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# Evolution and Trends in Arc Welding Process: A Holistic Assessment of Metal Joining Technology for Industrial Applications

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## Abstract

Despite the advancements in arc welding technology, there are still challenges faced by the industry in achieving high-quality and efficient metal joining processes. The lack of understanding of the welding process, the limitations of current welding equipment, and the need for skilled welders are some of the key issues that need to be addressed to improve the arc welding process for industrial applications. Additionally, the increasing demand for high-quality welded products in various industries has put pressure on manufacturers to enhance their welding processes to meet the growing market requirements. This study is based on a holistic assessment of conventional studies on arc welding processes, focusing on the metal joining approach for industrial applications. The research methodology involved a literature search of existing studies on the recent trends and applications, operation principles, welding positions, edge preparation techniques, arc welding electrodes, classification of welding machines and joint designs in arc welding processes using online databases. A thorough analysis of the findings in existing literature and industry reports was also conducted to conclude the trends in arc welding technology. The findings revealed that there have been significant advancements in welding technology over the years, including the development of new welding techniques such as pulsed arc welding and waveform control welding. Furthermore, the introduction of Gas Metal Arc Welding (GMAW) and Flux-Cored Arc Welding (FCAW) has also played a key role in improving the efficiency and quality of metal joining processes while shaping the future of manufacturing industries. However, challenges such as weld defects, distortion, and lack of skilled welders persist in the industry. To address these challenges, manufacturers must invest in advanced welding equipment, automation, and training programs to enhance welding quality and efficiency. This can enable them to meet the growing market demands for high-quality welded products while maintaining a competitive edge in the industry.

**Keywords:** Arc welding, Operation principles, Welding positions, Edge preparation, Joint designs.

## 1 | Introduction

Arc welding is a widely used welding process that involves the use of an electric arc to join metal pieces together. This process is commonly used in various industries such as construction, automotive, and manufacturing. This study provides a detailed definition, introduction, overview, and review of arc welding operation. Arc welding is a welding process that uses a power supply to create an electric arc between an

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electrode and the base material. The heat generated by the arc melts the base material and the electrode, creating a molten pool that solidifies to form a weld joint [1], [2]. This process is commonly used to join metals such as steel, aluminium, and stainless steel [3], [4]. Arc welding can be performed using different types of electrodes, such as stick electrodes, flux-cored electrodes, and metal-cored electrodes. Each type of electrode has its own advantages and disadvantages, depending on the specific application and material being welded. The arc welding process can be divided into several steps, including preparation, setup, welding, and post-welding inspection. During the preparation phase, the welder cleans the base material, selects the appropriate electrode, and sets up the welding equipment. The setup phase involves positioning the electrode and adjusting the welding parameters, such as voltage, current, and travel speed [5], [6]. The welding phase involves striking the arc, moving the electrode along the joint, and creating a weld bead. Finally, the post-welding inspection phase involves checking the quality of the weld joint and making any necessary repairs. Overall, arc welding is a versatile and efficient welding process that is widely used in various industries. It offers several advantages, such as high welding speeds, strong weld joints, and the ability to weld a wide range of materials. However, arc welding also has some limitations, such as the need for skilled welders, the generation of fumes and gases, and the potential for weld defects. In addition, arc welding is a complex and important welding process that plays a crucial role in various industries [7]. It offers several advantages but also has some limitations that need to be considered. By understanding the principles and techniques of arc welding, welders can produce high-quality weld joints that meet the requirements of their specific applications. This study focused on the evolution and trends in the arc welding process, holistically assessing the metal joining technology for industrial applications.

## 2 | History of Arc Welding Processes

Arc welding is a welding process that uses an electric arc to create a fusion between metals. This process has a long history of development, with various advancements and improvements over the years [8] . The origins of arc welding can be traced back to the late 19th century, with the invention of the carbon arc welding process in 1881 by Nikolai Benardos and Stanisław Olszewski. This early form of arc welding used a carbon electrode to create an arc between the electrode and the workpiece, producing a high heat that melted the metals together. In the early 20th century, advancements in arc welding technology continued with the development of metal arc welding processes[9] . One of the most significant developments was the invention of Shielded Metal Arc Welding (SMAW) in 1907 by Oscar Kjellberg. SMAW, also known as stick welding, uses a flux-coated electrode to protect the weld pool from atmospheric contamination, allowing for a stronger and more reliable weld. Another important development in arc welding technology was the invention of GMAW in the 1940s. GMAW, also known as MIG welding, uses a continuous wire electrode and a shielding gas to protect the weld pool from contamination. This process is widely used in industrial applications due to its versatility and efficiency. In the 1960s, the development of Gas Tungsten Arc Welding (GTAW) further expanded the capabilities of arc welding [10]. GTAW, also known as TIG welding, uses a non-consumable tungsten electrode and a shielding gas to create a precise and clean weld [11], [2]. This process is commonly used in industries that require high-quality welds, such as aerospace and nuclear power. The history of arc welding is a testament to the continuous innovation and improvement in welding technology. From the early carbon arc welding process to the modern GMAW and GTAW processes, arc welding has evolved to become a versatile and reliable method for joining metals. As technology continues to advance, it is likely that arc welding will continue to play a crucial role in various industries for years to come.

