

## Welding: Its methods, methodology and safety measures

Devaryan Gupta

Delhi Public School, Faridabad, Haryana, India

### Abstract

Welding is a process of joining two metal pieces by the application of heat. Welding is the least expensive process and widely used now a days in fabrication or sculptural process. In this paper there is a detailed description about welding. This paper gives the introduction of welding and its history. This paper describes various methods of welding. This paper tells about various welding joints. This paper also gives a knowledge on how welding is done and what are the safety measures that should be followed during welding. It gives a list of various welding tools and the applications of welding. This paper also discusses the factors on which the cost of welding depends.

**Keywords:** Gas Welding, Arc Welding, Resistance Welding, Solid State Welding, Thermo-chemical Welding, Radiant Energy Welding

### Introduction

Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing fusion, which is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal. Welding is a way to make high strength joints between two or more parts. In addition to melting the base metal, a filler material is often added to the joint to form a pool of molten material that cools to form a joint that can be as strong, or even stronger, than the base material. Pressure may also be used in conjunction with heat, or by itself, to produce a weld. Welding is the most economical and efficient way to join metals permanently. It is the only way of joining two or more pieces of metal to make them act as a single piece.

### History

#### From the Middle Ages to Modern Technology

Welding is a method of repairing or creating metal structures by joining the pieces of metals or plastic through various fusion processes. Generally, heat is used to weld the materials. Welding equipment can utilize open flames, electric arc or laser light.

#### Middle Ages

The earliest evidence of welding can be traced back to the Bronze Age. The earliest examples of welding are welded gold boxes belonging to the Bronze Age. The Egyptians also learnt the art of welding. Several of their iron tools were made by welding. During the middle Ages, a set of specialized workmen called blacksmiths came to the fore. Blacksmiths of the middle Ages welded various types of iron tools by hammering. The welding methods remained more or less unchanged until the dawn of the 19<sup>th</sup> century.

The history of joining metals goes back several millennia. Called forge welding, the earliest examples come from the Bronze and Iron Ages in Europe and the Middle East. The ancient Greek historian Herodotus states in *The*

*Histories* of the 5th century BC that Glaucus of Chios "was the man who single-handedly invented iron welding". Welding was used in the construction of the Iron pillar of Delhi, erected in Delhi, India about 310 AD and weighing 5.4 metric tons.



The Iron Pillar of Delhi

The Middle Ages brought advances in forge welding, in which blacksmiths pounded heated metal repeatedly until bonding occurred. In 1540, Vannoccio Biringuccio published *De la pirotechnia*, which includes descriptions of the forging operation. Renaissance craftsmen were skilled in the process, and the industry continued to grow during the following centuries.

In 1800, Sir Humphry Davy discovered the short-pulse electrical arc and presented his results in 1801. In 1802, Russian scientist Vasily Petrov created the continuous electric arc, and subsequently published "News of Galvanic-Voltaic Experiments" in 1803, in which he described

experiments carried out in 1802. Of great importance in this work was the description of a stable arc discharge and the indication of its possible use for many applications, one being melting metals. In 1808, Davy, who was unaware of Petrov's work, rediscovered the continuous electric arc. In 1881–82 inventors Nikolai Benardos (Russian) and Stanisław Olszewski (Polish) created the first electric arc welding method known as carbon arc welding using carbon electrodes. The advances in arc welding continued with the invention of metal electrodes in the late 1800s by a Russian, Nikolai Slavyanov (1888), and an American, C. L. Coffin (1890). Around 1900, A. P. Strohmenger released a coated metal electrode in Britain, which gave a more stable arc. In 1905, Russian scientist Vladimir Mitkevich proposed using a three-phase electric arc for welding. In 1919, alternating current welding was invented by C. J. Holslag but did not become popular for another decade.

Resistance welding was also developed during the final decades of the 19th century, with the first patents going to Elihu Thomson in 1885, which produced further advances over the next 15 years. Thermite welding was invented in 1893, and around that time another process, oxy fuel welding, became well established. Acetylene was discovered in 1836 by Edmund Davy, but its use was not practical in welding until about 1900, when a suitable torch was developed. At first, oxy fuel welding was one of the more popular welding methods due to its portability and relatively low cost. As the 20th century progressed, however, it fell out of favour for industrial applications. It was largely replaced with arc welding, as metal coverings (known as flux) for the electrode that stabilize the arc and shield the base material from impurities continued to be developed.

