.in

ABSTRACT:

In this abstract, welding metallurgy is briefly summarised. It discusses how crucial welding metallurgy knowledge is to producing high-quality welded joints. It talks about various welding techniques and how they affect metallurgical changes. It also emphasises important elements affecting metallurgical adjustments made during welding. The manufacturing and joining of metallic materials, which allows for the development of intricate structures and components, is greatly aided by welding metallurgy. This area of research focuses on the interactions between heat, filler material, and the base metal as they relate to the metallurgical features of the welding process. Engineers and welders can choose the best filler materials, optimize welding conditions, and guarantee the desired mechanical qualities of the welded junction by being aware of the underlying metallurgical processes. The abstract underlines the necessity of having a thorough understanding of the metallurgical changes that take place during welding and underscores the significance of welding metallurgy in the fabrication process. Welders can manage the microstructure, mechanical characteristics, and overall performance of the weld joint by analyzing the impacts of heat input, cooling rates, and filler material selection. The integrity and dependability of welded structures in a variety of industries, including the automotive, aerospace, building, and industrial sectors, depend heavily on this understanding.

KEYWORDS:

Consolidation, Fusion Zone, Grain Expansion, Microstructure, Persisting Tensions, The Heat-Affected Zone.

INTRODUCTION

The intricate microcosm of metallurgical reactions that can take place inside and around a weld during the quick heating and cooling cycles connected to the majority of welding procedures is referred to as welding metallurgy. Many of the existing basic metallurgical principles either cannot be used to welding since it always takes place under nonequilibrium conditions, where diffusion is frequently constrained only serve as an approximation of metallurgical behaviour when applied. As a result, a body of science called welding metallurgy has developed to explain the evolution of the microstructure and related properties of welds. Welding metallurgy is complicated because, depending on the metal being welded, how it was produced, and the welding procedure being employed, a single weld can entail a wide range of metallurgical processes. Understanding the metallurgical processes involved is crucial since they have a direct impact on the microstructure that is formed, which in turn affects the joint's eventual mechanical qualities. The majority of the time, the microstructural alterations brought on by welding cause the characteristics of the base metal to deteriorate [1]–[3].

Since they are essential to producing a good connection when using fusion welding methods, melting and solidification are significant processes. Dendrite nucleation and growth, segregation, and diffusion processesall of which are connected to solidification—lead to local compositional changes. Such compositional changes may affect performance in service and cause welding issues.Numerous metallurgical processes, such as phase changes, diffusion, precipitation reactions, recrystallization, and grain development, take place in the solid state. Cracking issues might arise from liquidation reactions, in which liquid films may form outside the fusion zone. Some or all of these procedures may contribute to the formation of the weld heat-affected zone (HAZ), depending on the metal being welded. The intensity of these reactions may substantially change the microstructure and welding characteristics in relation to the base metal.

Weld embrittlement is a potential outcome of many of these events, or combinations of reactions. It is crucial to first comprehend the microstructure formed during welding in order to predict and comprehend the mechanical properties of a weldment and how it will function in service. Understanding the base metal microstructure, how it was processed, and the sort of welding process being utilized is crucial before one can fully comprehend the microstructure. For instance, transformation hardening, in which martensite, a hard microstructure, is purposefully generated, can strengthen steel by altering its characteristics through a tempering heat treatment. It is quite possible that un-tempered martensite will form during the welding process of such a steel, which may result in cracking and/or a reduction in ductility and toughness. Martensite may occur more frequently during high energy density welding procedures like laser welding as opposed to submerged arc welding, which is noted for its high heat input and sluggish cooling rates. A precipitation hardening-enhanced aluminium alloy may be vulnerable to significant softening in the HAZ due to an overaging reaction. Due to its low heat input, a high energy density welding method like laser welding may be advantageous in this situation.

Fusion zone, which comprises of the composite zone (CZ) and unmixed zone (UMZ), and heat-affected zone, which consists of the partially melted and true heat-affected zone or HAZ, are terms used to characterize the areas of a fusion weld. The terminology used to describe these hasn't changed much since 1976, but a lot of work has been done to confirm the validity of these regions using a range of alloy systems. This initial terminology has undergone further elaboration. The actual HAZ in steels, for instance, has been broken down into a number of sub-regions, including the coarse-grained HAZ, the fine-grained HAZ, and the intercritical region (when peak temperatures exceed the alpha ferrite + austenite phase field). In welds between stainless steel and low alloy steel, for example, martensite may form in the transition zone even though it does not occur elsewhere in the weld, creating transition zones.

History Of Welding Metallurgy

Early civilizations found ways to combine metals, and this led to the development of welding metallurgy. But it wasn't until the 19th century that welding metallurgy was systematically studied as a scientific field. The history of welding metallurgy is described in the following detail:Early Development (Cretaceous Period to Eighteenth Century): Forge welding: Heating metals and pounding them together was the earliest known form of welding. Blacksmiths in ancient societies including the Egyptians, Greeks, and Romans used this technique.

Brazing and soldering: These techniques were created and used to unite metals. They both use a filler material having a lower melting point. Early scientific studies: In the 18th century, researchers like Alessandro Volta and Benjamin Franklin made the first observations of how metals behaved during welding processes.The Development of Science in the Nineteenth

Century:Electric arc welding experiments were carried out by Sir Humphry Davy at the beginning of the 19th century, establishing the groundwork for contemporary arc welding methods. Developments in metalworking: The development of welding processes and the requirement to comprehend their metallurgical behaviour were sparked by the discovery of new metals and alloys, such as steel and aluminium.Researchers like Michael Faraday and James Joule investigated the temperature gradients, phase transitions, and microstructural alterations caused by heat on metals.Industrial Development and World Wars in the 20th Century: World War I: As a result of the need for quick and effective joining methods, welding technology advanced during the conflict. The goal of metallurgical research was to comprehend how welding affects the characteristics of materials. World War II: During the conflict, welding was a crucial part in producing weapons. The investigation of novel welding materials, procedures, and quality control techniques expanded.Post-war industrial expansion: The need for welding metallurgical research increased as a result of the post-war era's tremendous industrial growth. Universities, research facilities, and commercial enterprises started carrying out in-depth studies in the area.

Modern Developments (Last Decade to the Present):Creation of new welding techniques: In the second half of the 20th century, sophisticated welding techniques such as gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), and laser welding came into being. These procedures created fresh metallurgical problems and study opportunities. Microstructural examination the development of electron microscopy and other cutting-edge characterization methods made it possible to thoroughly examine the microstructural changes that take place during welding. Materials science integration: In order to comprehend and improve welding processes, welding metallurgy began incorporating ideas from materials science, such as alloy design, phase diagrams, and thermodynamics [4]–[6].Due to improvements in technology, materials, and the desire for welded structures with improved quality and performance, welding metallurgy is still evolving today. The development of new joining procedures and the optimisation of welding parameters are among the current research's main topics of interest.

DISCUSSION

The Fusion Zone

The area of a fusion weld where full melting and resolidification occur during the welding process is known as the fusion zone. Typically, it is metallographically distinct from the base metal and HAZ around it. The alloy composition and the solidification conditions affect the microstructure in the fusion zone. For instance, high cooling rates will lead to a finer fusion zone microstructure and more rapid solidification. Three areas may theoretically arise in welds where the filler metal has a different composition than the base metal. The CZ, which is made of base metal that has been fused with filler metal to dilute it, is the largest of them. Two more zones could occur close to the fusion border [7]–[9].

The UMZ is made of molten base metal that has been briefly mixed with filler metal before being resolidified. A transition zone with a composition gradient from the base metal to the CZ must be present between the UMZ and CZ. A transition zone may be particularly crucial in a dissimilar metal weld, as was previously indicated. Autogenous, homogeneous, and heterogeneous fusion zones are the three types. These divisions are based on the presence or absence of filler as well as the filler's relative composition to the base material.

In instances where section thicknesses are small and penetration can be easily achieved by the technique chosen, autogenous (no filler added) fusion zones are typical. Autogenous welding frequently requires little to no joint preparation and can be done at high rates. Although butt joints are an option, edge welds are frequently preferable for autogenous welding. The word "autogenous" is only used to describe welds produced by the Gas Tungsten and Plasma Arc Welding procedures, even though there are several welding techniques, such as Electron Beam and Resistance Welding, that do not utilise a filler metal. Except for any losses from metal evaporation or gas absorption from the shielding atmosphere, the fusion zone's composition is practically the same as that of the base metal. Autogenous joining is not possible with all materials due to weldability problems such solidification cracking, which will be covered later.

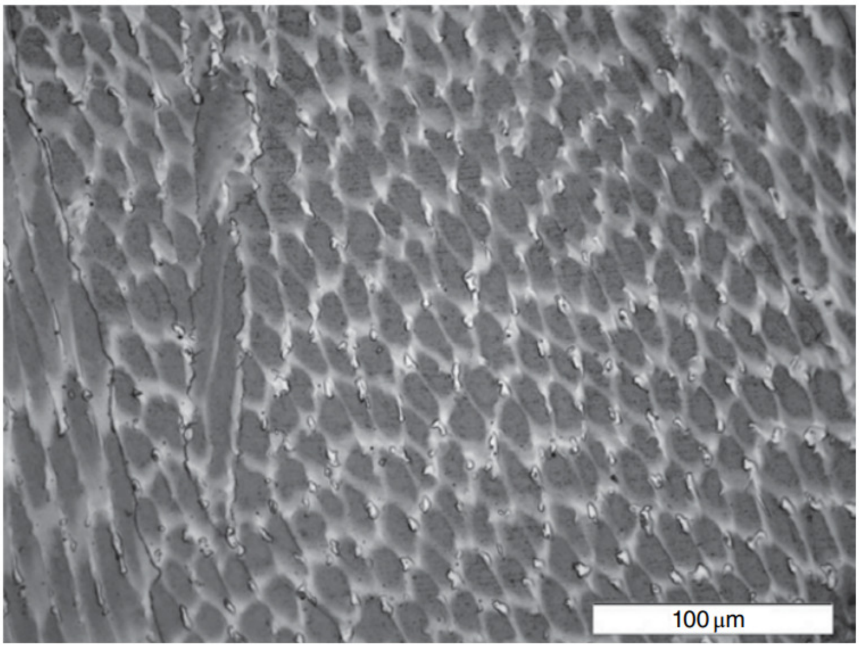


Figure 1: The Fusion Zone.

The employment of a filler metal that closely resembles the base metal composition results in homogenous fusion zones. When the filler and base metal qualities, such as heat treatment response or corrosion resistance, must closely match, this type of fusion zone is used. To create a heterogeneous fusion zone, it is frequently required to choose a filler metal composition that differs from the base metal. Examples of materials where dissimilar filler metals are used to lessen susceptibility to solidification cracking include austenitic stainless steels and specific aluminum alloys, albeit the mechanisms are different. Although the two types of fusion zones including a filler metal can be distinguished technically by the phrases homogeneous and heterogeneous, these terminologies are rarely applied in actual applications.

Fusion zone microstructures vary greatly; some examples nickel-based alloy fusion zone shows traces of a eutectic ingredient between the dendrites. This demonstrates how alloying and impurity elements were separated during the last phases of solidification. Alloys that display this type of fusion zone and generate eutectics are frequently prone to solidification cracking, especially if they have a broad solidification range. Austenitic stainless steel is displayed at the top of Figure 9.5 while plain carbon steel is displayed at the bottom. Dendritic solidification is visible in both situations.The area of the fusion zone just next to the fusion boundary is represented by the UMZ. Usually, it is somewhat narrow in comparison to the other weld areas. It could be challenging to distinguish this zone in many systems. The mechanical or corrosion properties of the UMZ can differ dramatically from those of the base and filler metals for specific metal alloy combinations. For instance, the UMZ in some combinations is vulnerable to localised corrosive assault or fracture.

Theoretically, every fusion weld contains a UMZ. At the fusion boundary, where the fluid velocity in the weld must equal zero, a stagnant liquid layer of certain dimension will be present. Since the surrounding weld metal will have a slightly different composition due to evaporation or contamination effects, a UMZ will still exist even in autogenous and homogeneous welds. Due to the UMZ's comparable microstructure to the bulk fusion zone, it is typically impossible to tell them apart in practise. The majority of the time, UMZ are connected to heterogeneous welds, especially when the relative compositions and physical characteristics are very diverse. Depending on a variety of material and process factors, the size and nature of the UMZ might vary greatly. However, the UMZ is typically not a significant factor.

The Partially Melted Zone

The zone that is partially melted is a transitional area between the 100% melting in the weld's fusion zone and its 100% solid portion (the actual HAZ). There are several metallurgical events that could lead to the formation of a partially melted zone. Segregation of alloying and impurity elements to the grain boundaries can occur in many commercial alloys. happen while processing. Overall, this leads to regional compositional variances that may cause the melting temperature at the grain boundaries to decrease.The temperatures corresponding to the welding process's thermal gradient are higher than this localized Grain boundary liquation, a phenomenon associated with melting temperatures, will take place. Exactly how much the magnitude and slope of the temperature gradient, among other things, determine whether or not this happens. of impurity and alloy separation. Processes for welding that generate more heat input include smoother temperature gradient is anticipated to result in a wider partially melted zone.

The fusion zone, sometimes referred to as the partially melted zone, is a crucial area in welding metallurgy. The section of the base metal that partially melts during the welding process is referred to by this term. The base metal melts here due to the heat produced by the welding operation, which results in the production of a molten pool. The two metal pieces being welded are joined by the weld metal, which is formed when the molten pool solidifies. The fast heating and cooling cycles that occur during welding cause considerable metallurgical changes in the partially melted zone. These alterations include grain expansion, the development of dendritic solidification structures, and the potential emergence of undesired phases.The welding procedure, welding parameters (such as heat input and travel speed), base metal composition, and heat treatment conditions all affect the features and attributes of the partially melted zone.The partially melted zone must be understood and managed in order to achieve the appropriate weld quality and mechanical qualities. A number of characteristics, including joint strength, toughness, and resistance to flaws such solidification fissures and porosity are influenced by the size and shape of the partially melted zone. The features of the partially melted zone can be controlled by optimising welding conditions and heat treatments, resulting in welds that have the appropriate properties and adhere to the necessary standards and specifications.

the partially melted zone, where the base metal partially melts during welding, is a crucial area in welding metallurgy. Its features and qualities are crucial to the overall effectiveness and quality of welded joints.Liquated grain boundaries can also result from constitutional liquation, another phenomena. When particles like carbides start to disintegrate in the vicinity of the HAZ in this situation, they may add a substance to the matrix around it that effectively reduces its melting point. When the HAZ When temperatures around a particle are higher than the localized melting temperatures, a pool of liquid will form. form. The liquid may wet the grain barrier if the particle is at a grain boundary, leading to on a grain border that is liquid. Liquated grain boundaries are easily pulled since they have no strength. Liquation cracks are created as the weld cools and residual strains increase.

Affected by heat zone (HAZ)

The genuine HAZ is the area between the undamaged base metal and the partially melted zone, despite the fact that the HAZ frequently includes the partially melted region. In a real HAZ, all metallurgical reactions take place in the solid form. Depending on the nature of the alloy, previous processing history, and thermal variables related to the welding process, the evolution of the microstructure in the real HAZ can be rather complex. The reactions in this area will be influenced by peak temperatures, heating and cooling rates, and can frequently have significant microstructural consequences within the same alloy or alloy system.

Within the same HAZ, a broad variety of microstructures are possible, and local variances might be significant. The most distinct HAZ microstructures are seen in materials that change phases when heated and cooled. Steels, for instance, change from a bcc ferrite phase to austenite (fcc) when heated above a critical temperature. Steel has a significantly different HAZ microstructure than base metals, in general.

Equilibrium binary phase diagrams are one tool for comprehending the microstructural characteristics of the HAZ. However, due to the nonequilibrium cooling circumstances that are typical of welds, metal alloys that undergo phase transformations, such as steels, may generate weld microstructures that are not predicted by equilibrium phase diagrams. Other diagrams that take into account nonequilibrium cooling in this situation have been produced and will be discussed in the following chapter on the welding metallurgy of carbon steels.

The HAZ may or may not be present in solid-state welding. An HAZ will be created during procedures like friction welding and resistance flash welding that depend on the production of a considerable amount of heat. However, because they rely more on pressure and/or time than intense heat, such as in the case of Diffusion Welding, Explosion Welding, and Ultrasonic Welding, these procedures either don't form a HAZ altogether or produce one that is very small and difficult to detect.

Overview of Phase Diagrams

Phase diagrams are frequently used in methods for learning about and comprehending welding metallurgy. The equilibrium phases that are present in a metal alloy as a result of temperature and composition are described by a phase diagram. The binary phase diagram, which describes the stability of phases between just two metals (or elements), is the most typical and basic sort of phase diagram. Phase diagrams can be highly complex. A weld's solidification process and the resulting microstructure are frequently predicted and understood using binary phase diagrams of the two constituent metal alloy components. Examples can be found in the basic binary eutectic phase diagram of elements A and B. There are always liquidus, solidus, and solvus lines in phase diagrams. All liquid material is distinguished from a mixture of liquid and solid by the liquidus lines. A blend of liquid and solid is distinguished from entirely solid material by the solidus lines. Additionally, the solvus lines reveal how much of one element may entirely dissolve in the other.

As it cools from the liquid phase, a weld fusion zone of composition 1 would first go through a liquid and solid phase. Since there is a mixture of liquid and solid at these temperatures, this stage is occasionally referred to as "mushy." The "liquidus" is the line that marks the start of solidification as it cools from the liquid. The remaining liquid solidifies after additional cooling, as seen by the "solidus" line. At composition 1, the liquid completely turns into a "alpha" phase. The "solvus" line is crossed after additional cooling, indicating that if cooling rates were slow enough, the (beta) phase should emerge in the solid state. It is crucial to realise that the "solvus" line shows the maximum amount of element "B" that may dissolve in metal "A" at a specific temperature, while the "phase" indicates element "A" with some element "B" dissolved. In conclusion, a metal with composition 1 solidification should have a microstructure with some phase.

The horizontal line denoting the eutectic temperature is achieved at composition 2 after solidification starts to happen at a lower temperature. All liquid that is still present solidifies into its eutectic composition at the eutectic temperature. Comparing this to component 1, which solidified as 100%, is considerably different. As a result, it would be anticipated that the microstructure of the weld fusion zone in composition 2 would differ greatly from that of composition 1. The primary phase islands in the composition 2 microstructure would indicate the solidification up to the eutectic temperature and be encircled by the eutectic phase. The ratios of each component are determined by the phase diagram, and they are combined to form the eutectic phase.