## 3 | Advancements in Arc Welding Processes

Technological advancements in arc welding processes have revolutionized the manufacturing industry, allowing for faster, more efficient, and higher-quality welding. Over the years, key milestones have been achieved in the development of arc welding techniques, leading to significant improvements in welding capabilities. Some of the earliest milestones in arc welding are highlighted as follows:

I. The invention of the carbon arc welding process in the late 19th century. This process involved using a carbon electrode to create an arc between the electrode and the workpiece, allowing for the fusion of metals. While this process was effective, it was also limited in its applications and required skilled operators to control the arc [12].

II. The advancements in arc welding technology in the early 20th century led to the development of the SMAW process, also known as stick welding. This process involved using a consumable electrode coated in flux to protect the weld pool from atmospheric contamination. SMAW quickly became the most widely used welding process due to its versatility and simplicity [7].

III. The GMAW process was developed in the 1940s, which used a continuous wire electrode and a shielding gas to protect the weld pool. This process allowed for higher welding speeds and improved weld quality, making it ideal for industrial applications [13].

IV. The GTAW process, also known as TIG welding, was developed in the 1960s. This process used a non-consumable tungsten electrode and a shielding gas to create a high-quality weld with minimal spatter. GTAW became popular for welding thin materials and for applications requiring precise control over the welding process [14].

V. In recent years, advancements in arc welding technology have focused on improving automation and robotics in welding processes. This has led to the development of robotic welding systems that can perform complex welds with high precision and repeatability. These systems have revolutionized the manufacturing industry by increasing productivity and reducing labor costs [2].

Overall, technological advancements in arc welding processes have significantly improved the efficiency, quality, and versatility of welding operations. From the early days of carbon arc welding to modern robotic welding systems, arc welding has come a long way in terms of innovation and development. As technology continues to evolve, we can expect further advancements in arc welding processes that will continue to shape the future of manufacturing.

# 4 | Recent Trends in are Welding Processes

Arc welding is a widely used method for joining metals in various industries, including construction, automotive, and manufacturing. This process involves creating an electric arc between an electrode and the workpiece, which melts the metals and forms a strong bond when cooled. Over the years, arc welding has evolved significantly, with conventional trends giving way to recent advancements that have improved efficiency, quality, and safety in the welding process. Some of the conventional trends in arc welding are stated as follows:

I. The use of traditional welding machines that rely on Constant Current (CC) or Constant Voltage (CV) power sources. These machines have been the standard for many years, providing reliable performance for a wide range of welding applications. However, recent advancements in welding technology have led to the development of inverter-based welding machines that offer greater control over the welding process. These machines are more compact, lightweight, and energy-efficient than traditional welding machines, making them ideal for portable and high-performance welding applications [15].

II. The use of manual welding techniques, such as SMAW and GMAW. While these techniques are still widely used in many industries, recent advancements in automation and robotics have revolutionized the welding process. Automated welding systems, such as robotic welding cells and Computer Numerical Control (CNC) welding machines, offer greater precision, consistency, and productivity compared to manual welding techniques. These systems can perform complex welding tasks with minimal human intervention, reducing the risk of errors and improving overall welding quality [16].

III. Recent advancements in arc welding technology have also focused on improving welding consumables, such as electrodes and shielding gases. New electrode materials, such as flux-cored wires and metal-cored wires, offer improved weld quality, higher deposition rates, and reduced spatter compared to traditional electrodes. Similarly, advanced shielding gases, such as argon-helium mixtures and carbon dioxide blends, provide better arc stability, penetration, and weld bead appearance. These advancements in welding consumables have helped to enhance the overall performance and efficiency of arc welding processes [17].

IV. Advancements in arc welding equipment have also led to the development of new welding techniques, such as pulsed arc welding and waveform control welding. Pulsed arc welding allows for precise control of the welding current and voltage, resulting in reduced heat input, distortion, and spatter during the welding process. Waveform control welding, on the other hand, enables welders to adjust the shape and frequency of the welding waveform to optimize penetration, fusion, and bead appearance. These advanced welding techniques have revolutionized the way welding is performed, offering greater flexibility, control, and efficiency in the welding process [18].

Conventional trends in arc welding have given way to recent advancements that have transformed the welding industry. From inverter-based welding machines and automated welding systems to advanced welding consumables and techniques, these advancements have improved efficiency, quality, and safety in arc welding processes. As technology continues to evolve, welders and welding professionals need to stay updated on the latest trends and advancements in arc welding to remain competitive in the industry.

# 5 | Procedure for Conducting Arc Welding Operations

Arc welding is a common method used in various industries for joining metals together. It involves the use of an electric arc to melt and fuse the metals, creating a strong bond. This section will discuss the step-by-step procedure for conducting arc welding operations.

I. Prepare the workpiece: before starting the welding process, it is important to prepare the workpiece. This includes cleaning the surface of the metals to be welded and removing any rust, paint, or other contaminants. It is also important to ensure that the metals are properly aligned and clamped together to prevent any movement during the welding process [18].

II. Select the appropriate welding equipment: it is important to select the appropriate welding equipment for the job. This includes choosing the right type of welding machine, electrode, and protective gear. It is important to ensure that the welding machine is properly set up and calibrated for the specific job at hand [19].

