MRT-10

WELDING

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. In addition to melting the base metal, a filler material is typically added to the joint to form a pool of molten material (the weld pool) that cools to form a joint that is usually stronger than the base material. Pressure may also be used in conjunction with heat, or by itself, to produce a weld.

Although less common, there are also solid state welding processes such as friction welding or shielded active gas welding in which metal does not melt.

Types of the best known welding methods :

- Shielded metal arc welding (SMAW) – also known as "stick welding or electric welding", 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.
- Gas tungsten arc welding (GTAW) – also known as TIG (tungsten, inert gas), 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.
- Gas metal arc welding (GMAW) – commonly termed MIG (metal, inert gas), 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_2) over the weld puddle to protect it from atmospheric contamination.
- Flux-cored arc welding (FCAW) – 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) – 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.
- Electroslag welding (ESW) – 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.
- Electric resistance welding (ERW) - a welding process that produces coalescence of laying surfaces where heat to form the weld is generated by the electrical resistance of the material. In general, an efficient method, but limited to relatively thin material.

Weldability

The weldability, also known as join ability, of a material refers to its ability to be welded. Many metals and thermoplastics can be welded, but some are easier to weld than others (see Rheological Weldability). A material's weldability is used to determine the welding process and to compare the final weld quality to other materials.

Weldability is often hard to define quantitatively, so most standards define it qualitatively. For instance the International Organization for Standardization (ISO) defines weldability in ISO standard 581-1980 as: "Metallic material is considered to be susceptible to welding to an established extent with given processes and for given purposes when welding provides metal integrity by a corresponding technological process for welded parts to meet technical requirements as to their own qualities as well as to their influence on a structure they form." Other welding organizations define it similarly.

Weldability by process

Material	Arc welding	Oxy-acetylene welding	Electron beam welding	Resistance welding	Brazing	Soldering	Adhesive bonding
Cast iron	C	R	N	S	D	N	C
Carbon steel and low-alloy steel	R	R	C	R	R	D	C
Stainless steel	R	C	C	R	R	C	C
Aluminium and magnesium	C	C	C	C	C	S	R
Copper and copper alloys	C	C	C	C	R	R	C

Weldability by process							
Material	**Arc welding**	**Oxy-acetylene welding**	**Electron beam welding**	**Resistance welding**	**Brazing**	**Soldering**	**Adhesive bonding**
Nickel and nickel alloys	R	C	C	R	R	C	C
Titanium	C	N	C	C	D	S	C
Lead and zinc	C	C	N	D	N	R	R
Thermoplastic[†]	N	N	N	N	N	N	C
Thermosets	N	N	N	N	N	N	C
Elastomers	N	N	N	N	N	N	R
Ceramics	N	S	C	N	N	N	R
Dissimilar metals	D	D	C	D	D/C	R	R
[†]Heated tool = R; Hot gas = R; Induction = C Key: C = Commonly performed; R = Recommended; D = Difficult; S = Seldom; N = Not used							

Welding Metallurgy

An understanding of the properties of the makeup of alloys and the effects of joining methods on their microstructures is crucial to ensure the performance of components and structures in service.

TWI has a broad mix of engineers and consultants with up-to-date expertise, industry experience and strong academic backgrounds, allowing us to bridge the gap between academia and industry and provide world-leading consultancy services on metallic materials.

Our multi-disciplinary teams can provide advice on:

- Alloy selection
- Diagnosis of failure mechanisms
- Fitness-for-service
- Development of specialised joining techniques and optimisation of existing ones
- Assessment of microstructures
- Testing of interactions with extreme environments.

Our expertise covers ferrous alloys (steel), aluminium, titanium and corrosion-resistant alloys.

A fundamental aspect of a metal's property is its weldability: its ability to be welded and suitability for different welding techniques. This is not a fixed parameter for a given material, but will depend on joint details, service requirements and available welding processes and facilities.

A metal's weldability is a measure of how easy it is to:

- Obtain crack-free welds
- Achieve adequate mechanical properties
- Produce welds that are resistant to service degradation.

The process of welding can have a significant effect on a metal's properties; many of the characteristics of welded joints are determined by the microstructures developed during welding.

TWI is dedicated to the evaluation and understanding of the relationships between material properties and their underlying structures, with particular focus on the effect of joining on the microstructures developed.

The thermal cycles imposed during welding can completely change the microstructure of the parent material, posing serious challenges for material scientists looking for the optimal joining technique. The rapid solidification of the weld metal itself, composed of a mixture of parent materials and filler material (when filler material is used) adds to the challenge.

We have a team of specialists covering metallurgy, joining techniques, non-destructive testing, structural integrity and modelling who, together, form a powerful resource to solve all kinds of joining challenges for a wide range of functional materials.