Composition 3 is the eutectic composition, to finish. When the liquid cools to the eutectic temperature, it all instantly solidifies as the eutectic phase. This microstructure would be made up entirely of eutectic phase, a combination of and. In conclusion, the phase diagram suggests that the three distinct compositions of an element A and B mixture should each result in noticeably different weld microstructures.The complexity of real binary phase diagrams can vary greatly.

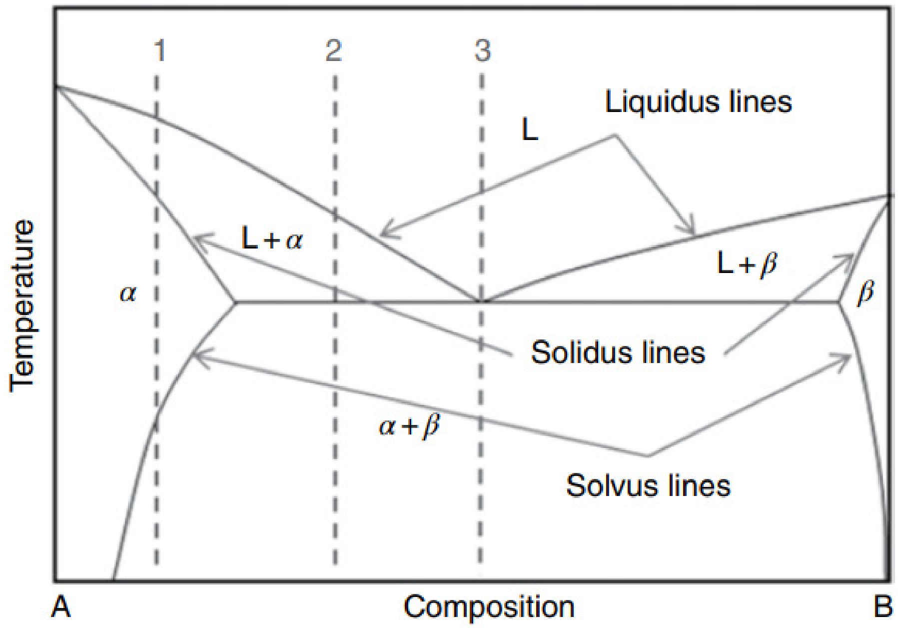


Figure 2 Phase Diagrams.

Even more difficult are three-dimensional ternary diagrams that depict the phase equilibrium of a mixture of three components. However, because weld solidification seldom takes place under the equilibrium conditions that the diagrams show, and because very few metal alloys include only two elements, these equilibrium diagrams should only be used for theoretical understanding and forecast reasons. Predicting weld microstructures is increasingly being done using robust modelling tools like ThermoCalcTM. To more precisely depict the solidification of actual weld metals, these software programmers enable the user to produce phase diagrams based on various alloying constituents and no equilibrium solidification conditions [10]–[12].

CONCLUSION

To sum up, welding metallurgy is an important area that investigates the characteristics and behavior of metals during the welding process. Through the ages, the study of welding metallurgy has changed, progressing from primitive forging methods to contemporary cutting-edge welding procedures. To guarantee the caliber and integrity of welded joints, one must have a solid understanding of welding metallurgy. The discipline is still being advanced by ongoing research and developments in materials science and technology, with the goals of streamlining welding procedures, enhancing weldability, and raising the effectiveness of welded structures.

REFERENCES

[1] P. Ramakrishnan, “Welding Metallurgy,” *Indian Weld. J.*, 1972, doi: 10.22486/iwj.v4i3.150243.

[2] P. Ferro and J. O. Nilsson, “Welding metallurgy of stainless steels,” in *Handbook of Welding: Processes, Control and Simulation*, 2021. doi: 10.22486/iwj.v2i2.150282.

[3] J. Lippold, “Welding metallurgy and weldability of stainless steels,” *Choice Rev. Online*, 2005, doi: 10.5860/choice.43-2230.

[4] J. C. Lippold, *Welding Metallurgy and Weldability*. 2014. doi: 10.1002/9781118960332.

[5] W. Reitz, “A Review of: ‘Welding Metallurgy and Weldability of Stainless Steel,’” *Mater. Manuf. Process.*, 2006, doi: 10.1080/10426910500476747.

[6] J. Andersson, “Welding metallurgy and weldability of superalloys,” *Metals*. 2020. doi: 10.3390/met10010143.

[7] S. Kou, *Welding Metallurgy*. 2002. doi: 10.1002/0471434027.

[8] H. Xu, J. Sun, J. Jin, J. Song, and C. Wang, “Comparison of structure and properties of mo2feb2-based cermets prepared by welding metallurgy and vacuum sintering,” *Materials (Basel).*, 2021, doi: 10.3390/ma14010046.

[9] M. Pouranvari, M. Alizadeh-Sh, and S. P. H. Marashi, “Welding metallurgy of stainless steels during resistance spot welding part I: Fusion zone,” *Sci. Technol. Weld. Join.*, 2015, doi: 10.1179/1362171815Y.0000000015.

[10] M. Alizadeh-Sh, M. Pouranvari, and S. P. H. Marashi, “Welding metallurgy of stainless steels during resistance spot welding part II –heat affected zone and mechanical performance,” *Sci. Technol. Weld. Join.*, 2015, doi: 10.1179/1362171815Y.0000000010.

[11] W. A. Baeslack, D. W. Becker, and F. H. Froes, “Advances in Titanium Alloy Welding Metallurgy,” *JOM J. Miner. Met. Mater. Soc.*, 1984, doi: 10.1007/BF03338455.

[12] S. Salimi Beni, M. Atapour, M. R. Salmani, and R. Ashiri, “Resistance Spot Welding Metallurgy of Thin Sheets of Zinc-Coated Interstitial-Free Steel,” *Metall. Mater. Trans. A Phys. Metall. Mater. Sci.*, 2019, doi: 10.1007/s11661-019-05146-8.

CHAPTER 21

PROCESS OF HEAT FLOW IN WELDING

Mr. Sanjeet Kumar, Assistant Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id: sanjeet.kumar@jnujaipur.ac.in

ABSTRACT:

The simple description of heat flow in welding procedures in this abstract. It emphasizes how crucial it is to comprehend heat transport in order to achieve the best possible weld quality and joint integrity. The main determinants of heat flow are discussed in the abstract, including heat sources, heat dispersion, and the function of welding settings. It emphasizes how crucial it is to effectively regulate and control heat during welding operations in order to achieve excellent results.The formation and properties of welds are influenced by heat flow, which is a critical component of the welding process. For welding parameter optimization, thermal distortion prediction, and assuring the necessary mechanical properties of the welded connection, it is crucial to comprehend the heat flow in welding. The relevance of heat flow in welding and its consequences for welding techniques and design concerns are succinctly summarized in this abstract.The importance of heat flow in welding and its effect on the entire welding process are emphasized in the abstract. It underlines the requirement for a complete comprehension of all relevant heat transmission modes, such as conduction, convection, and radiation. Welders can efficiently manage residual stresses, reduce distortion, and regulate the microstructure and mechanical properties of the weld by managing heat input and heat dissipation.

KEYWORDS:

Base Metal, Fusion,Heat Input, Temperature Distribution, Weld Pool, Welding Parameters.

INTRODUCTION

During fusion welding, the interaction between the base metal and the heat source causes the metal to heat up quickly, melt, and circulate ferociously. This molten metal circulates in the weld pool due to buoyancy, the gradient of the surface tension, jet impingement, friction, and, when electric current is utilised, electromagnetic forces. The transient temperature distribution in the base material, the size and form of the weld pool, and the solidification behaviour are all impacted by the heat transfer and fluid flow that follows [1]–[3].The thermal cycle, or change in temperature over time, has an impact on the weldment's microstructure, residual stresses, and degree of deformation. The temperature distribution on the weld pool surface influences the absorption and desorption of gases, including hydrogen, as well as the loss of alloying components via evaporation. The weldment's composition is impacted as a result. Depending on the local temperature, inclusions inside the weld pool may grow or dissolve. To guarantee sound welds with the proper fusion-zone shape, chemical composition, and microstructure, as well as with minimal residual stress and distortion, it is essential to manage these temperature fields and cooling rates.

Since the qualities of a weldment are governed by its geometry as well as by the composition and structure of the materials being welded, it is crucial to have a solid knowledge of heat transmission while creating welds. Important information about the properties of heat transport is obtained from the measurement of the temperature fields that develop inside the weldment and on the surface of the weld pool.However, it might be challenging to monitor surface temperatures while fusion welding. Although trustworthy methods are being created, such measures are rather complicated and need for specialised tools. At the moment, there is no accurate method for measuring the temperature of the molten weld pool. The use of bulky, costly thermocouples in the holes bored in the plates is often used to detect temperature in the solid portions. Consequently, one option is to employ quantitative**.**

History of heat flow in welding

Since the beginning of welding as an industrial process, the study of heat flow in welding has been a key subject of research and development. The desire to increase welding processes, process parameters, and the quality and efficiency of welded connections has led to an evolution in our knowledge of heat flow in welding. Here is a thorough account of heat flow throughout welding history:From the late 19th through the early 20th century: Forge welding and resistance welding were among the first welding techniques used in industry. However, there was little knowledge of how heat moved in these early processes; heat was mostly produced by mechanical deformation or electrical resistance.

Development of Arc Welding: - In the early to mid-20th century, arc welding technologies like shielded metal arc welding (SMAW) and gas metal arc welding (GMAW) led to important improvements in our knowledge of heat movement.The distribution of heat around the welding arc and its impact on weld penetration, weld form, and distortion have been the subject of research.Studies concentrated on the welding current, electrode diameter, arc length, and shielding gas composition as well as other elements that impact heat transmission.Development of Heat Transfer Models: From the 1960s to the 1970s, numerical simulations and mathematical models allowed for a better knowledge of heat flow in welding.Based on the theories of heat conduction, convection, and radiation, researchers started to create heat transfer equations.To model and examine the heat flow characteristics during welding, the finite element method (FEM) has become more prominent.

Welding Process Improvements: Late 20th century: The development of novel welding procedures including gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) resulted in further improvements in our knowledge of heat movement.

In order to accomplish the necessary heat distribution and control, research has concentrated on optimising welding parameters such as welding current, voltage, travel speed, and shielding gas flow rate.Laser and Electron Beam Welding: Since the 1970s, the development of laser and electron beam welding has presented both new obstacles and possibilities for the study of heat flow.To prevent excessive melting or deformation, these procedures create tremendous heat in a very small region, necessitating careful monitoring of heat flow.

Research focused on comprehending how the laser or electron beam interacts with the material of the workpiece as well as the impact of scanning patterns and beam characteristics on heat transfer.Recent Developments:Computational modelling, data-driven strategies, and real-time heat flow monitoring during welding have all advanced recently.To record and analyses heat flow patterns in real-time, researchers are investigating cutting-edge methods including infrared thermography, temperature sensors, and thermal imaging.The development of welding techniques, the improvement of weld quality, and heat management optimization can all be seen throughout the history of heat flow in welding. Increased productivity, less faults, and expanded welding applications across several sectors have all been made possible by improvements in our knowledge of heat flow [4]–[6].

DISCUSSION

Heat flow fundamentals

In this part, the key aspects of thermal energy transmission from the welding arc to the work piece and inside the work piece are discussed.

The element's maximum or peak temperatures, the size and form of the weld pool and the heat-affected zone, and the cooling rates of the weld metal and the heat-affected zone are all determined by these factors.

Heat Input

You are right, you are. The area of heat input during welding is quite tiny as compared to the whole size of the workpiece. Around the weld joint, there is a concentrated concentration of heat input. Welding heat input is primarily influenced by three variables: heat distribution, weld travel speed, and rate of energy input.1. Heat Distribution: How the heat is dispersed inside the weldment is referred to as the heat distribution. The welding procedure, welding conditions, joint arrangement, and material qualities may all have an impact on it. In order to maintain good fusion, reduce distortion, and manage the heat-affected zone (HAZ), it is crucial to manage the heat distribution.2.Weld Travel Speed: The pace at which the welding process moves along the joint is known as the weld travel speed. It establishes the duration during which heat is administered to a certain location. In contrast to slower travel rates, which give heat more opportunity to transfer, faster travel speeds result in less heat input per unit length of the weld.

The whole quantity of energy given to the welding process is referred to as the input energy. It is based on the power source's efficiency and energy output per unit of time, which is commonly measured in watts. Depending on the welding procedure being employed, the power source may be a laser, electric arc, or flame. The heat produced and transported to the workpiece is influenced by the energy input.The word "heat input" is often used to describe how much heat is utilised during welding. It is a measurement of the energy that is transmitted from the welder to the workpiece. The ratio of the arc power entering the workpiece to the weld travel speed is often stated as a single variable, Hnet. This variable aids in comparing the degrees of heat input used in various welding techniques.It's essential to remember that some welding energy does not really permeate the workpiece. Through processes like radiation, convection, and conduction, some energy is lost. In order to accurately describe the actual quantity of energy that is successfully delivered into the workpiece, the phrase "heat input" is utilized [7]–[9].

The heat input rate and weld speed sometimes need to be taken into account separately in order to appropriately characterise the weld thermal cycle close to the heat-affected zones. This is due to the possibility that various welding techniques and joint arrangements may lead to variations in heat distribution and thermal cycles, which will influence the material's characteristics in the heat-affected zones.Welders may optimise the welding process to achieve desired weld quality, reduce distortion, and efficiently manage the heat-affected zones by managing the heat input by careful management of the parameters stated above..

Absorption of Energy

Only a part of the total energy provided by the heat source is absorbed by the workpiece during welding. The result of the welding, including the creation of the liquid pool, the building of the time-dependent temperature field across the weldment, and the structure and characteristics of the weldment, are all due to the energy that was absorbed.Each welding technique has its own specific physical phenomena that affect how much energy is absorbed by the workpiece. The amount of energy that is absorbed by the workpiece for a particular power source depends on the kind of material, the heat source, and the welding process's specifications. The ratio of the energy given by the heat source to the energy absorbed by the workpiece, or the proportion of ene, is known as the efficiency of the heat source, or.

Process of Heat Flow in Welding

Heat is transferred from the heat source to the base materials during the welding process, causing the materials to fuse together and produce a weld junction. Here is a thorough description of the welding process' heat flow:

1. Heat Source: To provide the required heat, welding normally uses a heat source such an electric arc, laser, or flame. The weld pool is a concentrated area of high temperature created by the heat source.
2. Heat Production: The heat source produces heat through a number of techniques. In arc welding, an electric arc is created between the electrode and the workpiece, which generates a great deal of heat because of the electrical current's resistance. In contrast to flame welding, which uses gas combustion, laser welding uses a concentrated laserbeam to generate heat.
3. Heat Transfer Modes: There are three main ways that heat is transported from the heat source to the base materials:
4. Conduction: Direct molecular contact between nearby particles is what causes conduction, which is the transport of heat. Conduction transfers heat from the surrounding base materials to the hot weld pool during welding.
5. Convection: The movement of fluids or gases causes heat to be transferred by convection. When welding, the heat produced may warm the air or shielding gas nearby, which then convects heat to the base materials.
6. Radiation: Heat is transferred by electromagnetic waves through the process of radiation. The foundation materials may absorb the heat energy that the high-temperature weld pool emanates.
7. Heat Distribution: Near the weld joint, the heat produced by the heat source is dispersed. The welding procedure, welding settings, material characteristics, and joint design all have an impact on how heat is distributed.
8. Heat Absorption: The heat that is supplied from the heat source is absorbed by the base materials that are close to the weld joint. Thermal conductivity, material thickness, and heat capacity are just a few examples of the variables that affect how quickly and how much heat is absorbed.
9. Melting and Solidification: The foundation materials heat up to their corresponding melting temperatures as they absorb heat. The filler material, if employed, and the parent materials melt due to the heat, creating a liquid weld pool. The molten metal cools and solidifies, joining the base materials metallurgically.
10. Heat-Affected Zone (HAZ): The heat-affected zone is the area around the weld joint. During welding, this area's temperature varies significantly, yet it never reaches the melting point. The amount of the HAZ is influenced by the material's characteristics, welding speed, and heat input. The HAZ may experience a variety of metallurgical modifications, including as grain expansion, phase shifts, and residual stresses.
11. Cooling and Solidification: Following the welding procedure, the welded junction and its surroundings cool, and the molten metal solidifies. The microstructure and mechanical characteristics of the weld are impacted by the cooling rate. In order to obtain desirable material characteristics and reduce residual stresses, appropriate cooling and post-weld heat treatment may be required.

Controlling the welding process, improving joint quality, and maintaining the appropriate mechanical qualities of the weld all depend on an understanding of heat flow in welding. In order to control heat input, heat distribution, and cooling rates and produce good welds with the appropriate qualities, a variety of welding methods and parameters may be used.

Melting Efficiency

The ability of the heat source to melt both the base metal and the filler metal is something that the welder is really interested in during welding. The base metal (Abase) and the filler metal are included in the cross-sectional depiction of the weld metal.The major component being brought together, which may be a single piece or many parts, is referred to as the base metal. The structure or component to which the weld is being applied is made of the current material. The composition, mechanical characteristics, and thickness of the base metal all play a significant part in defining the welding parameters and the final weld quality.On the other hand, the filler metal is an extra substance that is added during welding to fill the joint and offer more strength or other desirable features. It usually takes the shape of a wire or rod and is mechanically compatible with the base metal in terms of composition. The welding procedure, the joint design, and the necessary strength or other performance characteristics of the weld are all taken into consideration when selecting the filler metal.

The heat source is used throughout the welding process to provide the required heat to melt both the base metal and the filler metal. The weld pool is a localised region of high temperature created when the heat is focussed on the joint area. The base metal and, if needed, the filler metal are melted to create the weld pool.The base metal and filler metal's temperatures must be raised beyond their respective melting points using a heat source, such as an electric arc, laser, or flame. This facilitates the fusing of the two components by allowing the base metal to melt and create a liquid pool with the filler metal.To guarantee that the heat source can successfully melt both the base metal and the filler metal, proper management of the heat input, welding parameters, and technique is essential. It's crucial to strike the right balance between melting the materials and staying away from overheating, which may result in flaws like burn-through or severe distortion.

The fused zone, where the two elements have consolidated and created a metallurgical link, is shown in the cross-sectional depiction of the weld metal, which contains the base metal and the filler metal. To achieve the required strength and integrity of the weld connection, this bond is necessary.To sum up, the welder is primarily concerned with making sure that the heat source can melt both the base metal and the filler metal. This makes it possible to generate a weld pool, which, when it solidifies, produces a cross-sectional image of the weld metal, which is made up of the base metal and the filler metal and is joined together to form a durable weld connection.The welding arc's high melting efficiency may be described in the following way:(2.5), where V is the welding speed, Hbase is the amount of energy needed to melt one unit volume of base metal, and Hfiller is the amount of energy needed to melt one unit volume of filler metal. The amount enclosed in brackets refers to the volume of material that has melted, while the denominator refers to the amount of heat that has been transferred from the heat source to the workpiece.