III. Set up the welding machine: once the welding equipment has been selected, it is important to set up the welding machine. This includes adjusting the voltage, current, and wire feed speed to the appropriate settings for the specific job. It is also important to ensure that the welding machine is properly grounded to prevent any electrical hazards

IV. Prepare the electrode: before starting the welding process, it is important to prepare the electrode. This includes removing any coating or flux from the electrode and sharpening the tip to a fine point. It is also important to ensure that the electrode is properly inserted into the welding machine and secured in place [20].

V. Start the welding process: once everything is set up and prepared, it is time to start the welding process. This involves striking an arc between the electrode and the workpiece, creating a pool of molten metal that fuses the metals. It is important to maintain a steady hand and move the electrode in a controlled manner to create a strong and consistent weld [21].

VI. Monitor the welding process: throughout the welding process, it is important to monitor the weld pool and adjust the welding parameters as needed. This includes adjusting the voltage, current, and wire feed speed to ensure a proper weld bead is formed. It is also important to ensure that the weld is free of any defects, such as porosity or cracks [22].

VII. Complete the weld: once the welding process is complete, it is important to allow the weld to cool before removing any clamps or supports. It is also important to inspect the weld for any defects and make any necessary repairs. Finally, it is important to clean up the work area and properly store the welding equipment for future use [23].

Arc welding is a complex process that requires careful preparation and attention to detail. By following the step-by-step procedure outlined in this article, welders can ensure a successful and high-quality weld.

# 6 | Operation Principles of Arc Welding Processes

Arc welding is a widely used welding process that involves the use of an electric arc to join metal pieces together. The operation principles of arc welding are extensively detailed and involve several key components and processes. Some of the main components of arc welding are outlined as follows:

I. The power source that provides the electrical current needed to create the arc: this current is typically supplied by a welding machine, which converts the input power into a suitable output for welding. The power source also controls the welding parameters, such as voltage and current, which are crucial for achieving a successful weld [24].

II. The electrode that is used to create the arc: the electrode can be either consumable or non-consumable, depending on the welding process being used. Consumable electrodes are typically used in processes such as SMAW, where the electrode is consumed as it melts and deposits filler metal into the weld joint. Non-consumable electrodes, on the other hand, are used in processes such as GTAW, where the electrode does not melt and is used to create the arc [25].

III. The arc itself is created when the electrode is brought into proximity to the workpiece and an electrical current is passed through the circuit. The intense heat generated by the arc melts the base metal and the filler metal (if used), creating a molten pool that solidifies to form the weld joint. The arc also generates a shielding gas, such as argon or carbon dioxide, which protects the weld pool from atmospheric contamination and helps to produce a clean, strong weld [26].

IV. In addition to the power source, electrode, and arc, arc welding also involves several other processes and techniques, such as welding position, travel speed, and welding technique. These factors can have a significant impact on the quality and integrity of the weld and must be carefully controlled and monitored to ensure a successful outcome[27].

The operation principles of arc welding are complex and involve a number of key components and processes. By understanding these principles and following best practices, welders can produce high-quality welds that meet the requirements of their specific application.

# 7 | Welding Positions in Arc Welding Processes

Arc welding is a widely used welding process that involves the use of an electric arc to melt and join metal materials. In arc welding operations, different welding positions are used to achieve optimal weld quality and efficiency. Understanding the different welding positions is essential for welders to produce high-quality welds in various applications. The four main welding positions in arc welding operations are flat, horizontal, vertical, and overhead. Each position has its own set of challenges and requirements, and welders must be proficient in all positions to carry out welding tasks effectively.

The flat welding position is the most common and easiest position to weld in. In this position, the weld is performed on a flat surface, with the welding rod held at a 90-degree angle to the workpiece (see *Fig. 1*). The flat position allows for good penetration and control over the weld pool, making it ideal for welding thicker materials [28], [29].

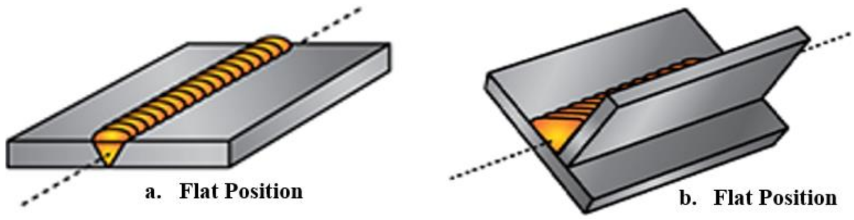


**Fig. 1. Flat welding position [30].**

I. The horizontal welding position is used when welding on a horizontal surface, such as the side of a pipe or a plate. In this position, the welder must adjust the angle of the welding rod to ensure proper penetration and fusion (see *Fig. 2)*. Horizontal welding requires more skill and control than flat welding, as gravity can affect the flow of the weld pool [31].

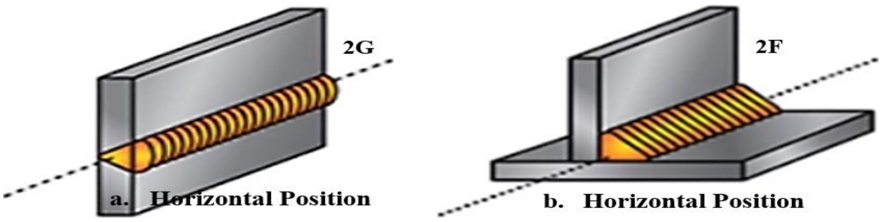


**Fig. 2. Horizontal welding position [32].**

II. The vertical welding position is used when welding on a vertical surface, such as the side of a wall or a beam. In this position, the welder must maintain a consistent travel speed and angle to prevent the weld pool from sagging or dripping (see *Fig. 3*). Vertical welding is more challenging than flat or horizontal welding, as the welder must work against gravity to achieve a strong and uniform weld [33].