TWI has introduced numerous inventions and innovations in this field, and we continue to invest in improvements to our capability and understanding of joining technologies.

ARC WELDING

Arc welding is a process that is used to join metal to metal by using electricity to create enough heat to melt metal, and the melted metals when cool result in a binding of the metals. It is a type of welding that uses a welding power supply to create an electric arc between an electrode and the base material to melt the metals at the welding point. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. The welding region is usually protected by some type of shielding gas, vapor, or slag. Arc welding processes may be manual, semi-automatic, or fully automated. First developed in the late part of the 19th century, arc welding became commercially important in shipbuilding during the Second World War. Today it remains an important process for the fabrication of steel structures and vehicles

Power supplies

To supply the electrical energy necessary for arc welding processes, a number of different power supplies can be used. The most common classification is constant current power supplies and constant voltage power supplies. In arc welding, the voltage is directly related to the length of the arc, and the current is related to the amount of heat input. Constant current power supplies are most often used for manual welding processes such as gas tungsten arc welding and shielded metal arc welding, because they maintain a relatively constant current even as the voltage varies. This is important because in manual welding, it can be difficult to hold the electrode perfectly steady, and as a result, the arc length and thus voltage tend to fluctuate. Constant voltage power supplies hold the voltage constant and vary the current, and as a result, are most often used for automated welding processes such as gas metal arc welding, flux cored arc welding, and submerged arc welding. In these processes, arc length is kept constant, since any fluctuation in the distance between the wire and the base material is quickly rectified by a large change in current. For example, if the wire and the base material get too close, the current will rapidly increase, which in turn causes the heat to increase and the tip of the wire to melt, returning it to its original separation distance.

The direction of current used in arc welding also plays an important role in welding. Consumable electrode processes such as shielded metal arc welding and gas metal arc welding generally use direct current, but the electrode can be charged either positively or negatively. In welding, the positively charged anode will have a greater heat concentration (around 60%)[2] and, as a result, changing the polarity of the electrode affects weld properties. If the electrode is positively charged, it will melt more quickly, increasing weld penetration and welding speed. Alternatively, a negatively charged electrode results in more shallow welds.[3] Non-consumable electrode processes, such as gas tungsten arc welding, can use either type of direct current (DC), as well as alternating current (AC). With direct current however, because the electrode only creates the arc and does not provide filler material, a positively charged electrode causes shallow welds, while a negatively charged electrode makes deeper welds.[4] Alternating current rapidly moves between these two, resulting in medium-penetration welds. One disadvantage of AC, the fact that the arc must be re-ignited after every zero crossing, has been addressed with the invention of special power units that produce a square wave pattern instead of the normal sine wave, eliminating low-voltage time after the zero crossings and minimizing the effects of the problem. **Duty** is a welding equipment specification which defines the number of minutes, within a 10-minute period, during which a given arc welder can safely be used. For example, an 80 A welder with a 60% duty cycle must be "rested" for at least 4 minutes after 6 minutes of continuous welding.[6] Failure to observe duty cycle limitations could damage the welder. Commercial- or professional-grade welders typically have a 100% duty cycle.

Consumable electrode methods

Shielded metal arc welding

One of the most common types of arc welding is shielded metal arc welding (SMAW), which is also known as manual metal arc welding (MMAW) or stick welding. An electric current is used to strike an arc between the base material and a consumable electrode rod or *stick*. The electrode rod is made of a material that is compatible with the base material being welded and is covered with a flux that gives off vapors that serve as a shielding gas and provide a layer of slag, both of which protect the weld area from atmospheric contamination. The electrode core itself acts as filler material, making a separate filler unnecessary. The process is very versatile, requiring little operator training and inexpensive equipment. However, weld times are rather slow, since the consumable electrodes must be frequently replaced and because slag, the residue from the flux, must be chipped away after welding.[7] Furthermore, the process is generally limited to welding ferrous materials, though specialty electrodes have made possible the welding of cast iron, nickel, aluminium, copper and other metals. The versatility of the method makes it popular in a number of applications including repair work and construction.[8]

Gas metal arc welding (GMAW), commonly called *MIG* (for *metal/inert-gas*), is a semi-automatic or automatic welding process with a continuously fed consumable wire acting as both electrode and filler metal, along with an inert or semi-inert shielding gas flowed around the wire to protect the weld site from contamination. Constant voltage, direct current power source is most commonly used with GMAW, but constant current alternating current are used as well. With continuously fed filler electrodes, GMAW offers relatively high welding speeds, however the more complicated equipment reduces convenience and versatility in comparison to the SMAW process. Originally developed for welding aluminium and other non-ferrous materials in the 1940s, GMAW was soon economically applied to steels. Today, GMAW is commonly used in industries such as the automobile industry for its quality, versatility and speed. Because of the need to maintain a stable shroud of shielding gas around the weld site, it can be problematic to use the GMAW process in areas of high air movement such as outdoors.[9]

Flux-cored arc welding (FCAW) is a variation of the GMAW technique. FCAW wire is actually a fine metal tube filled with powdered flux materials. An externally supplied shielding gas is sometimes used, but often the flux itself is relied upon to generate the necessary protection from the atmosphere. The process is widely used in construction because of its high welding speed and portability.