World War I caused a major surge in the use of welding processes, with the various military powers attempting to determine which of the several new welding processes would be best. The British primarily used arc welding, even constructing a ship, the "Fullagar" with an entirely welded hull. Arc welding was first applied to aircraft during the war as well, as some German airplane fuselages were constructed using the process. Also noteworthy is the first welded road bridge in the world, the Maurzyce Bridge designed by Stefan Bryła of the Lwów University of Technology in 1927, and built across the river Słudwia near Łowicz, Poland in 1928.



Acetylene welding on cylinder water jacket, 1918

During the 1920s, major advances were made in welding technology, including the introduction of automatic welding in 1920, in which electrode wire was fed continuously. Shielding gas became a subject receiving much attention, as scientists attempted to protect welds from the effects of oxygen and nitrogen in the atmosphere. Porosity and brittleness were the primary problems, and the solutions that developed included the use of hydrogen, argon, and helium as welding atmospheres. During the following decade, further advances allowed for the welding of reactive metals like aluminium and magnesium. This in conjunction with developments in automatic welding, alternating current, and fluxes fed a major expansion of arc welding during the 1930s and then during World War II. In 1930, the first all-welded merchant vessel, M/S Carolinian, was launched.

During the middle of the century, many new welding methods were invented. In 1930, Kyle Taylor was responsible for the release of stud welding. The New York Navy Yard developed stud welding. Stud welding was increasingly used for the construction industry and also for shipbuilding. It was during this time that the National Tube Company developed a welding process called smothered arc welding. In the sector of shipbuilding, the stud welding process was replaced by the more advanced submerged arc welding.

In 1932 a Russian, Konstantin Khrenov successfully implemented the first underwater electric arc welding.

A new type of welding for seamlessly welding aluminium and magnesium was developed in 1941 by Meredith. This patented process came to be known as Heli arc welding. The gas shielded metal arc welding or GTAW was another significant milestone in the history of welding which was developed in Battelle Memorial Institute in 1948.

Gas tungsten arc welding, after decades of development, was finally perfected in 1941, and gas metal arc welding followed in 1948, allowing for fast welding of non-ferrous materials but requiring expensive shielding gases. Shielded metal arc welding was developed during the 1950s, using a

flux-coated consumable electrode, and it quickly became the most popular metal arc welding process. In 1957, the flux-cored arc welding process debuted, in which the self-shielded wire electrode could be used with automatic equipment, resulting in greatly increased welding speeds, and that same year, plasma arc welding was invented. Electro slag welding was introduced in 1958, and it was followed by its cousin, electro gas welding, in 1961. In 1953 the Soviet scientist N. F. Kazakov proposed the diffusion bonding method.

Other recent developments in welding include the 1958 breakthrough of electron beam welding, making deep and narrow welding possible through the concentrated heat source.

There were several advancements in the welding industry during the 1960's. Dual shield welding, Inner shield, and Electro slag welding were some of the important welding developments of the decade. Plasma arc welding was also invented by Gage during this time. It was used for metal spraying. The French also developed electron beam welding, which is still used by the aircraft manufacturing industries of the United States.

Following the invention of the laser in 1960, laser beam welding debuted several decades later, and has proved to be especially useful in high-speed, automated welding. Magnetic pulse welding (MPW) is industrially used since 1967. Friction stir welding was invented in 1991 by Wayne Thomas at The Welding Institute (TWI, UK) and found high-quality applications all over the world. All of these four new processes continue to be quite expensive due the high cost of the necessary equipment, and this has limited their applications.

Some of the recent developments in the welding industry include the friction welding process developed in Russia, and laser welding. Laser was originally developed in Bell Telephone Laboratories but it is now being used for various kinds of welding work. This is due to the inherent capacity of lasers in rendering precision to all kinds of welding jobs.

### **Types of Welding**

There are different types of welding. These are:

- Gas Welding
- Arc Welding
- Resistance Welding
- Solid State Welding
- Thermo-chemical Welding
- Radiant Energy Welding

### **Methods of ARC Welding**

#### **Shielded metal arc welding (SMAW)**

It is also known as "stick welding or electric welding" or "arc welding". It uses an electrode that has flux around it to protect the weld puddle. The electrode holder holds the electrode as it slowly melts away. Slag protects the weld puddle from atmospheric contamination. Arc welding is the most basic of all welding types, is easy to master in a home welding situation. Stick welding can be used for manufacturing, construction and repairs, very much well suited for heavy metal size 4 millimetres upwards. Thinner

sheet metals and alloys are usually more suited to this welding type.

#### **Gas tungsten arc welding (GTAW)**

It is also known as TIG (tungsten, inert gas). It uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas such as argon or helium. TIG welding is comparable to oxy acetylene gas welding and needs a lot more expertise from the operator. It employed for carrying out high-quality work when a superior standard of finish is needed without making use of excessive clean up by sanding or grinding.