Effect Of Welding Parameters

The form of the weld pool changes from elliptical to teardrop when the heat input Q and welding speed V both rise. the weld pools that were identified from photographs taken during the autogenously GTAW process on 304 stainless steel sheets that were 1.6 mm thick (56). The scale bar only applies to lengths in the welding direction since the pools were taken from the side at an inclination (rather than vertically). The cross in each pool shows where the electrode tip is in relation to the pool. The length-width ratio increases as welding speed increases, and the geometric center of the pool moves further away from the electrode tip.

Using 1.6-mm 309 stainless steel sheets with autogenously GTAW, Kou and Le (57) quenched the weld pool and noted the acute pool end. The welding parameters were 85A current, 10V voltage, and 4.2mm/s [10in./min (ipm)] speed. It is clear that a teardrop-shaped weld pool has a sharp edge. Compared to aluminium sheets, the influence of the welding settings on the pool form in stainless steel sheets is more substantial. The weld pool has a harder time dissipating heat and solidifying due to stainless steels' much poorer thermal conductivity.

Applications

Weld thermal simulators have a wide range of uses. For instance, a weld thermal simulator and a high-speed dilatometer may be used to create continuous-cooling transformation diagrams that are helpful for researching phase transitions in welding and steel heat treatment. The elevated-temperature ductility and strength of metals may be assessed by carrying out high-speed tensile testing during weld thermal simulation. The hot-ductility test is the name given to this. For instance, Nippers and Savage (64, 65) examined the heat-affected zone fissuring in austenitic stainless steels using this technique. Additionally, specimens (1 1 cm in cross section) that have gone through different temperature cycles may be used to create chirpy impact test specimens. Numerous researchers have used this synthetic specimen or simulated-microstructure approach to investigate the toughness of the heat-affected zone**.**

Limitations

Despite being quite helpful, weld thermal simulators have several restrictions and disadvantages. First, because to the simulators' limited cooling capability, very high cooling rates experienced during electron and laser beam welding cannot be replicated. Second, if the peak temperature is high and the thermal conductivity of the specimen is low, the temperature at the surface may be lower than that at the midline of the specimen due to surface heat losses (66). Third, the gradient of temperature in the specimen is significantly less than that in the weld heat-affected zone, for example, 10°C/mm as compared to 300°C/mm close to the fusion line of a stainless steel weld. The specimen microstructure generally differs from the microstructure of the heat-affected zone because to this significant temperature differential. In the specimen, for instance, the grain size is often much greater than in the heat-affected zone, particularly at high peak temperatures of 1100°C and higher.

Weld thermal simulators do have the restrictions and disadvantages you described. Here is further information about these restrictions: Limited cooling capacity: Laser and electron beam welding processes undergo very rapid cooling rates that weld thermal simulators may not be able to adequately simulate. Since the cooling capacity of the simulators is often limited, it's possible that they won't accurately represent the quick cooling rates connected to these high-energy welding processes.During weld thermal modelling, surface heat losses are possible. This implies that the specimen's surface temperature may be lower than its centerline temperature. When the peak temperature is high and the specimen's thermal conductivity is poor, this impact is very important. Surface heat losses may alter the temperature profile and result in different microstructural development from the weldments themselves. And Temperature gradient discrepancy: During weld thermal simulation, the temperature gradient in the specimen is often much smaller than the temperature gradient in the real weld heat-affected zone. For instance, a stainless-steel weld's fusion line may have a temperature gradient as high as 300°C/mm whereas the temperature gradient inside the specimen may be about 10°C/mm. The specimen's microstructure may vary, including the size of the grains, as a consequence of the extreme temperature differential between it and the heat-affected zone. Particularly at high peak temperatures, the specimen's grain size tends to be bigger than that of the heat-affected zone.When using and analyzing the data from weld thermal simulators, it is crucial to keep these limits in mind. Although simulators are useful tools for learning welding techniques, they may not accurately replicate all the subtleties and unique circumstances of real weldments [10]–[12].

CONCLUSION

To sum up, heat flow in welding is a challenging procedure that uses focused heat application to fuse materials. The base metal and filler metal must both melt for the welder to produce a weld pool that solidifies into a solid joint. Heat input is primarily influenced by three variables: heat distribution, weld travel speed, and energy input rate. While weld travel speed affects how long heat is provided, heat distribution impacts how heat is disseminated throughout the element. The overall amount of energy delivered to the work piece depends on the input energy supplied by the power source. Thermal simulators for welding are valuable instruments for researching heat transfer. They may be used to create continuous-cooling transformation diagrams, analyses the toughness of heat-affected zones using Chirpy impact tests, and examine the ductility and strength of materials at high temperatures using high-speed tensile testing.

REFERENCES

[1] M. B. Nasiri and N. Enzinger, "Powerful analytical solution to heat flow problem in welding," *Int. J. Therm. Sci.*, 2019, doi: 10.1016/j.ijthermalsci.2018.08.003.

[2] S. Kou, "Simulation Of Heat Flow During The Welding Of Thin Plates.," *Metall. Trans. A, Phys. Metall. Mater. Sci.*, 1981, doi: 10.1007/BF02644171.

[3] R. Nandan, G. G. Roy, T. J. Lienert, and T. Debroy, "Three-dimensional heat and material flow during friction stir welding of mild steel," *Acta Mater.*, 2007, doi: 10.1016/j.actamat.2006.09.009.

[4] R. Nandan, G. G. Roy, and T. Debroy, "Numerical simulation of three dimensional heat transfer and plastic flow during friction stir welding," *Metall. Mater. Trans. A Phys. Metall. Mater. Sci.*, 2006, doi: 10.1007/s11661-006-1076-9.

[5] H. Schmidt and J. Hattel, "Modelling heat flow around tool probe in friction stir welding," *Sci. Technol. Weld. Join.*, 2005, doi: 10.1179/174329305X36070.

[6] C. L. Tsai and C. M. Tso, "Heat Flow in Fusion Welding," in *Welding, Brazing, and Soldering*, 2018. doi: 10.31399/asm.hb.v06.a0001333.

[7] D. Rosenthal, "The Theory of Moving Sources of Heat and Its Application to Metal Treatments," *J. Fluids Eng. Trans. ASME*, 1946, doi: 10.1115/1.4018624.

[8] L. Shi and C. S. Wu, "Transient model of heat transfer and material flow at different stages of friction stir welding process," *J. Manuf. Process.*, 2017, doi: 10.1016/j.jmapro.2016.11.008.

[9] M. Zhai, C. S. Wu, and H. Su, "Influence of tool tilt angle on heat transfer and material flow in friction stir welding," *J. Manuf. Process.*, 2020, doi: 10.1016/j.jmapro.2020.09.038.

[10] A. H. Faraji, C. Maletta, G. Barbieri, F. Cognini, and L. Bruno, "Numerical modeling of fluid flow, heat, and mass transfer for similar and dissimilar laser welding of Ti-6Al-4V and Inconel 718," *Int. J. Adv. Manuf. Technol.*, 2021, doi: 10.1007/s00170-021-06868-z.

[11] S. Kou and Y. Le, "Heat Flow During The Autogenous Gta Welding Of Pipes," *Metall. Trans. A, Phys. Metall. Mater. Sci.*, 1984, doi: 10.1007/bf02644711.

[12] N. Dialami, M. Cervera, and M. Chiumenti, "Effect of the tool tilt angle on the heat generation and the material flow in friction stir welding," *Metals (Basel).*, 2019, doi: 10.3390/met9010028.

CHAPTER 22

EXPLORING THE ROLE OF FILLER MATERIALS IN ARC WELDING

Mr. Dipendra Kumar, Associate Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id:dipendra1987@jnujaipur.ac.in

ABSTRACT:
Arc welding requires filler materials because they supply the necessary metal to create a solid link between two or more pieces. Depending on the type of metal being welded, the welding process, and the desired mechanical qualities of the resulting weld, filler materials are commonly available as wires, rods, or sticks. For arc welding, the most often employed filler materials are alloys of carbon and stainless steel, aluminum, and nickel. The melting temperature, chemical makeup, and mechanical strength are only a few of the distinctive characteristics that each material possesses and which have an impact on the welding procedure. It can be difficult to choose the best filler material for a particular welding application since there are so many things to take into account, including the type of connection, the thickness of the materials being welded, and the required weld quality. To maintain the strength and longevity of the completed weld, the proper filler material must be chosen.

KEYWORDS:

Wires, Flux, Cored, Shielded, Gas, Welding, Metal, Consumables.

INTRODUCTION

The development of consumables for conventional welding techniques like MMAW and SAW has progressed, partly in response to the requirement to match advancements in the characteristics of new materials while simultaneously enhancing the operating tolerance and stability of the techniques. Little has changed in filler wires for continuous-feed consumable electrode procedures like GMAW, but substantial advancements have been achieved in the creation and use of flux-cored wires [1]–[3]. The following are a few of the more crucial consumables used in the fusion welding processes:

1. coated electrodes for MMAW welding
2. wires and fluxes for SAW
3. filler wires for GMAW and FCAW.

Mmaw Consumables

There is currently a wide variety of MMAW consumables available to meet the joining needs of the most significant engineering materials as well as electrodes for repair, surfacing, cutting, and gouging. The following are the significant advancements that have occurred in these consumables.

1. increased toughness
2. enhanced hydrogen-controlled ferritic steel electrodes
3. enhanced stainless steel consumable performance.

For the production of carbon-manganese and low alloy steels, MMAW has been widely utilized in the shipbuilding, military, offshore, and power generation industries. In these applications, attaining excellent toughness and resisting hydrogen-induced cold cracking are crucial factors to take into account.

Improved toughness

Many buildings are expected to function at temperatures much below zero degrees Celsius, especially in the offshore and cryogenic sectors. By controlling the electrode composition and adding nickel, it has been possible to significantly increase the weld metal toughness of ferritic materials at temperatures below -40 C. The impact of this enhancement on a set of ferritic MMA electrodes' notch toughness.

Improved hydrogen control

Low-alloy and higher-carbon steels have had substantial hydrogen-induced or hydrogen-assisted cold cracking (HICC or HACC) issues, especially when thicker sections are welded. This issue may be avoided by controlling the hydrogen concentration of the weld metal, and this control can be enhanced by the formulation, storage, and packing of the electrodes. By carefully choosing the coating's parts and using proper packaging, it is possible to reduce the electrode coating's ability to reabsorb moisture, which is the primary source of hydrogen. There are now accessible basic hydrogen-controlled electrodes that, for up to ten hours after opening the packaging, will provide weld metal hydrogen concentrations of less than 50 ml kg-1 under ambient circumstances of 35 °C and 90% humidity.

MMA electrodes for stainless steel

The use of rutile (TiO_2) based flux coatings has significantly increased the operational performance of standard austenitic stainless steel MMA electrodes. Improved arc stability and superior weld bead surface quality are provided by these coatings. Additionally, novel corrosion-resistant alloys, particularly duplex and high molybdenum stainless steels, have been created using electrodes.

Submerged arc welding consumables

A standard variety of wires and fluxes have been developed for the most typical applications of the well-established submerged arc technique. Two crucial developments in the procedure have been made possible:

a. the utilization of iron powder additives
b. the creation of consumables with high levels of durability.

High-toughness consumables

To meet the demand for offshore constructions to have appropriate impact characteristics down to -40 C, higher-toughness consumables have been created. This has been accomplished by using titanium and boron micro-alloyed wires with a semi-basic flux. [42] Common Charpy-V notch curves demonstrate the increase in toughness when compared to a standard SD3 molybdenum wire.

Addition of iron powder

The deposition rate of the submerged arc weld process is increased by more than 60% [44–46] when the iron powder is used, and the quality of the weld metal also improves. The method makes use of the extra arc energy that is often present during submerged arc welding, which typically causes enhanced melting of the parent plate and significant dilution. The rate at which joints are completed increases if the metal powder is introduced to the weld pool because part of the arc energy is lost in melting it. This approach decreases the heat input to the parent plate and subsequent thermal damage in the HAZ (heat-affected zone), in contrast to other techniques for boosting process productivity. The iron powder may be added to the joint in three ways:

Before welding, pre-fill the joint; employ a forward-feed system; and apply magnetic feeding to the wire surface [4].

1. pre-filling the joint before welding
2. using a forward-feed system
3. magnetic feeding on the wire surface.

It has been discovered that the pre-filling procedure can increase productivity while also allowing for a sizable reduction in overall heat input. Since it reduces the negative impacts of large heat inputs on the thermo-mechanical treatment that is used to attain enhanced qualities, this might be especially helpful for fine-grained, high-strength low-alloy steels. The method has been used to fabricate high-toughness steels for offshore applications, and values of 173 J at -40 C have been reported [39] for a 50 mm thick single-V butt weld in typical fine grain steel (BS 4360 50DD) using the forward-feed system, a basic flux, and a 1.7% Mn wire Charpy-V notch.

DISCUSSION

Filler Wires For Gmaw And Fcaw

Solid wire consumable/shielding gas packages have made some progress as a result of increased GMAW process usage, although flux-cored consumables have made the biggest strides in this area.

Solid filler wires for GMAW

The composition of solid filler wires is often nominally the same as the material being linked. Although it has been demonstrated that small chemical alterations, such as the addition of deoxidants, might improve transfer and bead form, there is little room for improvement in this area. Although early attempts to increase metal transfer by surface treatment were undertaken, the probability of surface coating degradation makes this approach often impracticable. The transfer of steel wires in pure argon can be enhanced, according to recent research on rare-earth additions to the filler wire, however, this is of little practical consequence unless very low levels of weld metal oxygen are being sought (for example, in the welding of 9% Ni steel with matched fillers). Metal oxidation during transfer depends on the oxidation potential of the gas and the reactivity of the element concerned, crossing the arc may lower the level of some alloying elements.Additionally, it has been discovered that even very little variations in the ferritic steel wires' remaining chemical makeup can significantly affect their low-temperature toughness. These modifications may be substantial in critical low-temperature and cryogenic connections, but they are inadequate to modify the weld metal property requirements for the majority of applications [5]–[7].

It has been discovered that an extremely thick copper coating on carbon steel wires might affect feed ability, and there was once concern that the coating's copper vapors would pose a health risk. Uncoppered cables became accessible as a result. Due to a surface lubricant, these wires have high feed ability and have been shown to lower fume levels in the breathing zone. Higher contact tip wear, however, has been mentioned as a possible issue. It is currently usual practice to restrict the thickness of copper coatings to a relatively thin layer, and it has been shown that doing so solves feed ability and fume difficulties.

Flux-cored wire

Flux-cored wires are made of a metal outer sheath that is filled with a mix of metal powders and mineral flux. The theory is presented and the FCAW process is run similarly to GMAW welding. The most typical way to make wire is to fold a thin metal strip into a U shape, fill it with the flux ingredients, close the U to form a circular section, and then draw or roll the tube to reduce its diameter. In a diagram, the production process is depicted. Throughout the reduction process, the seam is closed. Alternate configurations can be created by lapping or folding the strip, or the consumable can be created by putting flux in a tube and drawing it to shrink the size.The diameters of completed wires typically fall between 3.2 and 0.8 mm. The benefits that flux-cored wires provide are as follows.

1. high deposition rates
2. alloying addition from the flux core
3. slag shielding and support
4. improved arc stabilization and shielding.

Deposition rate

The deposition rate will be significantly greater than that attained with MMAW typically and only slightly better than that with a solid wire GMAW. Due to the higher current density and the fact that the sheath carries all of the current, the rate of deposition has risen. However, the electrode stick-out, polarity, thickness, and resistivity of the sheath material will all affect the rate of deposition. A flux-cored wire's melting rate, MR, can be represented as follows the mean current I, l is the stick-out length, and A is the conductor's cross-sectional area, where k, a, and b are constants. While the phrase blI2/A denotes resistive heating in the wire extension, the term aI stands for arc melting. It is clear from this equation that increasing the wire extension and operating current can result in substantial increases in burn-off rate (for typical burn-off curves that demonstrate this connection.

Alloying addition

Because of the technological and financial challenges involved in manufacturing relatively small amounts of specialty compositions, the variety of compositions of solid GMAW wires is constrained. However, slight changes in the flux formulation may be made to flux-cored wires to yield a variety of weld metal compositions and operating characteristics.

The range of compositions currently available for plain carbon and alloy steels is comparable to that for MMA electrodes, with rutile (TiO_2) based formulations for ease of operation, basic (CaO) high-toughness, hydrogen-controlled formulations, and metal powder cores for high recovery and low slag formation (the Australian, UK, and US specifications for flux-cored welding consumables are summarised in Appendix).This method may also be expanded to create austenitic stainless steel or highly alloyed hard-facing deposits at a low cost from wires covered in a simple carbon steel sheath. The slag's solidification properties may be engineered to improve the process efficiency. For instance, in vertical or overhead welding, a fast-freezing rutile slag may be utilized to support the weld pool, allowing for larger working currents, increased productivity, and enhanced fusion properties. As an alternative, the slag properties can be changed to increase shielding and regulate bead form. This is crucial for the stainless-steel consumables covered in the next section.

Arc stabilization and shielding

As in MMA welding, the breakdown of the flux ingredients may be employed to produce shielding gases. For instance, the decomposition of calcium carbonate may result in the production of CO2.

CaO + CaCO3 + CO2

To enhance operating characteristics and arc stability, arc ionizers may also be introduced to the flux. These methods may be used to create electrodes that run on alternating current or DC electrode negative, and this may improve the melting rate and weld bead characteristics.

Modes of operation

It is possible to run flux-cored wires both with and without an extra gas shield.

Self-shielded operation

The flux must offer enough shielding in self-sheltered flux-cored wires so that the molten metal droplets are shielded from air pollution as they form and move across the arc. Weld metal chemistry is frequently changed to account for unavoidable nitrogen and oxygen pick-up (by adding aluminum, for example). The flux must also carry out arc stabilization, alloy addition, and slag management tasks in addition to its shielding role. As a result, creating appropriate flux compositions is more challenging, yet there are various effective consumable design options. For usage on sites with moderate side winds, these self-shielded wires do offer advantages.Poorer process tolerances, however, may be a result of the demands on flux design. For instance, to create the necessary mechanical qualities and avoid porosity, the operating voltage range for particular positional structural wires must be maintained within 1 V of the suggested level. The application of an extra shielding gas eases these restrictions.

Gas-shielded operation

If a traditional GMAW torch is utilized, further shielding may be offered. For this purpose, CO2 or argon/CO2 mixtures are frequently used with steel; this improves positional performance, mechanical characteristics, and process tolerance, and, despite the increased cost of the shielding gas, frequently results in lower process costs overall.