Submerged arc welding (SAW) is a high-productivity welding process in which the arc is struck beneath a covering layer of granular flux. This increases arc quality, since contaminants in the atmosphere are blocked by the flux. The slag that forms on the weld generally comes off by itself and, combined with the use of a continuous wire feed, the weld deposition rate is high. Working conditions are much improved over other arc welding processes since the flux hides the arc and no smoke is produced. The process is commonly used in industry, especially for large products.[10] As the arc is not visible, it is typically automated. SAW is only possible in the 1F (flat fillet), 2F (horizontal fillet), and 1G (flat groove) positions.

Non-consumable electrode methods

Gas tungsten arc welding (GTAW), or *tungsten/inert-gas* (TIG) welding, is a manual welding process that uses a non-consumable electrode made of tungsten, an inert or semi-inert gas mixture, and a separate filler material. Especially useful for welding thin materials, this method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds. It can be used on nearly all wieldable metals, though it is most often applied to stainless steel and light metals. It is often used when quality welds are extremely important, such as in bicycle, aircraft and naval applications.[11]

A related process, plasma arc welding, also uses a tungsten electrode but uses plasma gas to make the arc. The arc is more concentrated than the GTAW arc, making transverse control more critical and thus generally restricting the technique to a mechanized process. Because of its stable current, the method can be used on a wider range of material thicknesses than can the GTAW process and is much faster. It can be applied to all of the same materials as GTAW except magnesium; automated welding of stainless steel is one important application of the process. A variation of the process is plasma cutting, an efficient steel cutting process.[12]

Other arc welding processes include atomic hydrogen welding, carbon arc welding, electro slag welding, electro gas, and stud arc welding.

Corrosion issues

Some materials, notably high-strength steels, aluminium, and titanium alloys, are susceptible to hydrogen embrittlement. If the electrodes used for welding contain traces of moisture, the water decomposes in the heat of the arc and the liberated hydrogen enters the lattice of the material, causing its brittleness. Stick electrodes for such materials, with special low-hydrogen coating, are delivered in sealed moisture-proof packaging. New electrodes can be used straight from the can, but when moisture absorption may be suspected, they have to be dried by baking (usually at 450 to 550 °C or 840 to 1,020 °F) in a drying oven. Flux used has to be kept dry as well.

Some austenitic stainless steels and nickel-based alloys are prone to intergranular corrosion. When subjected to temperatures around 700 °C (1,300 °F) for too long a time, chromium reacts with carbon in the material, forming chromium carbide and depleting the crystal edges of chromium, impairing their corrosion resistance in a process called sensitization. Such sensitized steel undergoes corrosion in the areas near the welds where the temperature-time was favourable for forming the carbide. This kind of corrosion is often termed weld decay.

Knifeline attack (KLA) is another kind of corrosion affecting welds, impacting steels stabilized by niobium. Niobium and niobium carbide dissolves in steel at very high temperatures. At some cooling regimes, niobium carbide does not precipitate, and the steel then behaves like unstabilized steel, forming chromium carbide instead. This affects only a thin zone several millimeters wide in the very vicinity of the weld, making it difficult to spot and increasing the corrosion speed. Structures made of such steels have to be heated in a whole to about 1,000 °C (1,830 °F), when the chromium carbide dissolves and niobium carbide forms. The cooling rate after this treatment is not important.

Filler metal (electrode material) improperly chosen for the environmental conditions can make them corrosion-sensitive as well. There are also issues of galvanic corrosion if the electrode composition is sufficiently dissimilar to the materials welded, or the materials are dissimilar themselves. Even between different grades of nickel-based stainless steels, corrosion of welded joints can be severe, despite that they rarely undergo galvanic corrosion when mechanically joined.[15]

Safety issues

Welding can be a dangerous and unhealthy practice without the proper precautions; however, with the use of new technology and proper protection the risks of injury or death associated with welding can be greatly reduced.