#### **Gas metal arc welding (GMAW)**

It is commonly termed MIG (metal, inert gas). It uses a wire feeding gun that feeds wire at an adjustable speed and flows an argon-based shielding gas or a mix of argon and carbon dioxide (CO<sub>2</sub>) over the weld puddle to protect it from atmospheric contamination. The GMAW process is suitable for fusing mild steel, stainless-steel as well as aluminium.

#### **Flux-cored arc welding (FCAW)**

It is almost identical to MIG welding except it uses a special tubular wire filled with flux; it can be used with or without shielding gas, depending on the filler.

#### **Submerged arc welding (SAW)**

It uses an automatically fed consumable electrode and a blanket of granular fusible flux. The molten weld and the arc zone are protected from atmospheric contamination by being "submerged" under the flux blanket.

#### **Electro slag welding (ESW)**

It is a highly productive, single pass welding process for thicker materials between 1 inch (25 mm) and 12 inches (300 mm) in a vertical or close to vertical position.

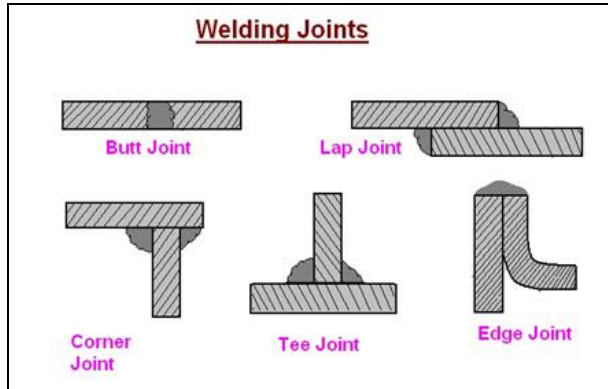
Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding may be performed in many different environments, including in open air, under water, and in outer space. Welding is a hazardous undertaking and precautions are required to avoid burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation.

Until the end of the 19th century, the only welding process was forge welding, which blacksmiths had used for centuries to join iron and steel by heating and hammering. Arc welding and oxy fuel welding were among the first processes to develop late in the century, and electric resistance welding followed soon after. Welding technology advanced quickly during the early 20th century as the world wars drove the demand for reliable and inexpensive joining methods. Following the wars, several modern welding techniques were developed, including manual methods like SMAW, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as GMAW, SAW, FCAW and ESW. Developments continued with the invention of laser beam welding, electron beam welding, magnetic pulse welding (MPW), and friction stir

welding in the latter half of the century. Today, the science continues to advance. Robot welding is commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality.

### Welding Joints

Different types of welding joints are: Butt, Lap, Corner, Tee and Edge Joints



### Methodology: How welding is done?

There are three parts of the welding process. These are:

1. Preparing the Job
2. Start the Weld
3. Finish the Job

Arc welding is a method of joining two or more materials with electrically generated heat. While there are many different welding processes listed by the American Welding Society, the one we are going to cover here is Shielded Metal Arc Welding (SMAW), also known as stick welding. Stick welding is one of the most common and versatile forms of welding, and is a relatively easy way to add professionalism and durability to your DIY projects.

#### i) Preparing the Job

1. Gather the materials. We should have a welding machine, electrode holder with lead, ground clamp with lead, electrodes and metal to be welded. We also need a chipping hammer to get rid of the slag and a wire brush to clean the welds.
2. Put on the safety gears. It includes a welding helmet, welding jacket or cotton sweatshirt, pants without cuffs, work boots, gloves and safety glasses. We should not wear tennis shoes, frayed clothes, pants with cuffs, a t-shirt, a shirt with open pockets or sleeveless shirts.
3. Prepare the area to be welded in. Remove all flammable materials and find a good surface to weld on. We can put the ground connection right on the piece we are welding. If other people are present there, set up welding curtains around the work area to prevent them from ultraviolet damage.
4. Set up the machine. Most welding machines are fairly straight forward. We should use amperage of around 90-120 amperes, although it can be adjusted for metal thickness and electrode diameter.
5. Use the correct electrode. DCEP (Direct Current Electrode Positive) sets an arc to go from the metal to the

electrode, heating the metal more. DCEN (Direct Current Electrode Negative) has the reverse effect. For stick welding, DCEP will give more penetration to the welding. Electrodes should be dry.

6. Clean the metal before welding. It is done by brushing the surface to be welded with a wire brush or grinder. Remove as much rust or paint as possible. Use acetone to clean off the metal, especially aluminium. We should not use a chlorinated solvent, as the reaction when heated with a welder can kill the welder instantly. Just because metal is shiny, it does not mean it is clean. We should use a hard grinding disc to remove the layer of mill scale and get down to the bare metal. It is applicable to steel.
7. Set the joint. Use clamps and vices to ensure that the joints we are welding are precisely and firmly held together.