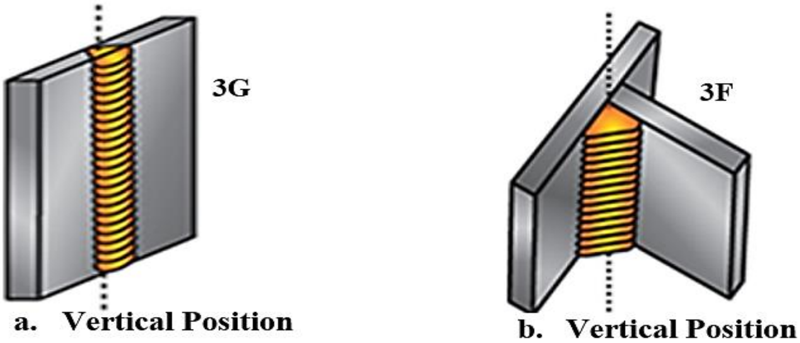


**Fig. 3. Vertical welding position [34].**

III. The overhead welding position is the most challenging position in arc welding operations (see *Fig. 4*). In this position, the weld is performed on the underside of a workpiece, requiring the welder to work against gravity and maintain control over the weld pool. Overhead welding requires a high level of skill and precision, as any mistakes can result in poor weld quality and structural integrity [35].

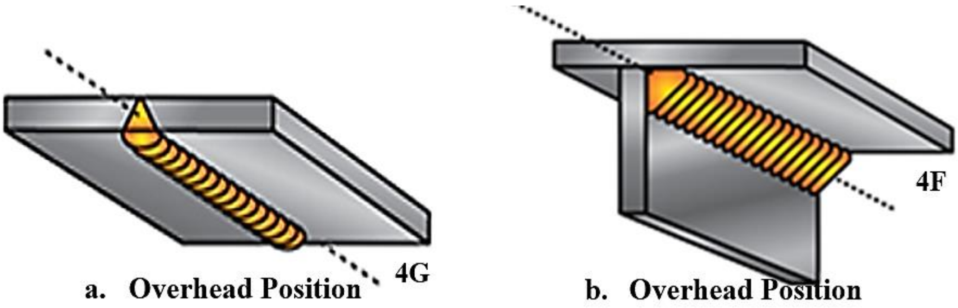


**Fig. 4. Overhead welding position [36].**

Understanding the different welding positions in arc welding operations is essential for welders to produce high-quality welds in various applications. By mastering the flat, horizontal, vertical, and overhead welding positions, welders can effectively carry out welding tasks and ensure the strength and durability of the welded joints.

# 8|Welding Speed in Arc Welding Processes

Welding speed is a critical factor in arc welding processes, as it directly impacts the quality and efficiency of the weld. The speed at which the welding electrode is moved along the joint determines the amount of heat input, penetration depth, and overall weld bead shape. This section provides an extensively detailed explanation of welding speed in arc welding processes, focusing on its importance, factors affecting it, and best practices for achieving optimal results. It is essential to understand the significance of welding speed in arc welding [37]. The speed at which the electrode is moved along the joint determines the amount of heat input into the workpiece. A slower welding speed results in higher heat input, which can lead to excessive penetration, distortion, and potential defects such as undercutting and burn-through. On the other hand, a faster welding speed may not provide enough heat input, resulting in poor fusion and incomplete penetration. Several factors can affect welding speed in arc welding processes. The type of welding process, welding parameters, material thickness, joint design, and welding position all play a role in determining the optimal speed for a given application [38]. For example, in a fillet weld, the welding speed may need to be adjusted to ensure proper fusion at the root of the joint. Similarly, welding in the vertical or overhead position may require a slower speed to prevent excessive sagging of the weld pool. To achieve optimal welding speed, it is essential to follow best practices and guidelines. One key consideration is the travel angle of the electrode, which should be maintained at a consistent angle to ensure proper heat distribution and penetration. Additionally, maintaining a steady travel speed and arc length is crucial for achieving a uniform weld bead and preventing defects such as porosity and lack of fusion. Welding speed is a critical factor in arc welding processes that directly impacts the quality and efficiency of the weld [39]. By understanding the importance of welding speed, considering factors that affect it, and following best practices, welders can achieve optimal results and produce high-quality welds. It is essential for welders to continuously monitor and adjust welding speed to ensure consistent and reliable welds in various applications.

# 9|Joint Designs in Arc Welding Processes

Arc welding is a widely used method for joining metal components in various industries. One of the key factors that determine the strength and quality of a welded joint is the design of the joint itself. Several different types of joint designs can be used in arc welding, each with its advantages and disadvantages. One of the most common joint designs in arc welding is stated as follows:

I. Butt joint: in a butt joint, the two pieces of metal to be welded are placed end to end and welded along the seam. This type of joint design is simple and easy to execute, making it ideal for a wide range of applications. However, butt joints are not always the strongest option, as they can be prone to distortion and lack of fusion if not properly executed [40].