Heat, fire, and explosion hazard

Because many common welding procedures involve an open electric arc or flame, the risk of burns from heat and sparks is significant. To prevent them, welders wear protective clothing in the form of heavy leather gloves and protective long sleeve jackets to avoid exposure to extreme heat, flames, and sparks. The use of compressed gases and flames in many welding processes also pose an explosion and fire risk; some common precautions include limiting the amount of oxygen in the air and keeping combustible materials away from the workplace.

Eye damage

Exposure to the brightness of the weld area leads to a condition called arc eye in which ultraviolet light causes inflammation of the cornea and can burn the retinas of the eyes. Welding goggles and helmets with dark face plates—much darker than those in sunglasses or oxy-fuel goggles—are worn to prevent this exposure. In recent years, new helmet models have been produced featuring a face plate which automatically self-darkens electronically.[17] To protect bystanders, transparent welding curtains often surround the welding area. These curtains, made of a polyvinyl chloride plastic film, shield nearby workers from exposure to the UV light from the electric arc.[18]

Inhaled matter

Welders are also often exposed to dangerous gases and particulate matter. Processes like flux-cored arc welding and shielded metal arc welding produce smoke containing particles of various types of oxides. The size of the particles in question tends to influence the toxicity of the fumes, with smaller particles presenting a greater danger. Additionally, many processes produce various gases (most commonly carbon dioxide and ozone, but others as well) that can prove dangerous if ventilation is inadequate.

Interference with pacemakers

Certain welding machines which use a high frequency alternating current component have been found to affect pacemaker operation when within 2 meters of the power unit and 1 meter of the weld site

Maintenance of welding Machine

One of the most important – and simplest – ways to create strong welds is to properly maintain your welding equipment. Taking care of your welder does not require a great deal of effort, and it can save you significant time and money in the long run – both in equipment longevity and in weld quality and performance. Proper short term machine maintenance will help you to avoid some common welding errors and help you avoid paying for costly repairs on improperly maintained or neglected equipment.

Depending on the type of welding equipment you're using, the maintenance required will be different. Stick (SMAW) welding equipment requires very little maintenance, while MIG (GMAW) and TIG (GTAW) welders need a bit more care and attention to stay in proper shape

Caring for your Stick (SMAW) Welding Equipment

Because the majority of the equipment components are contained inside the welder, stick welding equipment requires the least amount of machine maintenance.The only elements not contained inside the equipment are the electrode holder and the ground clamp. However, these elements do not require a great deal of day-to-day maintenance; rather, these parts have a tendency to wear over time, so it's good procedure to monitor their condition and replace these parts when needed.Long term, you will want to have a qualified technician check inside the machine for buildup of dirt, dust and grime on cooling fans, wiring, transformers and PC boards. Servicing the machine in this way will help to cool the components and prolong the service life of the unit. Be sure you always unplug the machine before performing any maintenance tasks.

JOB PREPARATION

Actual welding takes very little time. It is the getting ready to weld that takes the time. You can probably get away with welding pieces of 1/8 inch steel together without making a **chamfer** on the edges to be joined as you see in the graphic. Even 1/8 inch stock should be welded from both sides **for penetration and strength.** A friend brought me a bicycle rack for the bumper and trunk lid of their automobile. A 1/2 inch rod had broken off near the end of the threaded portion. She and her husband thought I would simply run a weld bead around the break. They were surprised when I made a deep "V" across the top and bottom of the joint. Then I made a **root weld** at the thin leading edge of each piece to join them together. See the red oval in the graphic. The root weld is often done with a thinner welding rod or more current or both to guarantee excellent penetration. I waited until the joint had cooled and chipped away the slag. Grind a little on the back side, too, to avoid any slag being trapped under a weld. Such **slag inclusions** would weaken the weld. I made a weld on both the top and the bottom of the root weld to keep stresses in the metal equalized. See the yellow and blue in the graphic. Clean away the slag after the welds cool and weld on both sides again. I repeated this process until the "V"s were full. Instead of a few minutes, this project took more than an hour to complete. You can see a real life example of this at this Instructable. The same Instructable is also linked in step 7 in regard to preheating.

An old adage is to **weld a little and cool a lot**. After welding, pounding on the welded joint with a chipping hammer reduces stresses in the weld. There is also the matter of **duty cycle**. Every welder has a duty cycle. That means it will overheat and stop welding if used continuously. The duty cycle is often 20/80. That means after welding for 2 minutes (20 percent) you must let the welder cool for 8 minutes (80 percent). Often a weld can be completed in less than 2 minutes and you will need more than 8 minutes to get ready for the next weld, anyway, so it all works out.