Types of flux-cored consumable

The subsequent categories of flux-cored wires have been created:

1. plain carbon and alloy steels
2. hard facing and surfacing alloys
3. stainless steel

Plain carbon and alloy steels

Although Appendix 5 includes specifics for some of these wires, the following categories may be used for discussion.

1. rutile gas-shielded
2. basic gas-shielded
3. metal-cored-gas-shielded
4. self-shielded

Rutile gas-shielded

Rutile gas-shielded wires have mechanical attributes that are comparable to or better than those attained with a simple solid wire of carbon steel, as well as very good running performance, outstanding positional welding capabilities, and good slag removal. Good low-temperature toughness (e.g. 100 J at -40 C) may be obtained by alloying with nickel.

Basic gas-shielded

Basic gas-shielded wires provide great operating parameter tolerance, respectable operating performance, and outstanding mechanical qualities. There are alloyed welding formulas for low-alloy and high-strength low-alloy steels. These wires' positioning performance, especially in the bigger diameters, falls short of the rutile consumables.

Metal-cored-gas-shielded

Iron powder or a combination of iron powder and ferro-alloys makes up the majority of the core of metal-cored wires, which contain very little mineral flux. In argon/CO2 gas mixes, these wires provide very smooth spray transmission, especially at currents around 300 A, however, they may also be employed in the dip and pulse modes at low mean currents. They produce less slag and work well in mechanized applications.

Self-shielded

A limited selection of wires is offered for applications that call for enhanced toughness, while self-shielded wires are provided for general-purpose down-hand welding and positional welding. Similar to rutile wires, alloying with nickel is typically used to meet the increased toughness requirements. These consumables have seen significant use in offshore applications, where it has been shown that strict control of the operating settings may result in consistently high toughness values under site circumstances. Flux-cored wires made from a variety of hard-facing and surfacing alloys are manufactured. (The Appendix contains a list of the typical hard-facing consumables. These include nickel- and cobalt-based consumables as well as austenitic stainless steels, high chromium alloys, plain carbon steels, and alloys incorporating tungsten carbide. Many of these cables are self-shielded and are particularly meant for usage on construction sites. Due to the increased ratio of alloying elements to arc stabilizers in the core material, the running performance is often not as excellent as that found in the constructional wires discussed above, but they offer a practical way to deposit wear- and corrosion-resistant material.

Stainless steel

For the majority of the popular corrosion-resistant materials, there are corresponding consumables and stainless-steel flux-cored wires that have also been introduced. There are rutile-based formulations as well as gas-shielded metal-cored formulations, with the latter offering, particularly good operating characteristics, a wide range of process tolerance, little spatter, and excellent surface quality.

Practical considerations

Although using gas-shielded flux-cored wires is frequently simpler than using solid wire GMAW, there are certain operational peculiarities. As was mentioned before, these consumables are sensitive to sticking out. Long electrode extensions increase burn-off rates, however, in the case of gas-shielded wires, the allowed length may be constrained by the loss of effective secondary shielding. An insulated guide with fume extraction may be advised in the case of self-shielded wires where extraordinarily lengthy wire extensions may be needed to achieve high deposition rates. Very short extensions may not be desired; for instance, it has been shown that fast-freezing slag and an excessive amount of surface lubricant on rutile wires intended for positional usage might result in surface cracking.if short electrode extensions are employed, especially in the down-hand position, porosity (also known as "worm tracks"). By lengthening the extension, the issue may be solved and the extra lubricant pushed off. Higher weld metal hydrogen levels are also related to shorter electrode extensions. In manual operation, the relative positions of the gas shroud and contact tip may be used to adjust the minimum extension. The equipment needed for flux-cored wire operation is essentially the same as that used for GMAW welding, albeit a voltage-stabilized power supply may be necessary for self-shielded consumables that are less tolerable. To prevent the wire from being crushed in the feed system, it is crucial to utilize specially engineered feed rolls for all flux-cored wires.

Applications of FCAW

Flux-cored wires are used for combining thick-section, high-strength steels for important applications, such as high-speed mechanical welding of lighter parts or the construction of process equipment made of high-quality stainless steel.

Limitations of flux-cored wires

Flux-cored wire's apparent limitations are:

- Cost
- Fume
- consistency of the consumable

Cost

Flux-cored wires may cost four times as much as solid wires, however, this must be taken into account in light of prospective productivity gains and the fact that consumable costs make up a very tiny portion of the overall fabrication costs. Using a flux-cored wire can frequently lower the overall cost. For instance, in tests on a vertical V-butt joint in a 25 mm thick piece of BS 4360 50D material, it was discovered that using a rutile flux-cored wire enabled a 28% cost reduction in the joint compared to GMAW welding with a solid wire. The savings came about as a result of lower labor expenses brought on by faster welding. (A greater mean current might be employed with the flux-cored wire).

Fume

Flux-cored wires will create more particle smoke than MMA or GMAW welding with a solid wire because of the rapid burn-off rate, the presence of mineral flux ingredients, and the continuous mode of operation.

While the majority of this article might be regarded as moderate When rutile flux-cored wire is used for vertical butt joints, costs are reduced. Symphony's spreadsheet was used to compute the costs for a 300 mm test weld. Hexavalent chromium from chromium-bearing consumables and barium compounds identified in the fume of some self-shielded wires are the major areas of concern. Inert dust, some consumables, and flux components also produce molecules that are regarded to be harmful.

To comply with health and safety regulations, the quantity of particle fume and, in particular, potentially dangerous compounds, must be regulated. This is often accomplished using a straightforward local fume extraction method.

Consistency of the consumable

Flux-cored consumables are more difficult to make than solid wires, although the process is comparable to that used to make MMAW electrodes. The flux core must be equally distributed throughout the consumable and chemically homogenous. Additionally, the wire's surface must be spotless and unobstructed by extra drawing lubricant. Although these criteria were a challenge for early consumables, the development of better manufacturing processes and online quality monitoring has now made it possible to maintain constant consumable qualities [8]–[10].

CONCLUSION

The tribological performance of polymers gliding against metals can be significantly impacted by filler compounds. The filler substance can improve the transfer film's homogeneity and adherence to the counterface when it does so. These advantages result from the filler particles' mechanical and chemical actions during the sliding process. The capacity of the filler particles to facilitate the interlocking of polymer in the asperities on metallic surfaces, the chemical interaction of the filler material with the counterface, or the chemical degradation of the filler material as it interacts with the environment are all examples of this. Electric arc welding is a procedure that is very flexible and can be used on almost any type of metal or material combination imaginable. As a result, it is crucial for many sectors in today's world. You should now have a better knowledge of what electric arc welding is all about and why it's so crucial in the modern world thanks to this brief introduction! There is little question that this technique will remain essential in many industrial operations for years to come due to its rapid joining of metals while retaining structural integrity.

REFERENCES

[1] M. Hindsén and M. Bruze, "Welding," in *Kanerva's Occupational Dermatology*, 2019. doi: 10.1007/978-3-319-68617-2_197.

[2] Ö. Üstündağ, V. Avilov, A. Gumenyuk, and M. Rethmeier, "Improvement of filler wire dilution using external oscillating magnetic field at full penetration hybrid laser-arc welding of thick materials," *Metals (Basel).*, 2019, doi: 10.3390/met9050594.

[3] J. P. Oliveira, T. G. Santos, and R. M. Miranda, "Revisiting fundamental welding concepts to improve additive manufacturing: From theory to practice," *Progress in Materials Science*. 2020. doi: 10.1016/j.pmatsci.2019.100590.

[4] D. Aravindkumar and R. Thirumalai, "Investigations on microstructural characteristics and mechanical properties of 316 L stainless steel welded joints using nickel coated filler material by gas tungsten arc welding," *Mater. Res. Express*, 2021, doi: 10.1088/2053-1591/abf3e7.

[5] C. Loukas *et al.*, "A cost-function driven adaptive welding framework for multi-pass robotic welding," *J. Manuf. Process.*, 2021, doi: 10.1016/j.jmapro.2021.05.004.

[6] M. Sathishkumar and M. Manikandan, "Influence of pulsed current arc welding to preclude the topological phases in the aerospace grade Alloy X," *Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl.*, 2020, doi: 10.1177/1464420720907993.

[7] J. Takahashi, H. Nakashima, N. Fujii, and T. Okuno, "Comprehensive analysis of hazard of ultraviolet radiation emitted during arc welding of cast iron," *J. Occup. Health*, 2020, doi: 10.1002/1348-9585.12091.

[8] Z. Nurisna and E. Setiawan, "Pengaruh Filler Pada Pengelasan Tig Baja Karbon Dan Stainless Steel 316l Terhadap Sifat Mekanik," *Quantum Tek. J. Tek. Mesin Terap.*, 2020, doi: 10.18196/jqt.010214.

[9] J. W. Kim, J. D. Kim, J. Cheon, and C. Ji, "Effect of filler metal type on microstructure and mechanical properties of fabricated nial bronze alloy using wire arc additive manufacturing system," *Metals (Basel).*, 2021, doi: 10.3390/met11030513.

[10] M. Sokoluk, C. Cao, S. Pan, and X. Li, "Nanoparticle-enabled phase control for arc welding of unweldable aluminum alloy 7075," *Nat. Commun.*, 2019, doi: 10.1038/s41467-018-07989-y.

CHAPTER 23

TEST METHODS FOR EVALUATING WELDED JOINTS

Mr. Ashok Singh Gour, Assistant Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id: asgour@jnujaipur.ac.in

ABSTRACT:

The country's methods for assessing welded joints differ according to the evaluation's goals, the welding process, the materials and thickness involved, and the demands of the specific industry doing the evaluation. Numerous distinct test specimens have been created as a result of these various needs. New materials and connecting techniques have greatly increased the variety of specimen types available, which has made it difficult to interpret the results. The utilisation of so many different specimen types is explained along with the benefits and drawbacks of each specimen type through an analysis of existing specimens. The analysis is a compilation of data from the literature, engineering expertise, and the outcomes of two industry surveys. All welded structures have a purpose, from steel bridges to parts for aeroplanes. Similar to how these structures and components' welded joints are created for capabilities and attributes that pertain to services. Because weld size, configuration, environment, and the types of loads that weldments are subjected to vary from structure to structure, predicting service performance based on laboratory testing offers a challenging task.

KEYWORDS:

Hardness, Metal, Strength, Specimen, Test, Tests, Tension, Weld.

INTRODUCTION

The fact that welded jointswhich are made up of undamaged base metal, weld metal, and a heat-affected zone (HAZ)are metallurgically and chemically heterogeneous adds to this complexity. Each of these zones is made up of a variety of various chemical and metallurgical heterogeneities [1].Typically, testing is done to make sure that welded joints can perform the specified purpose. Of course, the best test includes seeing the building in use, whether it be real or simulated. Such "mock-up" testing is used, for instance, to verify innovative moment frame and connection designs for large buildings in seismically active regions.1 Mock-up and real service tests are unfortunately costly, time-consuming, and possibly dangerous. To compare a specimen's results to those of metals and structures that have performed satisfactorily in service, standard tests and testing procedures are carried out in the lab. Standardized testing serves as a link between the properties that designers and analysts predict and those that the actual structure manifests. To determine the qualities of the remaining material within a lot, heat range, or welding method, mechanical testing offers information on the mechanical or physical properties of a small sample of welds or metals. To produce data that can be compared to design requirements, standardized methods are employed to sample, orient, prepare, test, and evaluate the specimens. For instance, almost all design rules are based on the requirement for a minimum tensile strength to be attained both in the base metal and the weldment.

The goal of the test must be taken into account while choosing a test technique, together with the amount of time and resources available. For instance, both tension and hardness tests can assess strength, although the latter is easier and more cost-effective to carry out. Hardness tests can be used to verify that some heat-treated components have reached a sufficient level of strength. Because welds are heterogeneous, hardness tests cannot accurately determine the strength of a welded joint, even though they can confirm that a maximum heat-affected-zone hardness has not been surpassed. No matter how different test methodologies are, they all measure either a composite average or a "weak-link" component of the relevant characteristic within the tested area. The test specifics must therefore be understood to evaluate the results. When evaluating a welded or brazed joint, the investigator must not only consider how the test will affect the actual structure's intended use but also consider whether the small area under the test is accurate in measuring the joint's true qualities. Therefore, it is important to evaluate and apply test results carefully.The majority of weldments are examined utilising several laboratory tests because each one only gives a limited amount of information on the characteristics of welded joints. Each test offers precise information on the weldment's suitability for use. Strength (such as ultimate tensile strength, yield strength, and shear strength), tensile ductility (such as elongation and reduction of area), bend test ductility, toughness (such as fracture toughness, crack arrest toughness, and Charpy V-notch toughness), fatigue, corrosion, and creep are among the properties that are assessed through testing.

Depending on the application, the scope of the testing is either described in the applicable code or standard or defined as part of the investigation. Samples that accurately represent the heat treatment conditions used in service should be tested. However, while testing welded joints, the issue of the ageing of steel specimens frequently comes up. Ageing in this sense refers to a degassing procedure carried out at ambient temperature or a little higher. For instance, the Structural Welding CodeSteel, AWS D1.1:2000,3, 4, as well as some welding codes like the American Welding Society's filler metal specification for carbon steel flux cored arc welding electrodes,2, allow the ageing of tension test specimens at 200°F to 220°F (93°C to 104°C) before testing. Other codes, such as ANSI/AASHTO/AWS D1.5-96,5's Bridge Welding Code, do not allow ageing for weld method qualification testing.

Hydrogen can be introduced into the metal during the welding process, usually from water that separates under the high arc temperature. Over time, the hydrogen diffuses out, although it could skew the findings of tensile tests. Even though normal cup-and-cone fracture may be seen if tested only days later, and the yield strength, ultimate strength, and impact test results will remain unchanged, these can occasionally be seen as "fisheyes" (small pores surrounded by a round, bright area on the fracture surface of tension tests of steel welds). Because it doesn't alter the metallurgical structure but rather speeds up the diffusion of hydrogen from the weldment, such low-temperature ageing is allowed. With this one exception, weldment testing is usually carried out using samples that accurately reflect the weldment's heat treatment state as it would be utilised in service [2]–[4].

This chapter examines the various testing techniques used to gauge the anticipated performance of brazed and welded connections as well as thermal spray treatments. A summary of the property being examined, the test procedures employed, the application of the results, and, most crucially, how these results relate to welded joints are all included in each method's description. Weldability testing is also described in general. The Standard Methods and Definitions for Mechanical Testing of Steel Products, ASTM A 370.8, and the Standard Methods for Mechanical Testing of Welds, ANSI/ AWS B4.0 and AWS B4.0M, are frequently cited in this chapter. For further information on the testing and assessment of welded joints, refer to the most recent edition of these standards. For more guidelines on health and safety considerations, refer to the American National Standard Safety in Welding, Cutting, and Allied Processes, ANSI Z49.1,9.

DISCUSSION

Testing For Strength

Almost all structures and components are designed using minimum tensile characteristics. Because of the metallurgical and frequent compositional alterations that emerge from the welding process, it is important to determine how these changes will affect the weldment's mechanical properties. While certain strength tests, like tension tests, directly measure tensile strength, others, like the peel test, make sure the weld is just as strong as the base metal. Below is a discussion of the many methods used to gauge the strength of weldments [5]–[7].

Tension Tests

The strength and ductility of the base metal, the weld metal, and the weldment are assessed using tension tests. These exams offer quantifiable information for the design and analysis of welded constructions. To ensure that a weldment's tensile strength satisfies the required minimum values, tension tests are commonly performed.

Fundamentals

In tension testing, specimens are loaded in tension until they fail. Two strength values—yield strength and ultimate tensile strength—as well as two metrics of durability are revealed by these tests. Dexterity: elongation and area reduction. These characteristics are frequently listed for the base material in reports based on testing done by the product's producer. The tensile test can also be used to estimate the elastic modulus (Young's modulus), but this parameter does not vary considerably for a given material and is not frequently reported.

Tension Test Specimens

The orientation of the test specimen within the weldment or structure is the main difference between the various types of tension tests. For instance, specimens for the uniaxial stress test used to evaluate base metal and weldments can either be a cross-section with a round ("round") or rectangular ("strap") shape with a shorter gauge length. There are two examples of common specimen arrangements.

Test Procedure

The specimen ends are inserted between the two grips of a tension wrench; they could be plain, threaded, or grooved, depending on the grips being used. machine. The specimen is then put in uniaxial tension while the grips are moved apart, and the load applied to the specimen is tracked or recorded. The only requirement to determine the ultimate tensile strength (UTS) is the maximum load (see below).

Data Collection and Interpretation

simultaneous recording of the load that is being applied as well as the lengthening that occurs in the specimen as a result To calculate the yield strength and establish the stress-strain curve, gauge length is required. Plotting the instantaneous load divided by the original cross-sectional area of the test specimen against the instantaneous displacement (within the gauge length) divided by the original gauge length of the specimen yields the engineering stress-strain curve. The term ultimate tensile strength (UTS) is used in engineering applications and is defined as the greatest force divided by the specimen's initial cross-sectional area. The tension testing machine load pointer can be used to directly determine the maximum load. It can also be calculated from the peak of the stress-strain curve upon yielding. It should be noted that the load at fracture, which is frequently lower because of considerable local yielding that has greatly decreased the specimen's cross-sectional area, is not normally the maximum load.

When the maximum load is reached, the specimen's elongation is distributed almost uniformly over the shortened section, but as necking sets in, it becomes progressively local. The yield strength, an arbitrary unit of measurement, is meant to show the stress at which permanent deformation starts to happen. Some materials have a clearly defined upper yield point on their stress-strain curves, which indicates the end of totally elastic behaviour. Stresses over this point cause the material to permanently elongate. The slope of the curve's first straight section is equal to the modulus of elasticity. The curve then rises once again as a result of work hardening after yielding at a constant, somewhat lower load (the lower yield point). However, as some materials lack a distinct yield point, arbitrary definitions of yield strength are required.

By drawing a line that is parallel to the elastic, straight portion of the curve (i.e., with a slope of the modulus of elasticity), but offset along the strain axis by 0.2% strain, one can calculate the offset yield strength. The 0.2% offset yield strength is the stress at the point where this offset line intersects the stress-strain curve. Figure 6.2 depicts the 0.2% offset approach, which is most frequently used for weldment testing. Utilising the stress at a particular strain, such as the 0.5% total strain yield strength, is a less-used technique. This approach assumes a particular stress-strain relationship rather than requiring a stress-strain curve. This makes it less trustworthy and less accurate in general.

The ratio of the increased gauge length to the initial gauge length is known as the per cent elongation. After reassembling the specimen's fractured pieces, the ultimate gauge length is measured. Local or necking strain, which is influenced by the specimen geometry, and uniform strain, which depends on the initial gauge length, are both included in the per cent elongation.