II. Lap joint: in a lap joint, one piece of metal is placed on top of another, with the two pieces overlapping. This type of joint design is often used when welding thin materials or when a flush surface is desired. Lap joints are generally stronger than butt joints, as the overlapping surfaces provide more area for the weld to bond to. However, lap joints can be more complex to execute and may require additional welding passes to ensure a strong bond [41].

III. T-joint: in a T-joint, one piece of metal is welded perpendicularly to another, forming a T shape. This type of joint design is often used in structural applications where strength and rigidity are important. T-joints are generally stronger than butt joints and lap joints, as the perpendicular surfaces provide additional support. However, T-joints can be more challenging to weld, as proper alignment and penetration are crucial for a strong bond [42].

IV. A corner joint is formed when two pieces of metal are joined at right angles to each other. This type of joint is commonly used in applications where strength and rigidity are important, such as in structural steel fabrication. The geometry of a corner joint is characterized by the intersection of two surfaces at a 90-degree angle. The weld bead is typically deposited along the entire length of the joint, ensuring a strong and secure connection between the two pieces of metal.

V. An edge joint is formed when two pieces of metal are joined along their edges. This type of joint is commonly used in applications where a flush and seamless finish is desired, such as in sheet metal fabrication. The geometry of an edge joint is characterized by the alignment of two surfaces along a common edge. The weld bead is typically deposited along the edge of the joint, creating a smooth and continuous weld seam

VI. The design of a welded joint plays a crucial role in determining the strength and quality of the final weld. While butt joints, lap joints, T-joints, corner joints and edge joints (see *Fig. 5*) are all commonly used in arc welding, each has its advantages and disadvantages. These joints play a crucial role in ensuring the structural integrity and strength of the welded components. It is important for welders to carefully consider the requirements of the application and select the appropriate joint design to ensure a strong and reliable weld.

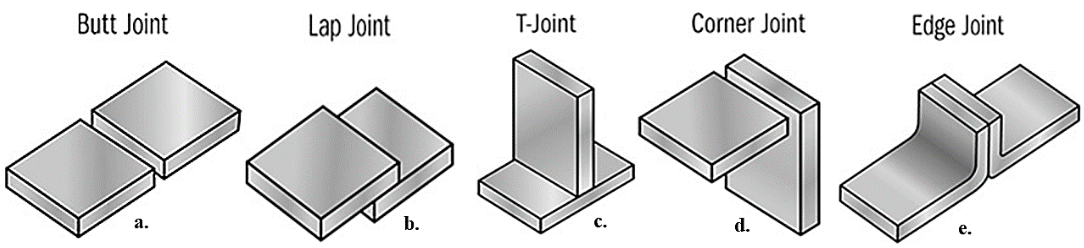


**Fig. 5. Basic types of weld joint designs.**

## 10 | Description of Arc Welding Components

Arc welding is a widely used welding process that involves the use of an electric arc to join metal pieces together. This process requires the use of various parts and components to ensure a successful weld. In this paper, we will discuss the different parts and components of arc welding and their importance in the welding process. Some of the key components of arc welding are:

I. Power source: the power source provides the electrical energy needed to create the arc between the welding electrode and the workpiece. The power source can be either a CC or a CV source, depending on the specific welding process being used. The power source also controls the welding current and voltage, which are critical parameters in determining the quality of the weld [43].

II. The electrode holder: this is a crucial component in arc welding, as it holds the electrode in place and provides a means for the welder to control the arc (see *Fig. 6*). The holder is typically made of heat-resistant materials such as copper or brass and is designed to withstand the high temperatures generated during welding. The electrode holder also provides insulation to protect the welder from electric shock [44].


**Fig. 6. Electrode holder [45].**

III. Electrode: the electrode is a consumable metal rod that is used to carry the electrical current and create the arc. The electrode material is chosen based on the type of metal being welded and the welding process being used. The electrode also provides the filler material that is deposited into the weld joint to create a strong bond between the metal pieces [46].

IV. Chipping hammers: these are used in arc welding to remove slag and excess weld metal from the finished weld (see *Fig. 7*). Slag is a byproduct of the welding process that forms on the surface of the weld joint and must be removed to ensure a clean and smooth finish. Chipping hammers are typically made of hardened steel and have a chisel-like end for chipping away slag and weld metal.

**Fig. 7. Clipping hammers [47].**

V. The welding torch: the torch holds the welding electrode and directs the arc onto the workpiece, as shown in *Fig. 8*. The torch also contains a gas nozzle that directs a shielding gas, such as argon or carbon dioxide, onto the weld pool to protect it from atmospheric contamination. The torch can be either manually operated or mechanized, depending on the specific welding application [48].

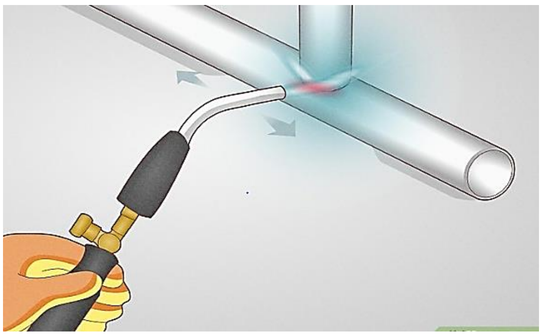

**Fig. 8. Welding torch [49].**

VI. Filler metal: this is used in arc welding to add material to the weld joint and create a strong bond between the two pieces of metal being joined. The filler metal is typically in the form of a rod or wire and is chosen based on the type of metal being welded and the desired properties of the finished weld. Proper selection and handling of filler metal are critical for achieving a high-quality weld with good mechanical properties.