ELECTRODE

An electrode is an electrical conductor used to make contact with a nonmetallic part of a circuit (e.g. a semiconductor, an electrolyte, a vacuum or air). The word was coined by William Whewell at the request of the scientist Michael Faraday from the Greek words *elektron*, meaning amber (from which the word electricity is derived). There are many different types of electrodes which vary by charge and by application.EDM electrodes are used in electrical discharge machining (EDM), a process that removes metal with an electrical discharge of very short duration and high current density between the electrode and the workpiece.

Anodes are positively charged electrodes used in a variety of electrochemical processes such as corrosion protection (sacrificial anodes) and electroplating (plating anodes) as well as components in batteries, fuel cells, and electrochemical devices.

Cathodes are negatively charged electrodes used in batteries, fuel cells, electrolysis systems, plating, electrowinning, electron emission, and other specialized processes.

Cathode emitters and filaments are cathodic, field, or thermionic emission cathodes that emit electrons under high voltage or high temperature conditions. Thermionic emitters often consist of a tungsten or refractory metal filament. Lathanum boride emitters are now used, which provide longer life.

Furnace electrodes are used to heat and melt metals or ceramics in arc furnaces. An arc is struck between the electrodes and furnace load material. The arc or plasma generates extremely high temperatures. The electrodes are commonly made from carbon-based materials.

Electrical contacts consist of a high-conductivity, soft, and oxidation-resistant material, often with a second phase to provide anti-welding and/or arc-resistance. They are used in circuit breakers, relays, switches, and EDM applications.

Electrode Materials

Some of the most prominent alloys and materials used as electrode materials are copper, graphite, titanium, brass, silver, and platinum. **Copper** is second only to silver in terms of bulk electrical conductivity. Copper has better strength than silver, but offers inferior oxidation resistance. Copper is a common base metal for electrical contact and electrode applications. It is also used in alloys with graphite, tellurium, and tungsten, and is used to make brass and bronze. Copper has better EDM wear resistance than brass, but is more difficult to machine than either brass or graphite. Copper is also more expensive than graphite.

Graphite and carbon are used in a variety of electrode applications. Graphite, flake graphite, and graphitic carbon have a hexagonal, crystalline structure that cleaves or shears easily, making graphite a soft material and effective lubricant. Graphite is the most commonly used EDM electrode material because of its good machinability, wear resistance, and low cost. Like carbon, graphite is a non-metallic substance with an extremely-high sublimation temperature which provides resistance to high-temperature arcs. Fine, grain-sized graphite tends to have better erosion and wear performance, but costs more. Carbon is very inter, corrosion resistant, and electrochemically noble compared to many metals, which make carbon a useful material for electrochemical and electrowinning electrodes.

Titanium is a non-ferrous metal with excellent corrosion resistance, good fatigue properties, and a high strength-to-weight ratio. Titanium’s excellent corrosion properties result in the use of titanium for electrochemical processes such as electroplating, electrophoresis, electrodeposition, electroforming, electro-hydrolysis, electrochlorinatio, electrofluorination, and electrolysis.

Brass is an alloy of copper and zinc. Brass materials are used to form EDM wire and small tubular electrodes. Brass does not resist wear as well as copper or tungsten, and has a lower conductivity than copper, but is much easier to machine and can be die-cast or extruded for specialized applications. EDM wire does not need to provide EDM wear or arc erosion resistance since new wire is fed continuously during the EDM wiring cutting process.

Silver has the highest conductivity of all metals. The high conductivity, softness (low hardness), and high resistance to oxidation make silver an excellent choice for contact materials. Silver is strengthened with copper and other alloy additions, but at the sacrifice of conductivity. Fine silver is silver with very high purity (99.99% Ag). Pure or fine silver is too soft for most commercial applications, but the material is used as a starting component to form other silver based alloys.

Platinum and palladium have very high erosion and corrosion resistance with low contact resistance. Platinum forms useful alloys with iridium, ruthenium, and tungsten. Palladium forms useful alloys with copper and ruthenium. Major drawbacks of these metals are high cost and the development of high contact resistance films in the presence of organic vapors.

Mixed metal oxide (MMO) electrodes have an oxide coating over an inert metal or carbon core. The oxides consist of precious metal (Ru, Ir, Pt) oxides for catalyzing an electrolysis reaction. Titanium oxides are used for inertness, electrode corrosion protection, and lower cost. Electrochlorination is one common application. The core metals are titanium (most common), zirconium, niobium, or tantalum.

Material Properties

Important properties of electrode materials are conductivity, corrosion resistance, hardness, current load, form, and size. Many of these are determined by inherent characteristics of the material.

Conductivity is the measure of a material's ability to carry or conduct an electric current. It is often given as percent of the copper standard, which is 100% IACS, (International Annealed Copper Standard). Silver has an IACS of 105 and has the highest conductivity.