#### ii) Start the Weld

1. Strike a welding arc. It is done by tapping the metal and quickly pulling up or striking it like a match. We are completing the circuit and pulling away; which causes the electricity to jump from the electrode to the metal. Most modern welding helmets allow us to see clearly until we strike the arc and then darken automatically to protect our eyes from UV damage.
2. Build up a weld pool. When a stable arc can be maintained, ignore the end of the electrode and instead watch the pool of molten metal. To create a good pool, we should stay where we started for a second or two before moving. The arc gap should not be wider than 1/8" from rod tip to metal. This gap dimension should be maintained by feeding on gently pushing the electrode toward the molten weld puddle. If the gap gets too wide, it will lead to excessive spatter.
3. Start moving the weld pool across the metal. Keep the electrode at an angle a few degrees shy of 90°. Do not travel too fast. When moving the weld pool, we can go in a straight line or move around in small circles. The length of arc and the distance from the tip of the electrode to the metal should be constant.

#### iii) Finish the Job

1. Finish the weld. Put the electrode back from the metal and allow it to cool for a few seconds. The metal will be very hot at this point.
2. Clean the slag. Slag is a residue left from the welding process. During the weld, the slag protects the hot metal from contaminants. The slag covering does not cool at the same rate as the weld bead, which can cause the slag to pop off the weld. Use the chipping hammer to break the slag off the weld. Safety glasses should be worn to protect the eyes. Tap the slag only hard enough to loosen the slag and avoid putting hammer marks in the new weld. Use the wire brush to clean the weld. Remove as many excess particles as possible.
3. Examine the weld. A welder's first weld is poor. Make another pass to fix any gaps or incomplete welds.

4. Allow the metal to cool. If it is only practice, then dip the metal in water for fast cooling. Cooling in water will make the weld brittle. So allow structural welds to cool by air.

#### **Safety measures to be followed during welding:**

- ALWAYS wear a proper face shield.
- ALWAYS wear close-toed shoes.
- ALWAYS wear a long-sleeved, non-flammable shirt.
- ALWAYS wear proper welding gloves.
- ALWAYS wear ear protection (earplugs or muffs) to prevent sparks from entering your ear canal. An eardrum punctured by a spark will instantly cauterize and never heal.
- NEVER weld on or near anything that's been cleaned with a chlorinated hydrocarbon like brake-cleaner. When combined with UV light, chlorinated hydrocarbons can create phosgene gas, which can cause serious injury or death. Ventilation will not prevent poisoning.
- If you burn yourself, immediately douse with cold water.

#### **Fire**

Make sure the weld area is free from all flammable materials such as flammable liquids, paper, etc. Do not wear clothing or gloves that have been exposed to flammable liquids.

#### **Electrocution**

Before turning on a welding machine, make sure there are no puddles of water on the floor around the weld bench or the machine. Make sure the weld machine is dry, including the main box, the torch, the pedal, and the plug.

There is little risk of fatal electrocution from a properly working TIG weld machine. When the user presses on the pedal to initiate the arc, a high-frequency low amplitude arc will emit from the tip of the weld torch. Once the machine detects the grounded metal piece that is to be welded, the arc will switch over to a high-amplitude DC current. Even if the operator deliberately points it toward their body, the shock will be mild, since the machine will not switch over to the high amplitude current.

#### **Burns**

Welded metal will remain hot for several minutes after it is welded. In most cases the heat is localized near the weld itself. In the case of more conductive materials, such as copper and aluminum, the heat may be more distributed throughout the material.

In the case of TIG welding, sparks and spatter are non-existent, unless rusty or dirty metal is used. MIG welding steel will create sparks, so earplugs and full coverage safety glasses should be worn to prevent burns to sensitive tissue.

Gloves **must** be worn when welding and handling recently welded material. White cotton welding gloves may be used for light TIG welding, as long as they are free of holes. For heavier welding, deerskin or heavy duty welding gloves should be used.

#### **UV Burns**

The light emitted from a weld arc is brighter than that of the sun. Do not look at the arc without wearing a full-faced

welding mask with a shade 10 or darker filter plate. Always make sure the weld curtains are in place between the welder(s) and other people in the shop. Be sure to cover any exposed skin, including cuff and collar areas, while welding or observing inside the weld area. The rays from the arc can cause a UV burn much worse than a sun burn. Observers may use a cardboard mask with a shade 10 filter plate.