VII. The welding cables: the cables connect the power source to the welding torch and electrode holder, allowing the electrical current to flow through the system. The cables must be properly insulated and maintained to ensure safe and efficient welding operations.

VIII. Cable connectors: these are used to connect the electrode holder to the welding machine, allowing the electric current to flow from the machine to the electrode. These connectors are typically made of copper or brass to ensure good conductivity and minimize heat buildup. Properly maintained cable connectors are essential for ensuring a stable arc and consistent weld quality [7].

Arc welding is a complex process that requires the use of various parts and components to achieve a successful weld. The power source, welding electrode, electrode holder, cable connectors, filler metal, chipping hammer, welding torch, and welding cables are all essential components that play a crucial role in the welding process. By understanding the function and importance of these components, welders can ensure high-quality welds and safe welding operations.

## 11| Edge Preparation Techniques in Arc Welding Processes

Edge preparation is a critical step in the butt welding process that involves the preparation of the edges of the two pieces of metal that are to be joined together. The purpose of edge preparation is to ensure that the weld joint is strong, durable, and free from defects. There are several different types of edge preparation (see *Fig. 9.*) that can be used, depending on the specific requirements of the welding project. Some of the most common types of edge preparation are as follows:

I. V-groove: V-groove involves cutting a V-shaped groove into the edges of the metal pieces. This type of edge preparation is often used for thicker materials or when a strong weld joint is required. The V-groove allows for a larger weld bead to be deposited, which can help to increase the strength of the weld joint [50].

II. U-groove: U-groove involves cutting a U-shaped groove into the edges of the metal pieces. This type of edge preparation is often used for thinner materials or when a more aesthetically pleasing weld joint is desired. The U-groove allows for a smaller weld bead to be deposited, which can help to create a smoother and more uniform weld joint.

III. J-groove: this edge preparation is characterized by a straight edge on one side of the joint and a curved edge on the other side, forming a J-shaped groove. This type of edge preparation is commonly used for butt joints in thicker materials, as it allows for deeper penetration of the weld metal and better control of the weld pool. The J-groove edge preparation also helps to minimize distortion and reduce the risk of weld defects such as lack of fusion [51].

IV. Bevel groove: this edge preparation involves cutting a V-shaped groove on both sides of the joint. This type of edge preparation is suitable for welding thinner materials and provides better access to the root of the joint. The bevel groove edge preparation allows for a larger weld volume and better control of the weld bead shape, resulting in a stronger and more uniform weld joint.

V. Double V-groove edge preparation is characterized by two bevels on both sides of the joint, forming a V-shaped groove. This type of edge preparation is commonly used for fillet welds or when welding materials with different thicknesses. The double V-groove provides good accessibility for the welder and allows for better control of the weld pool, resulting in a clean and uniform weld joint.

VI. Square groove edge preparation involves cutting a straight edge perpendicular to the surface of the base metal. This type of edge preparation is commonly used for butt joints in thick materials where full penetration is required. The square groove provides a large surface area for the weld metal to bond with the base metal, resulting in a strong and durable weld joint.

VII. Double J-groove edge preparation is similar to the square groove but with an additional bevel on both sides of the joint. This type of edge preparation is often used for thicker materials or when a higher-strength weld joint is required. The double J-groove allows for better penetration of the weld metal and helps to reduce the risk of incomplete fusion or lack of penetration in the joint.

VIII. Double bevel groove: This edge preparation is similar to the bevel groove but with a V-shaped groove on both sides of the joint that are angled in opposite directions. This type of edge preparation is commonly used for thicker materials and provides increased weld penetration and better control of the weld pool. The double bevel groove edge preparation also helps to reduce the risk of weld defects such as lack of fusion and porosity.

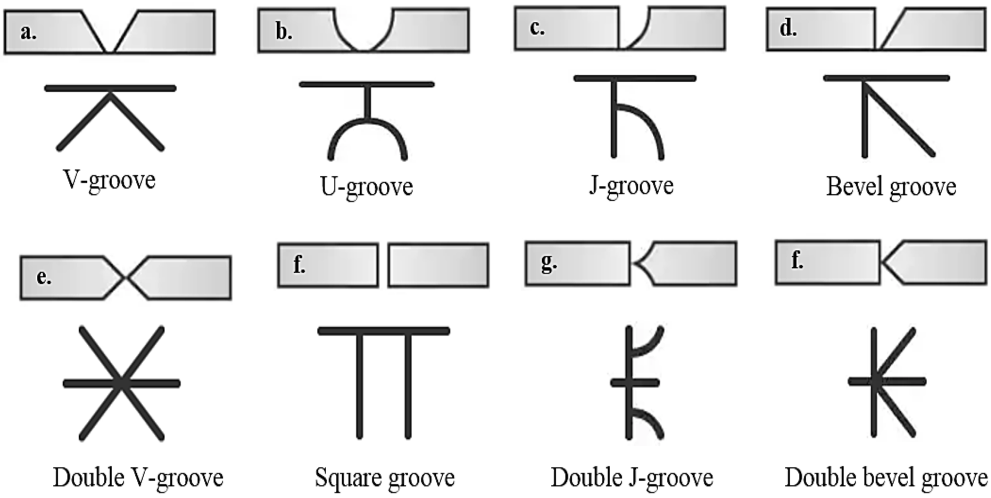


**Fig. 9. Basic types of edge preparation.**

Edge preparation is an essential step in the butt welding process that can have a significant impact on the quality and strength of the weld joint. By carefully selecting the appropriate type of edge preparation for the specific requirements of the welding project, welders can ensure that the weld joint is strong, durable, and free from defects.