Corrosion resistance is the material's ability to resist chemical decay. A material that has little corrosion resistance will degrade rapidly in corrosive environments; resulting in a shorter lifespan. Platinum group metals are known for their high resistance to corrosion.

Hardness is the measure of how resistant the material is to various kinds of permanent deformations resulting from an applied force. Hardness is dependent on a material's ductility, elasticity, plasticity, tensile strength, and toughness.

Form refers to the shape an electrical material must fit in order to carry out its operation. Some shapes include contact tips, pins, sockets, stampings, sheets, wires, and wheels.

Size relates to the thickness, length, and width or outer diameter of the form a material takes.

Selecting the Right Electrode for Welding

Consumable Electrode Rods drive the **Stick Welding** process – these skinny little stick-like rods are the real power behind the most versatile, portable and effective welding process. But how do you pick the right electrode for your particular welding project?

This is an incredibly important question, because there are literally hundreds of electrodes to choose from – each with its own unique properties, all of which have an impact on their effectiveness in relationship to your welding project – making your electrode selection a very important part of the stick welding process. So, the first part of answering the electrode selection question begins with determining the parameters of the welding project at hand. To begin with, you need to ascertain the following information as it relates to your welding project:

- Welding speed
- Power supply
- Position of the weld
- Type of metal
- Thickness of the metal

Welding Speed

Welding speed depends largely on the shielding gas, heat transfer properties, oxidation and metal transfer characteristics. An electrode's flux coating determines the composition of the shielding gas, which in turn affects oxidation, as well as heat and metal transfer. To achieve maximum welding speeds, you need an electrode that oxidizes quickly to ensure fast weld solidification.

Power Supply

Most electrodes are designed to work with either AC (Alternating Current) or DC (Direct Current) power sources, and some electrodes are designed to work with both AC or DC current. The type of electrical current involved in the welding process affects the level of penetration into the base metal, with AC current generally achieving deeper penetration.

Position of the Weld

Are you welding on a flat workbench in a welding shop? Are you welding overhead or in a straight-up-and-down position, as you might in an industrial setting or while making field repairs? Some electrodes are designed to weld in only one of the positions referenced above, while other electrodes are actually designed to work effectively in all positions.

Type of Metal

An electrode's filler metal should match the base metal used in your project.

Thickness of the Metal

The thicker the metal, the stronger the weld's tensile strength should be, and the deeper the penetration required to effectively bond the filler metal with the base metal.

Matching Up the Right Electrode with Your Welding Project

Now that you've defined your project parameters, it's time to go find the right electrode. But how do you match your electrode with your welding project's requirements?

The American Welding Society's (**AWS**) swoops in to the rescue with their electrode numbering system.

Electrodes are assigned a four to six digit number which corresponds to their specific properties, e.g., the tensile strength, weld position, power supply and penetration.

The Old Standards

Many seasoned welding veterans and welding instructors alike recommend certain electrodes, due to these electrodes versatility and general ease of use, as go-to options for a wide variety of welding projects.

The No-Brainer Electrode Options Include:

- 6010
- 6013
- 7018

While these electrodes are incredibly flexible, don’t end your search here, because as this post illustrates, there are a number of very important factors to consider when selecting the right electrode for your welding project.

Additional Electrode Resources

To learn more about the electrode selection, including an electrode's affect on the formation and physical appearance of a weld, check out Miller Welding’s article on selecting the right electrode.

To gain a better understanding of AWS electrode numbering system, cruise over to my latest post: Consumable Electrode Numbering System Quick Tutorial.

And for a comprehensive and highly educational overview of electrode rods (both consumable and non-consumable), Bakers Gas and Welding Supply published an outstanding article: How to Choose the Best Electrode.