As a result, only elongation percentages for identical specimens should be compared. The ratio of the reduction in the cross-sectional area upon fracture to the initial cross-sectional area yields a per cent reduction in area.

This "necking" of the specimen perpendicular to the loading axis due to plastic flow is what results in the reduction in area. After reassembling the fractured parts, the final area is calculated by measuring the diameter, width, and thickness.

Specimen Geometry

As was already mentioned, the specimen geometry has a major impact on the amount of elongation that happens during testing. The gauge length and reduced section diameter of standard round bar test specimens have a specified relationship that is typically 4 to 1. Though Because the shape of the specimen can have an impact on the results, key tensile specimen dimensions are standardised. The fracture surface for two tensile specimens evaluated at the same strain rate from the same material is shown in Figure 6.3. The specimen on the right exhibits a classic "cup-and-cone" fracture with good ductility and is necked. The specimen on the left, however, had a V-groove rather than a smoothly transitioning decreased portion, despite being machined to the same beginning diameter. This specimen had almost little ductility but a higher yield strength.

Steels are quite a notch sensitive, which has an impact on their perceived yield and ductility. When designing components with significant sectional area variations, this must be taken into account. Standard Test Methods and Definitions for Mechanical Testing of Steel Products, ASTM A 370.10, provides in-depth information on specimen preparation and test procedures for tension tests.

Base Metal Tension Tests

Base metals' strength and ductility are often measured using a straightforward uniaxial tension test. Base metals' strength qualities are normally assessed at the manufacturing mill and noted on the material test report. These evaluations for steel goods include usually carried out following ASTM A 370.11, Standard Test Methods and Definitions for Mechanical Testing of Steel Products. Similar techniques are occasionally used to do base metal tension testing during weld procedure qualification to confirm reported data.

The two most frequent orientations for base metal tension tests are longitudinal or transverse. Transverse specimens are oriented perpendicular to the rolling motion, whereas longitudinal specimens have a long axis parallel to the rolling direction. The sole distinction between longitudinal and transverse specimens is their orientation, and both are typically prepared and examined using the same uniaxial tension test procedures. Reports include the offset yield strength, ultimate strength, per cent elongation, and occasionally the per cent area decrease. For each place that was sampled, two samples are typically tested. The typical stress-strain curves for a variety of commercial steels, including mild steel (ASTM A 36) and high-strength structural steels (ASTM A 514 and A 517), are shown in Figure 6.4. A clear upper yield point may not always exist, it should be recognised. The through-thickness direction, a third orientation, is frequently employed to assess a rolled product's vulnerability to lamellar tearing rather than its strength. In tensile specimens obtained in the through-thickness direction, steels that are prone to lamellar ripping due to welding exhibit low area reduction. According to Standard Specification for Through-Thickness Tension Testing of Steel Plates for Special Applications, ASTM A 770/A 770M, the specimens are made by welding extensions on either side of a plate or other rolled product, then cut into round tensile specimens with the region of interest within the gauge length.

Weld Tension Tests

The stress testing of welds is a little more difficult than the testing of base metal because weld test sections are heterogeneous and contain weld, HAZ, and unaffected base metals. To get a reliable Depending on whether the qualities of the weld metal or the weldment are of interest, a variety of different specimens and orientations must be employed for the assessment of weld strength and ductility. The strength of the composite weldment is typically assessed using rectangular specimens with the entire test-piece thickness. Specimens can be collected longitudinally or transversely to the weld. The transverse configuration is typically used in weld method qualification testing, in part because the properties in the transverse direction are more susceptible to welding technique variations. For rectangular weld specimens, the entire test-piece thickness is normally evaluated, and occasionally the test specimen's weld reinforcement is kept intact to reflect the weldment's characteristics.

All-Weld-Metal Test

Determine the tensile strength, yield strength, elongation, and reduction area of the weld metal using the all-weld-metal tension test. In this test, the specimen is made entirely of weld metal and is orientated parallel to the weld axis. Joint preparation can influence the results because dilution from the base metal alters the chemical composition of the weld metal. The welding procedure and process to be utilised in production should be used to create the test weld when testing to ascertain the properties of the weld metal in a specific weldment. A standardised weld joint arrangement is employed in this test to minimise the impact of base metal dilution on the filler metal. Specifications for filler metal, such as Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding, ANSI/AWS A5.1.14, specify this process.

Longitudinal Weld Test

The test specimen is loaded parallel to the weld axis in the longitudinal weld test. The specimen's condensed cross section includes Base metal, weld metal, and heat-affected zone metal. During testing, equal and simultaneous strain is applied to all three zones. Regardless of strength, the base metal and the weld metal extend together till failure. Low weld metal ductility or a heat-affected zone may cause fracture at strengths lower than those of the base metal. The only information provided by the longitudinal weld test is regarding the ultimate tensile strength of weldments. Elongation can be quantified as a sign of the joint's ductility, though.

Transverse Weld Test

To make it easier to understand the test results for an entire welded joint, a transverse weld specimen is put to the test. The shortened portion of the base metal, heat-affected zones, and weld metal are all present in the specimen, which is often centred around the weld. The zone with the lowest strength tends to stretch and break first when all of these are tested at the same time under the same force. For instance, failure will occur outside the weld area if the weld metal has a higher strength than the undamaged base metal. In this situation, the test wouldn't offer any quantitative data regarding the metal used for the weld's strength. As a result, it shouldn't be utilised to compare weld metals quantitatively.

Most frequently, welding methods are qualified using the transverse weld tensile test to make sure that the resulting welds meet or surpass the design strength requirements. When transverse weld stress tests are conducted, only the ultimate tensile strength and the site of the fracture are typically reported. The tubular tension test is an additional type of transverse weld tension test. By inserting the welded pipe directly into the tension testing equipment, this test determines the strength of a complete girth weld in small-diameter (often smaller than 3 in. [75 mm]) pipes. Only the ultimate tensile strength is normally recorded, as with other composite weldment tests.

Fillet Weld Shear Test

Utilising a universal test machine, the fillet weld shear test is used to assess the shear strength of fillet welds. The test samples consist of Usually, actual weldments that are meant to be represented by the welds, therefore production techniques are used to prepare them. The two specimen kinds are longitudinal and transverse, If consistent, reliable test results are to be produced from the fillet weld shear test, specimen preparation methods are essential. For instance, when the root opening grows, the stress concentration at the root of the transverse fillet weld decreases, and differences in the root opening might lead to conflicting test results. Test specimens are also susceptible to undercut, bead surface contour, and heat-affected zone cracking. For this reason, crater effects should be eliminated by smoothing the longitudinal margins of transverse specimens. Additionally, corners should be somewhat rounded. The shear strength of the weld metal and the site of the fracture are the results that are often provided for transverse and longitudinal shear testing. As shown in Figure 6.7, the shear strength is computed by dividing the load by the shear area (effective weld length times theoretical throat). To prevent rotational and bending forces during testing, transverse shear specimens are tested as double lap joints.

When specimens are loaded parallel to the axis of the welds, the longitudinal shear test assesses the shear strength of the fillet welds. Two identical welded specimens are machined and then tackily joined to prevent bending while being tested, as shown in Figure 6.8. Alternatively, a single set of foundation plates can be welded to the lap plates.

Tension-Shear Test for Brazed Joints

The strength of the filler metal in brazed joints is assessed using the tension shear test. exemplifies the joint designs and specimen configuration used for this test. By brazing using a filler metal, two single ferrous or nonferrous sheets that are each 1/8 in. (3 mm) thick are bonded. The tensile load at failure is divided by the brazed area to get the filler metal's shear strength. To maintain precise specimen alignment during brazing, such test specimens require the right fixturing. The tension-shear test is largely utilised as a research tool for the development of filler metals and brazing techniques, even though it has been standardised for the control testing of samples from production brazing cycles. It is also used to contrast filler metals made by different producers.

Hardness Tests

Testing for hardness identifies a material's resistance to piercing. Even yet, the findings of hardness tests are frequently utilised as a rapid way to estimate ultimate tensile strength in the tested area. Hardness Measurements can also reveal details regarding welding-related metallurgical changes. In alloy steels, a high hardness may signify martensite in the heat-affected zone of the weld, whereas a low hardness may signify an over-tempered condition. Due to recovery and recrystallization, welding can dramatically reduce the hardness of the cold-worked metal in the heat-affected zone. Averaging from welding in age-hardened metal might lead to a decreased heat-affected-zone hardness.

To create an indentation on the test specimen's surface, a penetrator is used to perform hardness tests. The test technique and hardness range determine the type of material, geometry, and size of the penetrator, which can be hardened-steel spheres or diamond pyramids. Metals can be tested for hardness using the Brinell, Knoop, Vickers, and Rockwell tests. The area of indentation under load is used as a measure of hardness in the first three tests. The depth of indentation under load serves as a hardness indicator in the Rockwell test. Then, using a standardised approach for each method as specified in Standard Test Methods and Definitions for Mechanical Testing of Steel Products, ASTM A 370.20, the diameter or depth of the indentation is measured and translated to a hardness value.

The hardness number shall always be published, either explicitly or by standard acronyms such as those described in the document listed above, together with the method, test load, and type and size of penetrator employed. The hardness or strength of the metal, the size of the welded connection, and the sort of information required are the main factors in choosing a hardness test method. Hardness tests determine the material's average hardness by making an indentation in it. Larger indentation tests are more accurate representations of a metal's bulk characteristics. A large indentation, typically 0.08 in. to 0.22 in. (2 mm to 5.6 mm) in diameter, is produced by the Brinell test, which provides an average hardness for the largest sample of metal. The indentation created by the Rockwell test is substantially smaller and suitable for hardness traverses. These indentations, which may be larger than the precise areas of concern, like a fusion zone or a coarse-grain region in the heat-affected zone, are nonetheless macroscopic.

The Vickers and Knoop microhardness tests create tiny indentations for microscopic areas, which are ideal for hardness measurements of the various heat-affected zones and for closely spaced traverses. Using a metallograph and these tests, you may determine the metal's individual grains' and inclusions' hardness. Cross sections of a weld joint that have been ground, polished, or polished and etched can all be subjected to hardness tests. Depending on the test technique and objective, measurements can be done on any particular portion of the weld or base metal. As seen in Figure 6.19, hardness indentations are frequently made at regular intervals across the whole weld cross-section. The Vickers method is frequently used to conduct hardness traverses of a weld cross section because the minute indentation reveals local microstructural alterations in the weld metal and heat-affected zone [8]–[10].

CONCLUSION

To identify the root causes of failures and defects and provide suggestions to improve the quality of the weld joints, several approaches for assessing the weld joint quality of the pipes were combined. We can locate welding flaws on the macrostructures of welds utilising technical procedures and a stereomicroscope. We identified them and categorised them into groups, classes, and subgroups following reliable standards. Steel bridges and aeroplane parts are just two examples of the many uses for welded constructions. For capabilities and traits that relate to services, similar to how the welded joints are constructed in these structures and components. Predicting service performance based on laboratory testing presents a difficult problem since weld size, configuration, environment, and the kinds of loads that weldments are subjected to differ from structure to structure. This complexity is increased by the fact that welded jointswhich consist of undamaged base metal, weld metal, and a heat-affected zone (HAZ)are metallurgically and chemically heterogeneous.

REFERENCES

[1] P. Corigliano *et al.*, “Fatigue assessment of Ti-6Al-4V titanium alloy laser welded joints in absence of filler material by means of full-field techniques,” *Frat. ed Integrita Strutt.*, 2018, doi: 10.3221/IGF-ESIS.43.13.

[2] J. Sun, J. Hensel, T. Nitschke-Pagel, and K. Dilger, “Influence of restraint conditions on welding residual stresses in H-type cracking test specimens,” *Materials (Basel).*, 2019, doi: 10.3390/ma12172700.

[3] Z. G. Xiao and K. Yamada, “A method of determining geometric stress for fatigue strength evaluation of steel welded joints,” *Int. J. Fatigue*, 2004, doi: 10.1016/j.ijfatigue.2004.05.001.

[4] Y. Takashima and F. Minami, “Prediction of charpy absorbed energy of steel for welded structure in ductile-to-brittle fracture transition temperature range,” *Yosetsu Gakkai Ronbunshu/Quarterly J. Japan Weld. Soc.*, 2021, doi: 10.2207/QJJWS.38.103S.

[5] P. Štefane, S. Naib, S. Hertelé, W. De Waele, and N. Gubeljak, “Crack tip constraint analysis in welded joints with pronounced strength and toughness heterogeneity,” *Theor. Appl. Fract. Mech.*, 2019, doi: 10.1016/j.tafmec.2019.102293.

[6] G. Dell’Avvocato, D. Palumbo, R. Pepe, and U. Galietti, “Non-destructive evaluation of resistance projection welded joints (RPW) by flash thermography,” *IOP Conf. Ser. Mater. Sci. Eng.*, 2021, doi: 10.1088/1757-899x/1038/1/012003.

[7] A. Loureiro, M. Lopez, R. Gutierrez, and J. M. Reinosa, “Experimental evaluation, FEM and condensed stiffness matrices of 2D external welded haunched joints,” *Eng. Struct.*, 2020, doi: 10.1016/j.engstruct.2019.110110.

[8] H. Wang, F. Qiu, H. Qian, D. Chen, and F. Fan, "Bending performance of connection-corroded welded hollow spherical joints," *Thin-Walled Struct.*, 2021, doi: 10.1016/j.tws.2020.107226.

[9] T. Kannengiesser and T. Boellinghaus, "Cold cracking tests - An overview of present technologies and applications," *Welding in the World*. 2013. doi: 10.1007/s40194-012-0001-7.

[10] N. P. Senapati and R. K. Bhoi, "Numerical simulation of temperature distribution by 9-point finite difference scheme to study the weld properties of AA1100 friction stir–welded joints," *Weld. World*, 2021, doi: 10.1007/s40194-021-01142-y.

CHAPTER 24

EXPLORING THE ADVANTAGES OF AUTOMATEDROBOTIC WELDING

Mr. Ranveer Singh, Associate Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id: ranveer@jnujaipur.ac.in

ABSTRACT:
Advanced welding techniques such as robotic, automated, and mechanized welding have completely changed the welding business. These innovations have greatly increased welding productivity, quality, and efficiency; as a result, they are becoming more and more common in a variety of sectors, including the construction, automotive, and aerospace industries. Utilizing welding apparatus that is managed by a human operator constitutes mechanized welding. By automating some welding processes variables, such as the travel speed, torch angle, and wire feed rate, this method offers constant and accurate welding. Utilizing cutting-edge, computer-controlled welding technology that can complete welding tasks without the need for human interaction is known as automated welding. In high-volume production settings where accuracy and consistency are crucial, this technology is used. By employing robotic arms to carry out welding tasks, robotic welding advances automation. Complex welding processes can be completed quickly, accurately, and with high precision thanks to this technology. Robotic welding systems are flexible and may change to meet shifting production demands.

KEYWORDS:

Automated Welding, Mechanized Welding, Robotic Weald, Welding Equipment.

INTRODUCTION

The various welding processes' application techniques are divided into groups based on how much operator engagement is required. operations. Manual welding is defined as "welding with a torch, gun, or electrode holder held and manipulated by hand" in the American National Standard Standard Welding Terms and Definitions. The welder performs the welding function and maintains continuous control of the welding operations by hand. In semiautomatic welding, which is described as "manual welding with equipment that automatically controls one or more of the welding conditions," the electrode is automatically fed to the arc while the welder manipulates the welding gun to make the weld [1], [2].The welder's intervention in mechanized welding, which is defined as "welding with equipment that requires manual adjustment of the equipment controls in response to visual observation of the welding, with a torch, gun, or electrode holder held by a mechanical device, entails making adjustments to the equipment controls in response to visual observation of operations. The welder's involvement in automated welding, which is defined as "welding with equipment that requires only occasional or no observation of the weld, and no manual adjustment of the equipment controls, is limited to turning on the machine to start the welding cycle and occasionally if at all, looking at the weld.

Robotic welding, which is described as "welding that is performed and controlled by robotic equipment, doesn't require the welding operator to be present during the welding process because welding robots perform and control the welding activities. However, the operator actively participates in quality control in both robotic and automated welding by detecting the existence of weld discontinuities. Maintenance or programming workers must take the proper action to repair deviations when discontinuities are discovered. "Welding with a process control system that automatically determines changes in welding conditions and directs the equipment to take appropriate action" is what is meant by adaptive control welding. This process application uses sensors to give the computer controller real-time information on anomalies. The controller then adjusts the welding parameters as needed to produce high-quality welds. As a result, welding is carried out and managed without the help of an operator.Modern welding techniques such as robotic, automated, and mechanized welding have completely changed the manufacturing sector. These technologies conduct welding jobs with a high degree of precision and efficiency using specialized tools and software. Mechanized welding involves automating welding activities while still requiring human input for setup and control utilizing tools like weld carriages and manipulators. The use of pre-programmed welding patterns and sequences to carry out welding activities automatically takes automated welding a step further.

Robotic welding advances automation by using robots that are controlled by computers to carry out welding operations. These robots are extremely accurate, reliable, and effective, and they can work continuously. They are especially helpful in high-volume production settings where efficiency and reliability are essential. Compared to conventional hand welding, mechanized, automated, and robotic welding have various benefits. They can dramatically raise output, enhance quality, and lower the possibility of mistakes and flaws. By eliminating the need for physical labor in dangerous areas, they also provide higher safety advantages. To operate, maintain, and program these technologies, you must have specialized training and knowledge. They also demand a large upfront investment in hardware and software. Advanced welding techniques including robotic, automated, and mechanized welding have a big impact on production, quality, and safety. Although they demand specialized knowledge and funding, implementing these technologies can have significant long-term benefits for industrial companies.

Mechanized Welding

To save labor costs and increase quality, automated welding is frequently chosen and used, especially when welding and cutting activities involving huge constructions or components. The majority of fusion welding and thermal cutting techniques can be employed with it. When welding is done mechanically, it is done under the supervision and control of a welding operator. The following variables are within the control of the automated welding equipment.

1. Initiation and control of the welding arc,

2. Feeding the welding electrode wire into the arc.

3. Control of movement and travel speed along the joint.

The loading and unloading of the workpieces may or may not be handled by the equipment.

Mechanized welding needs to give enough time for the welding operator to keep an eye on and regulate both the welding process variables and the operation's guidance components. With adequate process variable control, weld quality and output are frequently improved. The operator must be situated close to the welding spot to properly monitor the process while doing this duty. He or she works continuously with the machinery to make sure the weld metal is placed correctly and is of high quality. It can be necessary to adjust the wire feed rate, current, voltage, torch position, torch extension, and travel rate.