#### **Compressed Gas Cylinders**

Argon and CO<sub>2</sub> are inert, nontoxic gases normally present in the atmosphere. However, if allowed to fill an enclosed area these gases can fully displace breathable air, causing asphyxiation and death. At the Asylum, the greater potential danger is the valve being knocked off the cylinder, turning it into a rocket powerful enough to severely injure or kill people and damage equipment and the building itself.

The following guidelines must be followed at all times:

##### **a) Storing**

- Cylinders must always remain upright and never be placed horizontally.
- Cylinders must be secured with a non-combustible material (metal) to an immovable object to prevent them from falling.

##### **b) Moving**

- Cylinders must be securely capped.

#### **Welding Tools**

The tools mandatory for welding purpose are:-

- A Pair of Safety Glasses (Green Shade #5 lens & clear lens... Worn during labs)
- A Head Protection (Do-Rag, Welders Cap, etc.)
- A Pair of leather boots (To be worn during labs)
- A Hearing protection (To be worn during labs)
- A ea. Welding Gloves (SMAW, MIG, TIG)
- A Welding Helmet (#10 & # 11 shade lenses required)
- A Leather Welding Jacket (Welding Sleeves are NOT suitable for ARC welding with the exception of TIG)
- A Welding Sleeves (Only used for WLD-104 Gas Welding & Cutting)
- A 24 ounce Ball Peen Hammer
- A Needle Nose Pliers 1 Lineman's Pliers
- A Tape Measure
- A Combination Square
- A Wire Brush (Stainless Steel)
- A Chipping Hammer
- A Gas/Cutting Torch Tip Cleaner
- A Flat Cross-Cut Bastard File
- A Round Cross-Cut Bastard File
- A Magnetic Torpedo Level
- A 4-1/2 inch Angle Grinder with two 60-Grit Sanding discs and two grinding wheels for steel
- A 10 FT. – 14/3 Extension Cord
- A Soap Stone or Scribe (Used for marking or layout)

#### **Cost of Welding**

As an industrial process, the cost of welding plays a very important role in manufacturing decisions. Many different variables affect the total cost, including equipment cost,

labour cost, material cost, and energy cost. Depending on the process, equipment cost can vary, from inexpensive for methods like shielded metal arc welding and oxy fuel welding, to extremely expensive for methods like laser beam welding and electron beam welding. Because of their high cost, they are only used in high production operations. Similarly, because automation and robots increase equipment costs, they are only implemented when high production is necessary. Labour cost depends on the deposition rate (the rate of welding), the hourly wage, and the total operation time, including time spent fitting, welding, and handling the part. The cost of materials includes the cost of the base and filler material, and the cost of shielding gases. Finally, energy cost depends on arc time and welding power demand. For manual welding methods, labour costs generally make up the vast majority of the total cost. As a result, many cost-saving measures are focused on minimizing operation time. To do this, welding procedures with high deposition rates can be selected, and weld parameters can be fine-tuned to increase welding speed. Mechanization and automation are often implemented to reduce labour costs, but this frequently increases the cost of equipment and creates additional setup time. Material costs tend to increase when special properties are necessary, and energy costs normally do not amount to more than several percent of the total welding cost. In order to minimize labour costs in high production manufacturing, industrial welding has become increasingly more automated, most notably with the use of robots in resistance spot welding and in arc welding. In robot welding, mechanized devices both hold the material and perform the weld and at first, spot welding was its most common application, but robotic arc welding increases in popularity as technology advances.

### Applications of Welding

Welding is widely used in many fields. Some of the application areas of Welding are:

- Automotive / auto suppliers
- Electrical / electronics
- Aerospace / air plane
- Train carriage / rail
- Radiator / container
- Domestic hardware
- Medical instruments
- Nuclear equipment
- Food and drink
- Other metal processing industries.

### Conclusion

Welding means the permanent joining together of components by means of heat or pressure, with or without welding additives. Welding is economical process. Welding process is very risky so a number of safety measures are followed. It has a number of application areas. Pressure may also be used in conjunction with heat, or by itself, to produce a weld.

### Future Aspects of Welding

Key areas of research and development include the welding of dissimilar materials (such as steel and aluminium) and new welding processes, such as friction stir, magnetic pulse,

conductive heat seam, and laser-hybrid welding. Furthermore, progress is desired in making more specialized methods like laser beam welding practical for more applications, such as in the aerospace and automotive industries. Researchers also hope to better understand the often unpredictable properties of welds, especially microstructure, residual stresses, and a weld's tendency to crack or deform. The trend of accelerating the speed at which welds are performed in the steel erection industry comes at a risk to the integrity of the connection.

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