WELDING JOINT

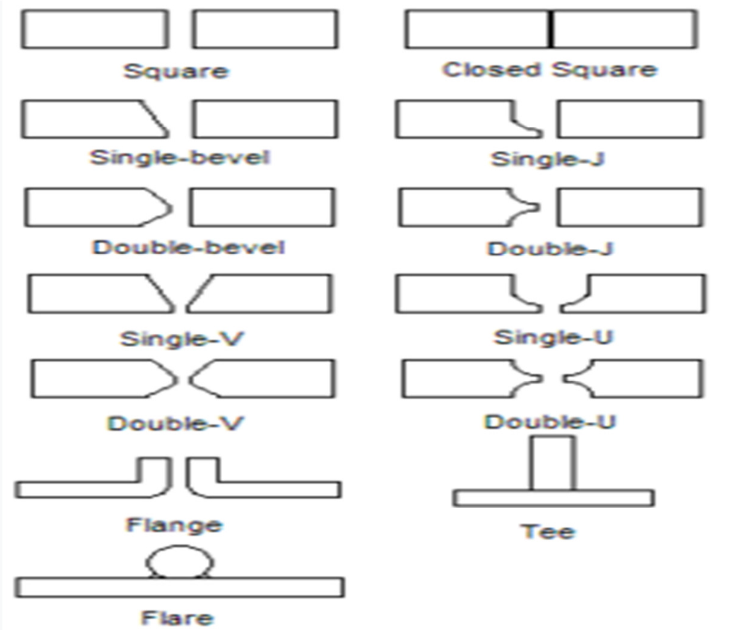
A **welding joint** is a point or edge where two or more pieces of metal or plastic are joined together. They are formed by welding two or more workpieces (metal or plastic) according to a particular geometry. Five types of joints referred to by the American Welding Society: butt, corner, edge, lap, and tee. These configurations may have various configurations at the joint where actual welding can occur.

Butt welds

Butt welding

Butt welds are welds where two pieces of metal are to be joined are in the same plane.[1] These types of welds require only some preparation and are used with thin sheet metals that can be welded with a single pass.[2] Common issues that can weaken a butt weld are the entrapment of slag, excessive porosity, or cracking. For strong welds, the goal is to use the least amount of welding material possible. Butt welds are prevalent in automated welding processes, such as submerged-arc welding, due to their relative ease of preparation.[3] When metals are welded without human guidance, there is no operator to make adjustments for non-ideal joint preparation. Because of this necessity, butt welds can be utilized for their simplistic design to be fed through automated welding machines efficiently.

Types



Butt joint geometries

There are many types of butt welds, but all fall within one of these categories: single welded butt joints, double welded butt joint, and open or closed butt joints. A single welded butt joint is the name for a joint that has only been welded from one side. A double welded butt joint is created when the weld has been welded from both sides. With double welding, the depths of each weld can vary slightly. A closed weld is a type of joint in which the two pieces that will be joined are touching during the welding process. An open weld is the joint type where the two pieces have a small gap in between them during the welding process.

Square butt joints

The square-groove is a butt welding joint with the two pieces being flat and parallel to each other. This joint is simple to prepare, economical to use, and provides satisfactory strength, but is limited by joint thickness. The closed square butt weld is a type of square-groove joint with no spacing in between the pieces. This joint type is common with gas and arc welding.

For thicker joints, the edge of each member of the joint must be prepared to a particular geometry to provide accessibility for welding and to ensure the desired weld soundness and strength. The opening or gap at the root of the joint and the included angle of the groove should be selected to require the least weld metal necessary to give needed access and meet strength requirements.

V-joints

Single butt welds are similar to a bevel joint, but instead of only one side having the beveled edge, both sides of the weld joint are beveled. In thick metals, and when welding can be performed from both sides of the work piece, a double-V joint is used. When welding thicker metals, a double-V joint requires less filler material because there are two narrower V-joints compared to a wider single-V joint. Also the double-V joint helps compensate for warping forces. With a single-V joint, stress tends to warp the piece in one direction when the V-joint is filled, but with a double-V-joint, there are welds on both sides of the material, having opposing stresses, straightening the material.

J-joints

Single-J butt welds are when one piece of the weld is in the shape of a *J* that easily accepts filler material and the other piece is square. A J-groove is formed either with special cutting machinery or by grinding the joint edge into the form of a J. Although a J-groove is more difficult and costly to prepare than a V-groove, a single J-groove on metal between a half an inch and three quarters of an inch thick provides a stronger weld that requires less filler material. Double-J butt welds have one piece that has a *J* shape from both directions and the other piece is square.

U-joints

Single-U butt welds are welds that have both edges of the weld surface shaped like a J, but once they come together, they form a U. Double-U joints have a U formation on both the top and bottom of the prepared joint. U-joints are the most expensive edge to prepare and weld. They are usually used on thick base metals where a V-groove would be at such an extreme angle, that it would cost too much to fill.

Others

Thin sheet metals are often flanged to produce edge-flange or corner-flange welds. These welds are typically made without the addition of filler metal because the flange melts and provides all the filler needed. Pipes and tubing can be made from rolling and welding together strips, sheets, or plates of material.[4]

Flare-groove joints are used for welding metals that, because of their shape, form a convenient groove for welding, such as a pipe against a flat surface.

The Tee Butt Weld is formed when two bars or sheets are joined perpendicular to each other in the form of a *T* shape. This weld is made from the resistance butt welding process.