The carriage's travel speed is a significant welding variable because consistent speed and weld direction during operation is essential for high-quality welds. The rigidness with which the welding carriage is fastened to the track also affects quality since excessive vibration or dimensional variation might harm the position of the wire tip. Mechanized welding increases the consistency and quality of the welds by boosting process efficiency and reducing operator fatigue. When making lengthy linear or circumferential welds, this application method is capable of providing weld profiles that are homogeneous and constant. Microprocessors are used to adjust preset parameters when a production change necessitates a new setup, lowering the possibility of human setup errors that could result in lower-quality welds and lost production. When opposed to manual welding, mechanical welding needs fewer starts and stops, which lowers the risk of various weld discontinuities brought on by stopping and starting the welding arc. A mechanized welding system that shows side-beam carriage welding structural columns with submerged arcs [3], [4].

DISCUSSION

System Components

A wire spool holder, gas supply, feeding mechanisms, tracking system, and power source are among the system components utilized in mechanized welding installation travel gadgets.

Travel Devices

Various travel devices are used in mechanized welding to move an automated welding head about the workpiece being welded or vice versa. The workpiece may be moved underneath a stationary welding head or it may be stationary while a welding head is physically moved along the weld joint. The following four categories best describe the travel devices used in mechanized welding operations.

1. Welding carriages

2. Welding head manipulators

3. Specialized welding machines

4. Welding positioners

Carriages being welded. Arc mobility may be accomplished reasonably cheaply with welding carriages. On the same kind of straight or curved track as a regular carriage, similar to the shape of the welding junction, some carriages are specifically made to ride on the surface of the material being welded when welding in the flat position, while others use the weld joint itself as guiding.The welding controls and carriage are often located close to the operator since the welding carriage is made to allow the operator to view and interact with the system. A worker supervises a side-beam carriage with a dual wire feed system while it welds submerged arcs on earth-moving machinery. Tractor carriages are typically welded flat or horizontally. For welding in horizontal, vertical, or above positions, other varieties of welding carriages are used. The welding carriage is positioned on a specific track or cam in carriages made to follow uneven joint contours. a mobile welding cart. The huge welds are necessary for structural, bridge, and ship weldingare frequently completed with this welding tractor, which moves along the surface of the workpiece during welding. It uses a tandem submerged arc technique. The side-beam carriage offers powered linear mobility for the welding heads and is positioned on a horizontal beam. The welding head, welding wire feeder, and typically the operator control panel are supported by the powered welding carriage. The horizontal cross-joint position and vertical height of the welding head are both movable. The welding operator keeps an eye on the process and modifies the side-beam carriage's travel speed and welding location to account for various welding techniques and differences in workpiece fit-up.The fabrication of lengthy, flat-position groove and fillet welds, like those seen in ships and barges, as well as cladding applications for increased wear or corrosion resistance, is where welding carriages are most productive. They are also helpful while conducting fieldwork, such as when building tanks and bridges [5], [6].

Welding Head Manipulators

To position the welding head for longitudinal, transverse, and circular welds, welding manipulators are employed. Most manipulators tend to consist of a vertical mast and a boom that is horizontal and has a welding head on it. The mast typically swivels on the traveling base, and they typically have the power to raise and lower the boom. In certain manipulators, the boom moves horizontally on the mast assembly while in others, the boom moves along the welding head. The majority of manipulators include controls that slowly move the weld head in both the transverse and vertical axes. With this motion, the operator can modify the welding wire's position to account for changes along the weld joint.

a substantial welding head manipulator transporting an underwater arc welding machine. All welding and manipulation controls are situated at the operator station, as can be seen. The boom or welding head must move during operation at consistent speeds that are compatible with the welding process. If the manipulator is intended to move along rails on the shop floor, the carriage must move consistently and at a set speed. To lessen the likelihood of weld wire mislocation, the manipulator must be rigid and deflection must be kept to a minimum. It's crucial to ascertain and account for the real weight that needs to be carried at the end of the boom when choosing and configuring a welding manipulator. Heavy-duty manipulators frequently sustain both the operator's weight and the weight of the welding apparatus.

Specialized Mechanized Welding Machines

Custom clamping devices, workpiece transfer, load and unload systems, torch travel mechanisms, and other unique characteristics can be found on specialised mechanised welding machines. On tanks and cylinders, pipe, and tubing, for instance, longitudinal and circumferential welds are created using welding machines with orbital heads. Other specialized welding equipment is used to construct flanged beams, weld studs or bosses to plates, and carry out unique maintenance tasks like upgrading crawler tractor trackpads. a specialized mechanized welding device for light vehicles that clamps and welds coverings on axle housings.

System Components

A power supply, system controller, welding interface, welding torches, seam-tracking system, and feeding system can all be found in automated arc welding equipment.

Power Source

For automated welding, a variety of power sources can be utilized. The two most typical types are pulsed arc and continuous voltage. Automated Arc welding power sources could need a few unique capabilities to work with the system controller. For instance, a power source must be able to electronically communicate with the controller using analog or digital inputs and outputs, or even both. Given that welding a component may necessitate the use of numerous welding programs, communication is essential for optimal welding performance. Throughout a typical automated function, welding schedules may change often. In manual welding, the welder frequently adjusts the welding power source settings to the midpoint of a welding current range that is suited for a variety of welds. To improve the quality of the weld, however, precise parameter modifications can be made automatically in automated welding. These parameter modifications must be repeated with accuracy and reliability. device. The details of these system parts are provided below.

System Controller

The welding system controller, the key component of an automated welding system by which each device in the system is controlled, is in charge of all other devices. The equipment performs its task. If configured properly, each device can inform the controller of its status. After that, the controller contrasts the feedback data with the anticipated data. If a variation occurs, the controller determines the necessary adjustment and modifies the operation as necessary.

Welding Interface

While accepting commands from the system controller, the welding interface coordinates the actions of the power source and feeder.

Welding Torches

For automated welding equipment, the duty cycle ranges from 50% to 90%. Torches that are water-cooled rather than air-cooled are when higher duty-cycle ratings are required, preferable. Water-cooled torches need more frequent maintenance and the installation of adequate flow sensors, whereas air-cooled torches do not rely on an additional cooling medium (such as water or pressurized air).

Seam-Tracking System

Positioning the welding gun or flame correctly concerning the workpiece is one of the difficulties in carrying out an automated arc welding procedure. so that the welds are created with uniform geometry and quality. to the weld joint. The precise location and homogeneity of the weld joints can vary from one assembly to the next due to dimensional tolerances of the parts, changes in edge preparation and fit-up, and other dimensional variables. As welding progresses along a joint, some adjustment of the welding gun or torch location may be necessary.

A welding gun or torch can be guided along a joint using several different ways.10 The simplest one uses a mechanical seam follower system, which physically centers the torch in the joint and tracks the contours of the workpiece vertically and horizontally using springloaded probes or another mechanism. These systems are restricted to weld junctions with characteristics that are tall enough or wide enough to sustain the mechanical followers. Other tracking systems make use of portable electronic probes that drive motorized slides that change the location of the torch to track the joint. These devices provide a substantial improvement over mechanical seam follower systems because they can function at greater speeds and follow much tiny joint features. They are typically utilized with nonrobotic automation and have a limited capacity to trace multiple-pass and square-groove welds.

There are still further seam-tracking systems that have arc detection capabilities. For both gas tungsten arc welding (GTAW) and plasma arc welding (PAW), the most basic type is arc voltage control. By using voltage feedback directly from the arc, this control keeps the torch consistently above the task. There are also numerous optical tracking technologies available. By adjusting process parameters (such as travel speed or wire feed speed) while tracking the joint, the most advanced seam-tracking systems are fully adaptable to accommodate volume changes in weld joints.

The single-pass or real-time system previews the operational arc and gives feedback for adjusting the welding variables and torch path. Sharp corners and highly shiny surfaces are challenging for real-time systems. Smoke and arc heat can also have an impact on them. These systems also call for a camera to be placed just inches away from the welding torch, which could provide a clearance issue when tracking into corners and small places. In the two-pass system, the arc is turned off while a camera or laser scan is moved along the nominal weld path. The system conducts analysis and welds pass correction during the first pass. A second pass is then made to weld the junction with the arc on. However, this technique is unable to compensate for any deformation that results from welding.

Feeding Device

A dependable, fast wire feeder that is connected to the system controller and the welding power supply is necessary for automated systems. To suit particular welding needs, a feeder enables variable control of wire-feed rates. The wire feeder may occasionally need to be calibrated to maintain optimal operation and dependability. Automated arc welding often uses more wire than manual arc welding, and the amount of arc-on time is typically two or three times that of semiautomated welding. The wire conduit liners and guides commonly become clogged with debris and leftover lubricants from the wire surface as a result of these high production rates. As a result, frequent inspection and cleaning procedures should be carried out.

Robotic Welding

Robots are described as "an automatically controlled, reprogrammable multipurpose manipulator programmable" by the Robotic Industries Association (RIA). for usage in industrial automation applications, in three or more axes that can either be stationary or mobile. Industrial welding robots use a variety of multiaxis, servo-controlled manipulators, and software to undertake intricate, continuous welding procedures. To handle new workpieces, a variation in existing workpieces, or a change to the weld seams solely, the welding program can be modified.

In the United States, industrial robots were first made available for purchase in 1961. Although these product options were not appropriate for arc welding applications, by 1964 they had been modified for resistance welding in the automotive sector. Although the first multiaxis robot suited for arc welding applications was introduced in 1972, it wasn't until the late 1970s that welding robot utilization became widely used. Robotic resistance welders dominated the market in terms of sales during the 1980s. Robotic arc welding equipment sales as a percentage of new robot sales increased in the 1990s, especially outside the automobile sector.

For a variety of reasons, robots are perfect for both arc and resistance welding. Robots can operate in dangerous conditions because they are resistant to the challenges that radiation, fumes, heat, and other hazards provide. Based on sensory input, they provide reproducibility and dependability and adjust to the welding process' physics. Robotic welding systems also have the adaptability to switch between welding processes in a manner that is nearly uninterrupted. Flexible automated welding systems and robotic systems have traditionally cost more than other automated or mechanical devices. However, the cost of robots has come down while their capabilities and usability have continually increased. However, while the overall capabilities have only marginally increased, the costs of fixed automation have stayed the same. Comparison research should be conducted to ascertain the actual life-cycle cost of each system under consideration to choose the one that is best for a given task.

Despite their higher cost, welding robots overtake manual, mechanical, and other fixed and flexible automation methods to take a larger share of the welding market every year. Although cost is a crucial consideration when choosing a process application method, the choice to use welding robots is often influenced by several factors. Flexibility, durability, product quality, ergonomics, and worker health and safety are a few of them.

Operator Training and Education

Training is essential to the success of any automated or robotic installation, regardless of how basic or sophisticated it may be. programs for operator education and training are crucial elements in the automation planning process. All people involved in welding automation have a strong basis thanks to the combination of fundamental knowledge and real-world experience. Operators and other relevant staff members need to be well-versed in the technique being used. It is vital to have a practical understanding of welding equipment, ancillary equipment, and cell component maintenance requirements. It's important to properly comprehend safety circuits and flexible automation's control logic.

Even while learning takes place a lot on the job, system programming calls for planned, ongoing training. The documentation for flexible automation must be fully understood by technicians working with it, covering the weld cell operation, weld operations, and weld troubleshooting. Personnel must be aware of the robot's arm's mechanical capabilities. The recommended training specifications are outlined. Long-term equipment and production metrics should be established in documentation for automated equipment. Equipment manuals, operating instructions, and graphical data that support system operation and maintenance should also be included in the documentation. Robots need a method for numbering, filing, updating, and maintaining their running programs.

Investment

An automated or robotic system requires expensive design and construction, thus the cost must be justified by showing how much better the system will be. economical. Potential welding automation initiatives should undergo a cost-justification study. The return on investment (ROI), return on assets (ROA), return on equipment (ROE), payback time, internal rate of return (IROR), and net present value (NPV) are a few of the measuring methodologies used to assess the investment and payback duration.

The net income is divided by the investment to determine the return on investment. An ROI calculation takes stockholders' equity, invested capital, and the average total assets over the previous two years into account, among other things. The investment is more attractive the larger the ratio. Consistent quality, lower variable welding costs, predictable welding production rates, ability to integrate with other automated operations, and increased productivity because of faster welding speeds, higher filler metal deposition rates, and longer arcon times (efficiency) are some factors that affect the return portion of the ratio. The procurement of automated or robotic equipment, tooling and fixturing, support equipment, and necessary upstream or downstream process modifications are among the variables that affect the investment side of the ratio.

The approach that is most frequently used to support an automation project to top management is the payback period calculation. This technique is straightforward to apply and comprehend. The following formula could be a straightforward repayment technique using the following variables:

$$\mathbf{P = I / L - E}$$

P = Payback,

I = Investment,

E = Expense of automation,

L = Savings (derived from reduced labor costs, quality enhancement, and so forth).

Changeover Time and Inventories

An automated cell's output levels are impacted by frequent changeovers, particularly when new fixturing is required. Fixture optimisation for cell utilisation Placement must be precise and effective. By supporting varied production needs, such as just-in-time inventory, the proper utilization of changeovers boosts overall efficiency. Flexible welding automation can significantly reduce costs by boosting inventory turnover. This saves money and space by reducing the inventory of finished goods and work-in-progress.

Floor Space

The amount of plant floor space affects product costs. When a cell concept is used, the quantity of floor space required for an operation can frequently be decreased. Product The amount of flow into and out of the cell matters just as much as the space it takes up. Inefficient material flow cannot be tolerated in a manual activity, yet it is necessary for automating an operation.

Personnel Requirements

The number of qualified workers that are readily available for welding shops is frequently restricted. Welders with advanced skills are in great demand and make a good living. However, Workers with less welding experience can operate automated and robotic welding equipment as long as experienced employees are present to maintain production uptime and quality. expenses can be reduced via automation by lowering the number of people required in a cell [7]–[8].

CONCLUSION

When welding is done mechanically, tools like automatic wire feeders, torches, and positioners are used to help the welder complete the job. The use of machines like welding robots and automated welding cells takes automated welding a step further by enabling welding operations to be completed automatically. The most sophisticated type of automated and mechanized welding is robotic welding, which uses programmed robots to carry out welding jobs with a high degree of reproducibility and precision. To further boost the effectiveness and quality of the welding process, robotic welding systems can also be integrated with other tools like vision systems and sensors. Technologies for robotic, automated, and mechanized welding are especially helpful in high-volume production settings where constant quality, speed, and efficiency are essential. Although these technologies may not be appropriate for low-volume production or projects requiring bespoke welding, they do demand major investments in hardware, software, and training.

REFERENCES

[1] H. B. Cary, “Modern Welding Technology 5/e,” *Ind. Robot An Int. J.*, 2004, doi: 10.1108/ir.2004.31.4.376.3.

[2] P. Kah, M. Shrestha, E. Hiltunen, and J. Martikainen, “Robotic arc welding sensors and programming in industrial applications,” *International Journal of Mechanical and Materials Engineering*. 2015. doi: 10.1186/s40712-015-0042-y.

[3] J. Rigelsford, “Modern Welding Technology 5/e,” *Ind. Robot An Int. J.*, 2004, doi: 10.1108/ir.2004.04931aae.002.

[4] Y. Xue *et al.*, “Fuzzy regression method for prediction and control the bead width in the robotic arc-welding process,” *J. Mater. Process. Technol.*, 2005, doi: 10.1016/j.jmatprotec.2005.02.174.

[5] A. Kumar, S. E. Sanjeev Kumar, and E. D. P. Singh, “Robotic & Automated Welding,” *Int. J. Eng. Res. Manag. Technol.*, 2015.

[6] Anon, “Developments In Welding Automation.,” *Met. Constr.*, 1987.

[7] D. Begg, G. Beynon, E. Hansen, J. Defalco, And K. Light, “Development Of A Hybrid Laser Arc Welding System For Pipeline Construction,” 2009. Doi: 10.1115/Ipc2008-64599.

[8] Anon, “Developments In Mechanised, Automated And Robotic Welding, An International Conference.,” 1981.

CHAPTER 25

ELECTRIC WELDING PROCESSES: AN ASSESSMENT

Mr. Robin Khandelwal, Assistant Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id:robinkh16@jnujaipur.ac.in

ABSTRACT:

To create a robust bond, electric welding frequently involves melting the workpieces using the heat generated by electric current and then adding a filler material to create a pool of molten material. Electric arc welding techniques are now widely used to quickly repair a wide range of machinery and apparatus necessary for the successful conduct of the current World War due to the demanding demands of the battle. The British Admiralty has extensively used the method for ship construction, including the sealing of seams, removal of some rivets, and minor structural components. To fuse materials, an electric arc and filler metal with a stick electrode or wire are used in electric welding. The Welding Technology program teaches four basic methods of electric welding, which are collectively known as arc welding. By heating two similar metals together, welding is the process of connecting them. The metal components are heated until they melt. The metal pieces that need to be linked may occasionally be heated to the plastic stage and fused. Either dc or ac type electric welding equipment is available.

KEYWORDS:

Welding, Arc, Electrode, Metal, Electric, Heat.

INTRODUCTION

There are two different types of DC welding sets: generator-type welding sets and dry-type welding sets. A differential compound wound dc generator with a drooping volt-ampere characteristic can be driven by any type of prime mover, including an induction motor with a squirrel cage or a gasoline or diesel engine. The control in generator-type welding setups may be obtained by tapping the series field or by offering an appropriateBy heating two metal or non-metal parts to their melting points, welding is the act of connecting them. It is possible to utilize filler metal to unite two components. When welding, the physical and mechanical characteristics of the material, such as the melting point, density, thermal conductivity, and tensile strength, are crucial. Different types of welding, such as thermal welding, gas welding, and electric welding, depending on how the heat applied is produced. Only electric welding will be covered in this chapter, along with a brief introduction to other contemporary welding methods. Nowadays, welding is widely employed in the car sector, thermal power plant pipe fabrication, machine repair, machine frames, etc. The formula for converting electrical energy to heat energy Electric welding is the practice of fusing two or more materials by heating them with an electric current. To create a robust bond, electric welding frequently involves melting the workpieces using the heat generated by electric current and then adding a filler material to create a pool of molten material [1].This is a process of welding in which the heat energy is obtained from electricity. The formula for converting electrical energy to heat energy

$$H = I\ 2RT$$

Were,

H Amount of heat produced on jouls.

I Amount of current passing in amps.

R Resistance of a medium in ohms.

T Time during which the current flow.

Electric Welding Types

There are primarily two categories for electric welding processes:

Electric arc welding: When the two terminals of an electric circuit are brought together and then separated by a little space, an electric arc is created. High current flows from one conductor to another over an air gap, creating extremely intense and concentrated heat. of a flame. This spark's (or arc's) temperature, which can swiftly melt and fuse the metal to create a homogenous weld, is around 3600°C. There are several different kinds of electric arc welding.