## 12 | Types of Arc Welding Electrodes

Arc welding is a widely used welding process that involves the use of an electric arc to melt and join metals. One of the key components of arc welding is the electrode, which serves as a conductor of the electric current and a source of filler material for the weld joint. There are several types of arc welding electrodes, each with its own unique characteristics and applications.

I. SMAW electrode: also known as a stick electrode SMAW electrodes are coated with a flux material that provides a protective gas shield and helps to stabilize the arc during welding. These electrodes are versatile and can be used on a wide range of metals, making them suitable for a variety of welding applications [52].

II. GMAW electrode: also known as a MIG electrode. GMAW electrodes are typically made of a solid wire that is fed through a welding gun along with a shielding gas to protect the weld pool from atmospheric contamination. These electrodes are commonly used for welding thin materials and are known for their high deposition rates and ease of use.

III. Flux-Cored Are Welding (FCAW) electrode: this is similar to a GMAW electrode but contains a flux material within the core of the wire. FCAW electrodes are often used in outdoor welding applications where wind and other environmental factors can affect the quality of the weld. These electrodes are known for their high deposition rates and ability to weld thick materials [53].

IV. In addition to these common types of arc welding electrodes, there are also specialty electrodes available for specific welding applications. For example, there are electrodes designed for welding stainless steel, cast iron, and other specialty metals. These electrodes have unique compositions and coatings that are tailored to the specific properties of the metal being welded.

There are several types of arc welding electrodes available, each with its own unique characteristics and applications. By understanding the differences between these electrodes, welders can choose the right electrode for their specific welding needs and achieve high-quality welds.

# 13 | Types of Arc Welding Machines

There are several types of arc welding machines available on the market, each with its own unique features and capabilities. This section will dissect the different types of arc welding machines, including SMAW, GMAW, and GTAW.

I. SMAW machine: also known as stick welding, it is one of the most common types of arc welding machines. In this process, a consumable electrode coated in flux is used to create the arc and deposit filler metal into the joint. SMAW is versatile and can be used on a wide range of metals, making it a popular choice for both professional welders and hobbyists [54].

II. GMAW or MIG welding machine: this is another popular type of arc welding machine. In this process, a continuous wire electrode is fed through a welding gun, along with a shielding gas, to create the arc and deposit filler metal into the joint. GMAW is known for its high welding speed and ease of use, making it a preferred choice for industrial applications [55], [56].

III. GTAW or TIG welding machine: this is a more advanced type of arc welding machine that uses a non-consumable tungsten electrode to create the arc. Filler metal is added to the joint separately, making GTAW a precise and clean welding process. GTAW is commonly used for welding thin materials and exotic metals, where high-quality welds are required [24], [57].

There are several types of arc welding machines available, each with its own unique advantages and applications. SMAW, GMAW, and GTAW are three of the most common types of arc welding machines (see *Fig. 10.*), each offering different capabilities and benefits. Whether you are a professional welder or a hobbyist, it is important to choose the right type of arc welding machine for your specific welding needs

**a. SMAW Welding Machine** **b. GMAW Welding Machine** **c. GTAW Inverter Welding Machine**

**Fig. 10. Basic types of arc welding machines.**

# 14 | Applications of Arc Welding Processes

Arc welding is a widely used process in various industries due to its versatility and effectiveness in joining metals. There are several different types of arc welding processes, each with its own unique applications and advantages. The various applications of arc welding processes in modern manufacturing are enlisted as follows:

I. One of the most common types of arc welding is SMAW, also known as stick welding. SMAW is used in a wide range of applications, including construction, shipbuilding, and pipeline welding. Its portability and simplicity make it ideal for outdoor and remote welding jobs where other methods may not be practical [58].

II. Another popular arc welding process is GMAW, also known as MIG welding. GMAW is commonly used in automotive, aerospace, and fabrication industries due to its high welding speed and ability to weld a wide range of materials. The process is also relatively easy to learn and can be automated for high-volume production.

III. GTAW, or TIG welding, is another commonly used arc welding process that is known for its precision and high-quality welds. GTAW is often used in industries such as aerospace, nuclear, and pharmaceuticals, where weld quality is critical. The process is also versatile and can be used to weld a wide range of materials, including aluminum, stainless steel, and titanium [59] .

IV. In addition to these common arc welding processes, there are also specialized processes, such as FCAW and submerged arc welding (SAW), that are used in specific applications. FCAW is often used in heavy fabrication and structural welding due to its high deposition rates and ability to weld thick materials. SAW, on the other hand, is commonly used in welding large structures and pressure vessels due to its high efficiency and ability to weld thick materials in a single pass.

Arc welding processes play a crucial role in modern manufacturing and construction industries. Their versatility, efficiency, and ability to produce high-quality welds make them indispensable for a wide range of applications. As technology continues to advance, arc welding processes will likely continue to evolve and improve, further expanding their applications and importance in the industry.