Electric resistance welding: it is a form of pressure welding in which heat is produced by the passage of a strong brief electric current. through the welding joint's built-in electrical resistance. A homogenous weld is obtained by applying enough pressure to promote fusion after the joint enters a plastic state.

Electric Arc Welding

Metallic arc welding

A metallic (consumable) electrode and the welding work form an arc during this arc welding procedure, which generates the welding heat. The electrode melts and serves as the filler metal.

Carbon arc welding

The welding job and a carbon electrode (which is non-consumable) are what create the arc in this instance. Since the carbon filler rod is separate, Since it is non-metal, the electrode won't melt.

Atomic hydrogen arc welding

In this procedure, an arc is created between two tungsten electrodes in a hydrogen gas environment. The welding task is yet unfinished. The filler metal is added to the welding circuit using a separate filler rod.

Tungsten inert gas arc welding; under this procedure

an arc is created between non-combustible tungsten electrodes and the weldment under an environment of inert gas (such as argon or helium). The filler metal is added using a different filler rod. This method is also known as the gas tungsten arc welding (GTAW) method.

Gas metal arc welding (GMAW) or Metal inert gas arc welding (MIG)

Metal inert gas arc welding (MIG) is the name of the process in which the arc is created between a continuous, automatically supplied, metallic consumable electrode and the weldment.

Submerged arc welding

In this procedure, an arc is created between a metallic consumable electrode that is continuously and autonomously fed and the weldment underneath a mass of powdered or granulated flux. The arc is completely obscured by the flow.

Electro-slag welding; Under a deep pool

The welding job and a continuous, automatically fed metallic consumable electrode form the arc. of flux, molten (slag). This automated method needs specialized gear and is only employed vertically for welding large, heavy plates.

Plasma arc welding

In this method, an atmosphere of the plasma-forming gases argon, nitrogen, and hydrogen is used to create an arc between the welding job and a tungsten electrode. a different If additional filler metal is required, it is added using a filler rod in the joint. However, a filler rod is not typically used. TIG welding is comparable to the procedure. Non-ferrous metals and alloys can be successfully and swiftly cut using plasma cutting.

Applications of electric welding

Empennages, wings, and fuselages, Cryogenic fuel containers for spacecraft, Tanks for aviation fuel, For military aircraft, external disposable tanks, rockets used in science and the military, and fixing damaged MIG welds.

DISCUSSION

Shielded Metal Arc Welding (Smaw)

Salient Features

It is an arc welding procedure in which an electric arc provides the heat needed for the welding**.** When electricity jumps across an air gap (ionization of air) between the end of the metallic electrode and the welding job surface, an electric arc is created. The consumable flux is typically applied to the metallic electrode. Between 3600 and 4000 degrees Celsius is the range of the temperature of the high arc heat produced by the arc formed by the ionization of air between the electrode tip and the base metal. An AC or DC machine provides the welding current. Immediately beneath the arc and at the end of the electrode, a small portion (molten pool) is instantly melted by the intense heat of the arc When the welding job's molten pool cools, the melted electrode fuses with it to form a homogeneous weld. Additionally melting, the electrode's flux coating creates a gaseous shield around the arc to provide safety. The molten metal from contaminated by the atmosphere. Therefore, this process is known as shielded metal arc welding (SMAW).The welder himself controls the electrode feed and welding speed manually. Therefore, manual metal arc welding (MMAW) is another name for it. The slag (of flux coating) is deposited on the weld metal's surface when it hardens because it is lighter than the metal and is allowed to cool gradually and slowly [2]–[4].

Advantages

The following benefits explain why the method is popular**:**Metals of every type, both light and heavy gauge, can be welded. It can be used for construction, maintenance, and fabricating tasks. You can weld any kind of metal, including ferrous, non-ferrous, and alloys.

It enables a professional operator to swiftly and easily complete the welding procedure. It is better suited for welding of shorter lengths. It costs less than the other processes. In comparison to other arc welding techniques, it is less sensitive to welding and portable**.**

Limitations

Less metal is deposited each hour, making it ineffective for heavy fabrication welding and necessitating the employment of more welders.It is challenging to control the distortion. Due to the precise length of the electrode, continuous and automatic welding is not possible. More pressure on the welder.

Applications

In small and medium-sized companies, it is utilized to weld both thick and thin gauge metals. Used for welding bus bodies, bridges, and household items including windows, doors, andgrilles for gates, seats, and tables. Used to weld water and oil tanks, cracked and fractured castings, and roof structures for workplaces.This procedure is highly helpful whenever welding is done outside because a diesel generator welding set can be employed. This procedure is utilized for welding repairs, hard-facing, and repairing shattered pieces.

Arc Length

When the arc forms, it is the straight distance between the electrode tip and the work surface. Arc lengths come in three different varieties:

- Medium or Normal
- Long
- Shor

Medium, normal arc

The correct arc length or normal arc length is approximately equal to the diameter of the core wire of the electrode. This is a stable arc producing a steady sharp cracking sound and causing**:**

- Even burning of the electrode
- Reduction in spatters
- Correct fusion and penetration
- Correct metal deposition

It is used to weld mild steel using a medium-coated electrode. It can be used for the final covering run to avoid undercut and excessive convex fillet/ reinforcement

Long arc

If the distance between the tip of the electrode and the base metal is more than the diameter of the core wire it is called a long arc. It makes a humming sound causing:

- unstable arc
- oxidation of welded metal
- poor fusion and penetration
- poor control of molten metal
- more spatters, indicating the wastage of electrode metal.

It is used in plug and slot welding, for restarting the arc, and while withdrawing the electrode at the end of a bead after filling the crater. Generally long arc is to be avoided as it will give a defective weld.

Short arc

If the distance between the tip of the electrode and the base metal is less than the diameter of the core wire, it is called a short arc. It makes a popping sound causing: the electrode melting fastly and try to freeze with the job

1. higher metal with narrow-width bead
2. fewer spatters
3. more fusion and penetration.

It is used for root runs to get good root penetration, for positional welding, and while using a heavy coated electrode, low hydrogen, iron, powder, and deep penetration electrode.

Safety In Manual Metal Arc Welding

During arc welding the welder is exposed to hazards such as injury due to harmful rays (ultraviolet and infra-red rays) of the arc, burns due to excessive heat from the arc and contact with hot jobs, electric shock, toxic fumes, flying hot spatters and slag particles and objects falling on the feet. The following safety apparel and accessories are used to protect the welder and other persons working near the welding area from the above-mentioned hazards.

1. **Safety apparels**
   a. Leather apron
   b. Leather gloves
   c. Leather cape with sleeves
   d. Industrial safety shoes
2. **Hand screen**
   a. Adjustable helmet
   b. Portable fireproof canvas screens
3. **Chipping/ grinding goggles**
4. **Respirator and exhaust ducting**

Safety apparel

To protect the welder's body, hands, arms, neck, and chest from heat radiation and hot arc spatters as well as from hot slag particles flying from the weld joint during chipping off the solidified slag, the welder wears a leather apron, gloves, a cape with sleeves, and leg guards. The welder must choose the proper size for all the aforementioned safety gear, which should not be worn loosely.To prevent slips and injuries to the toes and ankles of the foot, people wear industrial safety boots.Because the sole of the shoe is made specifically of shock-resistant material, it also shields the welder from electric shock.

Welding hand screens and helmet

These are used to shield a welder's face and eyes from sparks and arc radiation while arc welding. A hand screen is made to be held in the hand. The purpose of a helmet screen is to be worn on the head. It offers enhanced safety and enables the free use of both hands for the welder. To see the arc and molten pool when welding, screens are formed of non-reflective, non-flammable, insulated, dull-colored, light material with colored (filter) glasses fitted with plain glasses on both sides. The colorful glass has clear glasses installed on both sides to shield it from weld splatter. Depending on the welding current ranges utilized, colored (filter) glasses are produced in a variety of hues, as shown below: Arc flashes can harm those working close to a welding location, hence portable fireproof canvas screens are employed. When chipping or grinding the job, simple goggles are worn to protect the eyes. It is held firmly on the operator's head by an elastic band and has a Bakelite frame with clear glasses. It is made with a snug fit, appropriate ventilation, and complete all-around protection in mind.

Arc Welding Accessories

Arc welding accessories are a few crucial items that a welder uses with an arc welding machine during welding.

Electrode-holder

During arc welding, it is a clamping tool used to hold and move the electrode. It has superior electrical conductivity since it is constructed of copper and copper alloy. Different sizes of partially or fully insulated holders, such as 200, 300, and 500 amps, are available. A welding cable connects the electrode holder to the welding equipment.

Earth Clamp

It is used to firmly attach the earth cables to the work surface or welding table. Additionally, it is made of copper and copper alloys. There are different sizes of screw or spring-loaded earth clamps available, such as 200, 300, and 500 amps.

Welding cables/ leads

These are employed to transfer the welding current back and forth between the work and the welding machine. Both the lead from the work or job through the earth clamp to the welding machine and the lead from the welding machine to the electrode holder are referred to as electrode cables. Fine copper wires and layers of woven fabric serve as layers of reinforcement in cables, which are constructed of extremely flexible rubber insulation. Welding cables come in a variety of diameters (crosssections), such as 300, 400, and 600 amps, among others. For the electrode and the job, the welding wires must be the same size. The proper cable attachments (lugs) must be used to connect the cables. The cables overheat due to loose joints or poor connections.

Material Preparation Method

Cutting

Before welding them, the base metal must be cut and prepared to the necessary dimensions from the original material available. There are various ways to cut metals, including:

1. By chiseling the sheets, by hack-sawing, by shearing using hand lever shear, by using a guillotine shear, By gas cutting.

Tools and equipment used to cut metals

Cold chisel**,** Hacksaw with the frame**,** Hand lever shear**,** Guillotine shear**,** Oxy-acetylene cutting torch**.** The sheet or plate's cut edges must be filed to eliminate burrs and make the edges square (at a 90° angle) with one another. The edges of ferrous metal plates that are thicker than 3 mm can be prepared by grinding them on a bench or pedestal grinder.

Cleaning

Due to their prolonged storage, base metals will have contaminants including dust, oil, paint, water, and surface oxides when they are first cut to size. These contaminants will have an impact on the welding process and result in some welding joint problems. Therefore, it is essential to clean the surfaces to be joined and remove the dirt, oil, paint, water, surface oxide, etc. from the joining surfaces before welding to obtain a strong welded joint.

Importance of cleaning

Cleaning the connecting edges before welding is a fundamental need for any welding procedure. Oil, paint, grease, rust, dampness, scale, or any other foreign substance may be present on the connecting edges or surfaces. If these impurities are not eliminated, the weld will have weak, porous, and brittle characteristics. The state of the surface to be joined before welding has a significant impact on the success of welding.

Methods of cleaning

To remove oil, grease, paint, and other contaminants, chemical cleaning comprises washing the joining surface with solvents made from diluted hydrochloric acid. Wire brushing, grinding, filing, sandblasting, scraping, machining, and emery paper rubbing are all examples of mechanical cleaning. A wire brush made of carbon steel is used to clean ferrous metals. A stainless-steel wire brush is used to clean stainless and non-ferrous metals.

Open Circuit Voltage and Arc Voltage

An arc-welding electric circuit is depicted in the figure below. The voltage "V" displayed by the voltmeter in the circuit after turning on the welding machine is referred to as "Open circuit voltage" if no arc is formed or struck between the electrode tip and the base metal. Depending on the type of machine, this open circuit voltage can range from 60V to 110V. The voltage "V" displayed by the voltmeter in the circuit after turning on the welding machine is referred to as "Arc voltage" if an arc is struck or formed between the electrode tip and the base metal. Depending on the type of machine, the arc voltage will range from 18V to 55V.

Polarity In Dc Arc Welding

Importance of polarity in welding

When using a DC welder, two-thirds of the heat comes from the positive end and one-third from the negative end. The polarity is crucial for successful welding because it allows for the advantage of uneven heat distribution in the electrode and base metal. Because the power source's poles frequently change in AC, the polarity cannot be used. Two polarity types exist:

1. Straight polarity or electrode negative (DCEN)
2. Reverse polarity or electrode positive (DCEP).

Straight polarity (DCEN)

The work is linked to the positive terminal of the power source in straight polarity, while the electrode is connected to the negative terminal. Uses for straight polarity include:

1. welding with bare light-coated and medium-coated electrodes
2. welding the thicker sections down the hand position to obtain more base metal fusion and penetration.

Reverse polarity (DCEP)

In reverse polarity, the work is connected to the power source's negative terminal, and the electrode is attached to its positive terminal. Uses for reverse polarity include:

1. welding of non-ferrous metals
2. welding of cast iron
3. welding with heavy and superheavy coated electrodes
4. welding in horizontal, vertical, and overhead positions

5. sheet metal welding.

For hard-facing and stainless-steel welding, DC is recommended for AC. The producers of the electrodes must follow their instructions when choosing the polarity. The electrode must be connected to the proper welding machine terminal to produce the optimum results[5], [6].

Indication of the wrong polarity

If the electrode is used with the incorrect polarity, it will cause:

1. excess spatter and poor penetration
2. the improper fusion of the electrode
3. heavy brownish deposition on the face of the welded metal
4. difficulty in manipulation of the arc
5. the abnormal sound of the arc
6. poor weld bead appearance with surface defects and more spatter.

Advantages of Electric Welding

Electric welding is a quick and inexpensive way to join metals. Simple and transportable equipment is used for electric welding. The ability to weld any kind of metal is a huge benefit for welders. All metal products are manufactured or repaired frequently using welding. Design flexibility as needed can be accomplished. Electric welding can combine metal pieces in a shorter amount of time. Different metals can be welded using the electric welding technique, and high-quality products can be produced as a result. Electric welding is particularly helpful in the production of mechanization and automation. Electric welding does not require holes to create joins. Because less labor and material are needed, it is very economical. With electric welding, entire permanent joints can be created. Noise is made during the riveting process. But no noise is made during the welding process [7].The parent metal's structure is not identical to that of the electrically welded junction. Spatter, (light) vapors, and hazardous radiation are all produced by it. Such flaws, like internal air pockets or incomplete penetration, cannot be found [8], [9].

CONCLUSION

Electric welding typically entails melting the workpieces with the heat produced by electric current and then adding a filler material to create a pool of molten material to form a strong bond. Due to the rigorous requirements of the fight, electric arc welding techniques are now frequently utilized to quickly repair a wide range of machinery and apparatus necessary for the successful conduct of the present World War. The British Admiralty has made great use of the technique while building ships, sealing seams, and removing a few rivets and small structural elements.

Electric welding requires specialized labor. There is a great need for electricity. It's important to inspect the welded region once the equipment has been welded. Mercury is a metal that cannot be welded. Low-strength or low melting point metals cannot be used for electric welding. Checking a metal workpiece's physical and mechanical characteristics (such as temperature, density, thermal conductivity, tensile strength, ductility, etc.), availability, and cost are important before welding it.

REFERENCES

[1] Miller Welds, "Guidelines for Resistance Spot Welding," *Weld. Fundam. Process.*, 2018.

[2] Y. Yusmita and H. Hasanah, "Penerapan Ergonomi K3 Dalam Proses Pengelasan," *J. Tek. Ind. Terintegrasi*, 2021, doi: 10.31004/jutin.v3i2.1348.

[3] J. S. Reyna-Montoya, M. A. García-Rentería, V. L. Cruz-Hernández, F. F. Curiel-López, L. R. Dzib-Pérez, And L. A. Falcón-Franco, "Effect of electromagnetic interaction on microstructure and corrosion resistance of 7075 aluminium alloy during modified indirect electric arc welding process," *Trans. Nonferrous Met. Soc. China (English Ed.*, 2019, doi: 10.1016/S1003-6326(19)64956-3.

[4] H. Huh and W. J. Kang, "Electrothermal analysis of electric resistance spot welding processes by a 3-D finite element method," *J. Mater. Process. Technol.*, 1997, doi: 10.1016/S0924-0136(96)02705-7.

[5] I. Iatcheva, D. Darzhanova, and M. Manilova, "Modeling of electric and heat processes in spot resistance welding of cross-wire steel bars," *Open Phys.*, 2018, doi: 10.1515/phys-2018-0001.

[6] D. Devakumar and D. Jabaraj, "Research on Gas Tungsten Arc Welding of Stainless Steel–An Overview," *Int. J. Sci. Eng. Res.*, 2014.

[7] H. Zulhafril, J. Jasman, and K. J. Tespoer, "The Effect of Cooling Media on Tensile Strength of Medium Carbon Steel in Post Welding Process Using Electric Welding (SMAW) with E7018 Electrodes," *Teknomekanik*, 2020, doi: 10.24036/teknomekanik.v3i2.6472.

[8] N. H. Pattiasina, ST., MT, "Pelatihan Proses Pengelasan Menggunakan Mesin Las Listrik dalam Upaya Peningkatan Ketrampilan Pekerja di Desa Rumahtiga," *J. SIMETRIK*, 2018, doi: 10.31959/js.v8i1.90.

[9] A. Al-Faruk, M. A. Hasib, N. Ahmed, and U. K. Das, "Prediction of weld bead geometry and penetration in electric arc welding using artificial neural networks," *Int. J. Mech. Mech. Eng.*, 2010.

CHAPTER 26

POWER SOURCE TECHNOLOGY OF WELDING

Mr. Ashok Singh Gour, Assistant Professor,
Department of Mechanical Engineering, Jaipur National University, Jaipur, India,
Email Id: asgour@jnujaipur.ac.in

ABSTRACT:

welding power sources, different kinds, uses helpful definitions, relative benefits, drawbacks, what an inverter is generally, various power semiconductors used in inverters, various design topologies, Arcraft's welding inverters, and cost comparisons. Below, we'll look at the fundamental specifications for arc welding power supplies and describe the fundamentals of both traditional and cutting-edge power source designs, along with their benefits and drawbacks.The power source's main purposes are to provide a steady arc, enough heat to melt the joint, and metal transfer. Due to the high current (50-300A) and low voltage (10-50V) requirements of the welding operations, a transformer is required to lower the high voltage mains supply (230 or 400V). People take a long time to practice and become experts in welding because it is a difficult talent to perfect. No one can just pick up their vocation overnight. However, with all the technological improvements made today, it has become a lot simpler practice. Today's equipment is of such high quality that practically anyone may take up the pastime. The welding industry has difficulties as a result of demands for increased productivity, effectiveness, and quality. A more thorough and accurate understanding of how such materials might be connected for maximum efficacy and efficiency will become crucial as materials grow ever more complex in their chemical composition to deliver ever-better functionally specialized qualities.

KEYWORDS:

Power, Control, Output, Welding, Current, High, Voltage, Sources, Designs.

INTRODUCTION

The introduction of electronic control and advances in welding power supply design, in particular, have enabled many recent advancements in arc welding. Below, we'll look at the fundamental specifications for arc welding power supplies and describe the fundamentals of both traditional and cutting-edge power source designs, along with their benefits and drawbacks.Two metals are joined through welding. It takes a lot of heat to connect two metals. An electric arc is used to generate this heat. It takes a power source to produce this arc. Welding power sources have undergone constant innovation ever since the welding process joined the engineering field. Depending on the welding procedure, a power supply should be selected. The power source's main purposes are to generate a stable arc, enough heat to melt the joint, and metal transfer. Due to the high current (50-300A) and low voltage (10-50V) requirements of the welding processes, a transformer is required to lower the high voltage mains supply (230 or 400V).

Basic power source requirements

can be used in place of the typical diodes. The time interval between the usual beginning of conductionFor arc welding power sources, there are three fundamental prerequisites:Basic power create output current and voltage characteristics that are appropriate for the process.

Basic power enables regulation of the output to accommodate particular uses.Basic power regulate the output volume and order by the demands of the application and process.The typical mains power supply must be changed from high voltage-low current to comparatively high current at a safer low voltage to provide the output levels required for the majority of arc welding processes.

If direct current is needed, a rectifier can be added to the output of a standard transformer to carry out this job. With the installation of a rectifier, there is also the added benefit of being able to use a three-phase supply and having roughly equal currents drawn, which will result in more consistent loading on the supply.

Technology for welding power sources Although a three-phase supply can be converted to a single-phase output using the "Scott connection" system, this does not result in balanced loading. The usage of multi-operator transformers with three single-phase outputs and a three-phase input.a queue at a time.

1. The power source design must also adhere to the following standards:
2. adherence to established codes and standards;
3. Safe installation and operation
4. satisfactory operator controls, and, if required, automation system interfaces are all provided.

Conventional power source designs

Electro-magnetic control systems have been used by conventional power sources for a long time to enable the output power to be regulated; some of the more popular designs use the following control techniques:

1. tapped transformers
2. moving-iron control
3. variable inductor
4. magnetic amplifier

Tapped transformer

By incorporating tappings in the primary coil of the welding transformer, the turns ratio of the transformer may be varied and the output regulated. It is normal to provide tappings that allow adjustment to suit a range of main input voltages in most transformer-based designs, but when this technique is the principal method of control, additional tappings that are selected by a switch are provided. This type of control is simple, robust, and low in cost, but it will only provide a stepped output and, unless a large number of switch settings or dual-range switching are provided, the output voltage steps tend to be coarse. Remote control or continuous regulation advanced welding process.of the output are not feasible with this system, but it is often used for low-cost and light-duty GMAW equipment [1], [2].

Moving-Iron Control

An alternative technique for modifying the output of a transformer is to vary the magnetic leakage flux By controlling the position of the shunt, the amount of magnetic flux linking the primary and secondary coils is changed and the output varies (the output varies inversely with the amount of shunting). This method of control gives a continuous variation of the output and movement of the shunt may be motorized to allow remote operation, but it is costly, subject to mechanical wear and the output can only be regulated slowly. The use of this type of control is now largely confined to small low-cost MMA power sources.

Variable Inductor

A variable or tapped inductor may be connected to the ac output circuit of the transformer to regulate arc current. Although continuous current adjustment may be achieved with this design, remote operation is not usually feasible and the high-current inductor is a large, costly item. A possible advantage of the design is that the inductance causes a phase shift of up to 90∞ between AC and voltage waveforms. This may improve arc re-ignition (with 90∞ phase-shift, the voltage will be at its maximum value when the current passes through zero). This design has been used in the past for MMAW and GTAW power supplies.

Magnetic Amplifier

A magnetic amplifier or saturable reactor control is illustrated coil fed with a variable DC wound around a magnetic core which also carries a winding from the AC output of the transformer. As the DC level in the control coil is increased, the average value of magnetic flux within the core increases towards the saturation level thus limiting the variation of the magnetic field and reducing the AC output. The technique allows continuous variation of the output, remote control, and a certain amount of output waveform modification. The response rate of the system is, however, relatively slow, the DC control current can be fairly high and the saturable reactor is both bulky and expensive. Magnetic amplifier control has commonly been used for GTAW power sources although it has also been used in some GMAW equipment to obtain some measure of remote control. The adoption of current welding techniques and advancements in the materials utilized are two major factors that will influence welding's future growth. These materials and alloys include novel high-alloy, high-temperature steels as well as high-strength, low-alloy steels. Therefore, new technical approaches are required to advance welding techniques along with the creation of new materials.

DISCUSSION

Process performance can be significantly impacted by both the power supply's dynamic (such as the rate of change of current and the instantaneous relationship between current and voltage) and static (such as the relationship between the mean output current and voltage) properties. It is common practice to employ constant-current static characteristics with conventional power sources for the GTAW process to achieve the best striking and current stability, but constant voltage with GMAW to accomplish self-adjustment. Normally, these qualities are predetermined during the design phase and cannot be changed by the user. Electrical controls allow for the adjustment of dynamic properties, and in GMAW welding a DC inductor is frequently used in the power source output to regulate the rate of current rise during the brief A conventional variable slope/variable inductance unit has been developed but this costly and complexUser-defined features make equipment operation simpler and provide enough control for a variety of applications. However, it limits the likelihood of material process performance gains [3]–[5].

Electronic power regulation systems

A variety of alternative, electronic power source designs have emerged as a result of the accessibility of high-power semiconductors. These designs may be grouped into the following categories:

1. SCR phase control;
2. transistor series regulator
3. secondary switched transistor power supplies
4. primary rectifier–inverter

5. hybrid designs

SCR Phase Control

SCRs (silicon-controlled rectifiers) can be thought of as switchable diodes. When a signal is supplied to the gate connection, the device only then begins to conduct in the forward direction. The gadget cannot normally be shut off until the forward current reaches zero. In the secondary circuit of a DC power supply, these components n and the gate signal are adjusted to control voltage output. If the voltage waveform's amplitude is fixed, a long firing delay is required to attain low output levels, and the output waveform's ripple worsens. Using a three-phase SCR bridge, by using a three-phase SCR converter, byusing an inter-phase inductance, or a large output inductance. Alternately, the SCR control could be positioned in the transformer's primary, in which case the transformer would help with some smoothing. Any of the aforementioned forms of inductance are useful for smoothing, but they do restrict the power source's dynamic response.

SCRs can be linked "back to back," with one pair conducting during the positive half-cycle and the other during the negative half-cycle, to provide an AC output. Additionally, it is feasible to create a "square" output waveform with an inductor or an inverter circuit, which has advantages for GTAW, MMA, and SAW processes. The benefits of this sort of control are its simplicity, resilience, and the significant amplification produced, which enables extremely low-level electrical impulses to regulate high output levels. The system's ability to respond quickly is constrained by the requirement to pass current zero before a changed firing angle takes effect; as a result, the best response anticipated would fall between 3 and 10 ms.

Transistor Series Regulator

By altering the modest current running via a transistor's "base" connection, the output may be changed. The series regulator consists of a transistor connected in series with the DC welding supply, with the base current continually controlling the output power. A feedback control system and an amplifier are often used to assure output stabilization and deliver the driving signal to the transistor, respectively.

Up until recently, massive banks of transistors (connected in parallel) were required to handle ordinary welding currents since individual transistor capability was restricted. However, this issue has diminished as more powerful devices have recently become available. The fast reaction rate (transistors have a response time that is measured in microseconds) and ripple-free output of the transistor series regulator are its key features.

The system's poor effectiveness and expensive cost are its key drawbacks. Poor efficiency is caused by the devices' tendency to dissipate excess power as heat, which makes water cooling necessary for the majority of applications. The cost of the equipment depends on how many devices are employed and how well each transistor must be balanced to achieve current sharing.This sort of power supply is ideal for compact, high-precision supplies and, in particular, process research work because of its high reaction rate, accuracy, and minimal ripple. There are GTAW, GMAW, and SAW units.

Primary Rectifier–Inverter

The control strategies described above employ a standard transformer to produce the drop decrease in voltage necessary for welding. This transformer runs at 50 Hz, which is the frequency of the incoming mains. The primary inverter design makes use of the possibility of a large reduction in transformer size with an increase in operating frequency. The fundamental circuit is shown, as well as the workings.

The inverter electrically converts the high DC voltage produced by the first rectifying of the primary AC supply into high-frequency AC. The supply only enters the transformer at this point. The transformer is tiny since the operating frequency is between 5 and 100 kHz; in addition, output control is accomplished by chopping or phase-shifting within the inverter, and extremely high response rates are attained. To prevent possible losses in the high-frequency AC circuit, the transformer output must be rectified.

Although it is not possible to achieve the same response rates as those obtained with the series regulator, it is possible to produce the output characteristics needed for recent process control developments. The welding output is smooth and stabilized. Originally utilized for MMA power supplies, this sort of circuit is now used in GTAW and pulsed GMAW devices. It has exceptionally high electrical efficiency; at current settings of 250 A, a comparison of inverter and conventional power sources has revealed that idle power consumption is only one-tenth that of a conventional machine, and during welding, the efficiency is around 86% as opposed to 52% for a conventional unit.

Hybrid Designs

The performance and economy of the power source can be increased by combining the electronic control methods mentioned above. For instance, it has been detailed how to utilize a secondary chopper to pre-regulate the supply and then a tiny air-cooled transistor series regulator to control the output. The circuit is illustrated schematically, and the benefits of this strategy are enumerated By adding a secondary inverter to a DC phase-controlled unit's output, hybrid designs can also be used to generate a square-wave AC output. It is possible to combine SCR phase-controlled power sources with an SCR inverter, or the system might be built using an integrated primary rectifier-inverter architecture. For instance, sophisticated experimental hybrid units have been built. To increase the effectiveness of traditional electrical and hybrid systems, alternative power devices such as metal oxide-silicon field-effect transistors (MOSFETs) or asymmetrical SCRs (ASCRs) may also be utilized.

Features Of Electronic Power Source Designs

The electrical designs are all easily interfaced with system controllers found inside the power supply or from an external source, and they all can be controlled remotely. The attributes of the various designs are summarised, and the output responsiveness, precision, and repeatability are often significantly superior to those obtained with standard electromagnetic control systems. It is impossible to pick the perfect design from this list, however, primary inverter-based designs are affordable and suited for a variety of production activities, whereas series regulator designs are frequently only justified for very-high-precision and research applications. The use of feedback control is a crucial feature that all of these systems have in common.

Feedback control

Feedback control is a practical method that works best when used with electronic power sources. The fundamentals of the approach are demonstrated when the system's output is measured and compared to the desired output parameters. Any discrepancy between the two values will result in the generation of an "error" signal, and the feedback system will then alter the output to correct the imbalance.Although this kind of control may be used with designs for traditional power sources, it is typically expensive, intricate, and excessively slow. As a result, the majority of traditional power sources feature 'open-loop' control, meaning that if the input changes, the output will vary proportionally. Electronic control systems' faster reaction speeds and low signal levels enable "closed-loop" or feedback control, which is efficient and cost-effective and provides output stabilization automatically.

Output Level, Sequence, And Function Control

When starting or ending the majority of welding processes, a certain order must be followed. During welding, it can also be essential to modify the output and regulate the rate of current increase or decline. The usage of traditional power source design technologies and their use of them have hitherto limited the extent to which these functionalities could be given. approaches for electrical control and relay logic. To increase the adaptability and precision of sequence control, two new strategies have recently been introduced. These are:

1. the use of discrete electronic control
2. microprocessor control

Discrete Component Electronic Control

The control signal levels needed to 'drive' the aforementioned electronic power regulation circuits are typically low and may be produced from electronic logic circuits. Using common, single-chip analog and digital components (such timers, programmable logic arrays, power regulators, operational amplifiers, and comparator circuits), these circuits may be set up to carry out even the most difficult jobs. These systems perform far better than earlier relay logic designs in terms of price, speed, precision, and long-term durability. The facilities and operational range of discrete electronic control circuits are, however, often determined at the design stage and are specifically tailored for a certain power source. The storage of welding control parameters on electrically programmable read-only memory (EPROM) chips, which may be easily programmed by the equipment manufacturer and replaced when improved process parameters are developed or new facilities are added, has increased the flexibility of discrete electronic circuit designs [6], [7].

Microprocessor And Digital Signal Processor Control

Utilizing microprocessor control as an alternative might give considerably more flexibility and a variety of extra amenities. A single microprocessor chip is capable of managing both the output power regulation and the welding sequence.The following diagram shows the schematic design for a microprocessor control system. The microprocessor executes a series of instructions and calculations sequentially, but some crucial tasks might be given precedence over others. For instance, during welding, it might be necessary to check the output current level every 0.3 milliseconds, but the status of some front-panel controls might be disregarded until welding is finished.The resolution of the analog-to-digital converters, the microprocessor's operating speed (or "clock rate"), and the software architecture all have a role in how well this sort of system controls the output in real time. A typical system can verify and rectify any output discrepancies every 0.3 ms and keep the current within 1% of the required level utilizing clock rates of 12 MHz and a 10-bit analog-to-digital converter. The designer can incorporate the ability to change specific parameters based on an understanding of the welding process requirements, even though the dedicated microprocessor control approach does not permit complete design flexibility (the software will frequently represent a significant investment and revisions may be expensive). This might be used to make the equipment easier to use or provide the user with the option of reprogramming important process variables.

Programming and One-Knob Control

Power sources employing preset wire feed and voltage controls and a single condition selector switch were available in the middle of the 1970s, and the idea of a single adjustment knob for a 'complicated' parameter setup, such as in the GMAW process, is not new. However, given the absence of electronic feedback control, it was necessary to stabilize the mains voltage using creative but unreliable methods. Reliable "optimum" power sources can be programmed into power sources using electronic power regulation and feedback control. welding conditions. If microprocessor control systems are used as previously mentioned, programming and storing welding parameters is even simpler.

External Computer Control

It has also been used to control electrical power supplies using an external microcomputer. Many microprocessor-controlled power sources now can interface with a host computer using conventional serial communications protocols (RS232, RS423, USB, CAN, etc.). This has mostly been for research applications where a wide variety of process variables are under examination. This makes it possible to remotely control and monitor the welding process as well as "download" welding settings to the machinery. The robotic system being developed for remotely controlled repair welding of turbine runners is a nice illustration of how this method may be employed in industrial applications.

Practical Implications of electronic power regulation and Control

The above-discussed advancements in welding power source technology have some important practical ramifications: the power sources can be produced using cutting-edge electronic assembly methods, and their reliance on pricy raw materials, like copper for the windings and iron for transformer cores, is lessened. This should make it possible for the producers of these more sophisticated power sources to sell them for prices comparable to those of traditional models. The following benefits are also provided to the user by these designs:

1. improved repeatability
2. increased ease of setting
3. enhanced process capabilities.

The quality of the welded connection and the capacity to keep welding parameters within the range defined in the welding method are directly impacted by improved repeatability, both of which are likely to lower the repair and rework costs mentioned. The operational efficiency should rise and the possibility of operator mistakes should decrease due to the enhanced configuration simplicity. The capacity to alter different process output characteristics of an electronic power supply during welding leads to improved process capabilities. To get advantageous results, the output characteristics may be changed (within the constraints of the transformer output). For better control, constant-current output characteristics, such as in the case of GMAW, may be employed, and the output may be dynamically changed to allow self-adjustment.To avoid electrode "sticking," the current in MMA welding systems can be instantly raised at low voltages. In the chapters that follow, these traits will be covered in more detail. However, the user will need to take service assistance and training into consideration to operate the electronic power supply effectively. In contrast to typical electromagnetic power sources, this sort of equipment requires different repair and maintenance expertise [8], [9].

CONCLUSION

To execute arc welding, a welding power supply is a device that supplies or controls an electric current. Shielded Metal Arc Welding (SMAW) is one of the more straightforward arc welding procedures, while Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW), which employ an inert shielding gas, are more complex. Welding power supplies are generally used as tools that provide welders control over the quantity of current and voltage, as well as whether the current is alternating current (AC) or direct current (DC). In addition to connectors for gas and ways to manage gas flow, power supplies for welding procedures that employ shielding gas are available. The welding industry's most significant area of growth at the moment is automation. Automation will continue to be a priority due to the need for increased production and lower costs. Other factors driving the rise in automation utilization are worries about safety and initiatives to relieve welders of exhausting, repetitive tasks and prolonged fume exposure. Automation and robotization are starting to be recognized as crucial technologies for ensuring increased welding output and consistent quality.

REFERENCES

[1] D. P. Il'yaschenko, D. A. Chinakhov, E. D. Chinakhova, K. Y. Kirichenko, and E. V. Verkhoturova, "Assessment of negative influence of manganese in welding fumes on welder's health and ways to reduce it," *FME Trans.*, 2020, doi: 10.5937/fmet2001075I.

[2] J. P. Oliveira, T. G. Santos, and R. M. Miranda, "Revisiting fundamental welding concepts to improve additive manufacturing: From theory to practice," *Progress in Materials Science*. 2020. doi: 10.1016/j.pmatsci.2019.100590.

[3] D. Klobčar, M. Lindič, and M. Bušić, "Wire arc additive manufacturing of mild steel," *Mater. Geoenvironment*, 2018, doi: 10.2478/rmzmag-2018-0015.

[4] H. Wang, Z. Zhang, and L. Liu, "Prediction and fitting of weld morphology of Al alloy-CFRP welding-rivet hybrid bonding joint based on GA-BP neural network," *J. Manuf. Process.*, 2021, doi: 10.1016/j.jmapro.2020.04.010.

[5] J. Norrish, "Welding power source technology," in *Advanced Welding Processes*, 2006. doi: 10.1533/9781845691707.26.

[6] Z. X. Ma, P. X. Cheng, J. Ning, L. J. Zhang, and S. J. Na, "Innovations in monitoring, control and design of laser and laser-arc hybrid welding processes," *Metals*. 2021. doi: 10.3390/met11121910.

[7] H. Danielewski, A. Skrzypczyk, S. Tofil, G. Witkowski, and S. Rutkowski, "Numerical Simulation of Laser Welding Dissimilar Low Carbon and Austenitic Steel Joint," *Open Eng.*, 2020, doi: 10.1515/eng-2020-0045.

[8] B. Messer, C. Patrick, and S. Seitz, "Achieving cost savings with innovative welding and examination techniques," *Int. J. Press. Vessel. Pip.*, 2006, doi: 10.1016/j.ijpvp.2006.02.027.

[9] W. Guo, S. Dong, W. Guo, J. A. Francis, and L. Li, "Microstructure and mechanical characteristics of a laser welded joint in SA508 nuclear pressure vessel steel," *Mater. Sci. Eng. A*, 2015, doi: 10.1016/j.msea.2014.11.056.