## 15 | Advantages of Arc Welding Processes

There are several advantages to using arc welding processes, which make it a popular choice for many industries. The various advantages of arc welding processes are as follows:

I. Versatility: Arc welding can be used to weld a wide range of metals, including steel, aluminum, and stainless steel. This makes it a versatile option for many different applications, from automotive manufacturing to construction [60] .

II. Efficiency: Arc welding processes are generally faster than other welding methods, such as gas welding or resistance welding. This can help to reduce production times and costs, making arc welding a cost-effective option for many businesses [61] .

III. Arc welding also offers excellent control over the welding process. The heat input and welding parameters can be easily adjusted to achieve the desired weld quality and strength. This level of control helps to ensure consistent and high-quality welds, which is essential for many industries [62] .

IV. Arc welding processes are relatively easy to learn and use. With proper training and equipment, operators can quickly become proficient in arc welding techniques. This makes it a practical option for businesses looking to train new welders or expand their welding capabilities [63].

V. Arc welding processes offer a range of advantages that make them a popular choice for many industries. From their versatility and efficiency to their control and ease of use, arc welding processes provide a reliable and cost-effective solution for welding metal components.

## 16 | Disadvantages of Arc Welding Processes

Like any other welding process, arc welding also has its disadvantages that can affect the quality of the weld and the overall efficiency of the process. The main disadvantages of arc welding processes are as follows:

I. One of the main disadvantages of arc welding is the high heat input associated with the process. The intense heat generated during arc welding can lead to distortion and warping of the metal being welded. This can result in poor weld quality and structural integrity, especially in thin materials. Additionally, the high heat input can also cause the formation of Heat-Affected Zones (HAZ) in the surrounding metal, which can weaken the overall structure of the weld [64].

II. Another disadvantage of arc welding is the presence of spatter, which is the molten metal droplets that are expelled from the welding arc during the welding process. Spatter can cause contamination of the weld and the surrounding area, leading to poor weld quality and the need for additional cleaning and finishing processes. Spatter can also pose a safety hazard to the welder and other workers in the vicinity, as the molten metal droplets can cause burns and injuries [65].

III. Arc welding processes can be time-consuming and labor-intensive, especially when welding complex or intricate structures. The need for precise control of the welding parameters, such as voltage, current, and travel speed, can require skilled and experienced welders to ensure the quality and integrity of the weld. This can result in higher labor costs and longer production times, which can impact the overall efficiency and profitability of the welding process [66].

Arc welding processes have several disadvantages that can affect the quality, efficiency, and safety of the welding process. The high heat input, presence of spatter, and labor-intensive nature of arc welding can lead to poor weld quality, structural integrity issues, and increased production costs. It is important for welders and industry professionals to be aware of these disadvantages and take appropriate measures to mitigate them in order to achieve high-quality welds and efficient welding processes.

## 17 | Conclusion

The findings obtained from this study on arc welding processes have provided valuable insights into the various factors that influence the quality and efficiency of welding operations. This study has highlighted the importance of parameters such as welding current, voltage, and travel speed in determining the strength and integrity of weld joints. Additionally, it has shown that the choice of welding technique, such as GMAW , can have a significant impact on the final outcome of the welding process. However, proper training and certification for welders are highly essential to ensure that welding operations are carried out safely and effectively. By following established best practices and guidelines, welders can minimize the risk of defects and ensure that weld joints meet the required standards for strength and durability. The findings from this study underscore the importance of a systematic and well-informed approach to welding operations. By understanding the key parameters and techniques that influence welding outcomes, welders can optimize their processes and achieve high-quality weld joints. Based on the findings of this study, the following recommendations are suggested to improve the performance of arc welding processes.

I. One key recommendation is to carefully select the welding parameters, such as current, voltage, and travel speed, to ensure optimal weld quality. Studies have shown that the choice of welding parameters can have a significant impact on the strength and integrity of the weld joint. By conducting thorough experimentation and analysis, welders can determine the ideal set of parameters for a given welding application.

II. Another important recommendation is to properly prepare the welding surfaces before starting the welding process. Studies have demonstrated that proper cleaning and prepping of metal surfaces can greatly improve the quality of the weld. This includes removing any contaminants, such as rust or oil, that may interfere with the welding process. Additionally, ensuring proper fit-up of the metal components can help prevent defects and ensure a strong weld joint.

III. It is recommended to use high-quality welding consumables, such as electrodes and filler metals, to achieve consistent and reliable welds. Studies have shown that the choice of consumables can greatly impact the mechanical properties of the weld joint. By using reputable brands and following manufacturer recommendations, welders can ensure that they are using the best materials for the job.

IV. It is important to maintain proper welding techniques and adhere to industry best practices. Studies have highlighted the importance of maintaining a stable arc, controlling the heat input, and ensuring proper shielding gas coverage during the welding process. By following established guidelines and procedures, welders can minimize the risk of defects and produce high-quality welds.

Conventional studies on arc welding processes have provided valuable insights into the factors that influence weld quality and efficiency. By following the recommendations outlined above, welders can improve their welding performance and produce strong, reliable weld joints. It is essential for welders to stay informed about the latest research and developments in the field of arc welding to improve their skills and techniques continuously.

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