Selection of the right weld joint depends on the thickness and process used. The square welds are the most economical for pieces thinner than 3/8”, because they don’t require the edge to be prepared.[5] Double-groove welds are the most economical for thicker pieces because they require less weld material and time. The use of fusion welding is common for closed single-bevel, closed single J, open single J, and closed double J butt joints. The use of gas and arc welding is ideal for double-bevel, closed double-bevel, open double-bevel, single-bevel, and open single-bevel butt welds.

Below are listed ideal joint thicknesses for the various types of butt welding joints. When the thickness of a butt weld is defined it is measured at the thinner part and does not compensate for the weld reinforcement.

Workpiece thickness limits per joint type

Joint type	Thickness
Square joint	Up to $^1⁄_4$ in (6.35 mm)
Single-bevel joint	$^3⁄_{16}$–$^3⁄_8$ in (4.76–9.53 mm)
Double-bevel joint	Over $^3⁄_8$ in (9.53 mm)
Single-V joint	Up to $^3⁄_4$ in (19.05 mm)
Double-V joint	Over $^3⁄_4$ in (19.05 mm)
Single-J joint	$^1⁄_2$–$^3⁄_4$ in (12.70–19.05 mm)
Double-J joint	Over $^3⁄_4$ in (19.05 mm)
Single-U joint	Up to $^3⁄_4$ in (19.05 mm)
Double-U joint	Over $^3⁄_4$ in (19.05 mm)
Flange (edge of corner)	Sheet metals less than 12 gauge (0.1046 in or 2.657 mm)[*clarification needed*]
Flare groove	All thickness

Cruciform

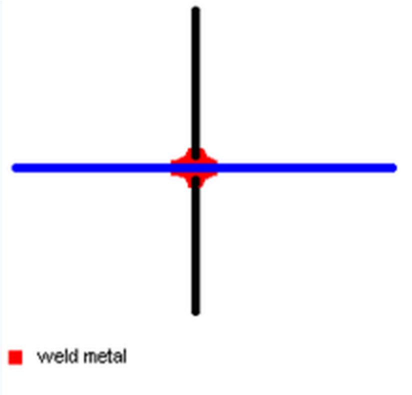


Diagram of a cruciform joint between 3 plates of metal

A *cruciform joint* is a specific joint in which four spaces are created by the welding of three plates of metal at right angles. Cruciform joints suffer fatigue when subjected to continuously varying loads.[6]

In the American Bureau of Shipping Rules for Steel Vessels, cruciform joints may be considered a double barrier if the two substances requiring a double barrier are in opposite corners diagonally. Double barriers are often required to separate oil and seawater, chemicals and potable water, etC

SAFETY PRECAUTIONS

GENERAL

a. To prevent injury to personnel, extreme caution should be exercised when using any types of welding equipment. Injury can result from fire, explosions, electric shock, or harmful agents. Both the general and specific safety precautions listed below must be strictly observed by workers who weld or cut metals.

b. Do not permit unauthorized persons to use welding or cutting equipment.

c. Do not weld in a building with wooden floors, unless the floors are protected from hot metal by means of fire resistant fabric, sand, or other fireproof material. Be sure that hot sparks or hot metal will not fall on the operator or on any welding equipment components.

d. Remove all flammable material, such as cotton, oil, gasoline, etc., from the vicinity of welding.

e. Before welding or cutting, warm those in close proximity who are not protected to wear proper clothing or goggles.

f. Remove any assembled parts from the component being welded that may become warped or otherwise damaged by the welding process.

g. Do not leave hot rejected electrode stubs, steel scrap, or tools on the floor or around the welding equipment. Accidents and/or fires may occur.

h. Keep a suitable fire extinguisher nearby at all times. Ensure the fire extinguisher is in operable condition.

i. Mark all hot metal after welding operations are completed. Soapstone is commonly used for this purpose.

PERSONAL PROTECTIVE EQUIPMENT

a. General. The electric arc is a very powerful source of light, including visible, ultraviolet, and infrared. Protective clothing and equipment must be worn during all welding operations. During all oxyacetylene welding and cutting proccesses, operators must use safety goggles to protect the eyes from heat, glare, and flying fragments of hot metals. During all electric welding processes, operators must use safety goggles and a hand shield or helmet equipped with a suitable filter glass to protect against the intense ultraviolet and infrared rays. When others are in the vicinity of the electric welding processes, the area must be screened so the arc cannot be seen either directly or by reflection from glass or metal.

b. Helmets and Shields.

(1) Welding arcs are intensely brilliant lights. They contain a proportion of ultraviolet light which may cause eye damage. For this reason, the arc should never be viewed with the naked eye within a distance of 50.0 ft (15.2 m). The brilliance and exact spectrum, and therefore the danger of the light, depends on the welding process, the metals in the arc, the arc atmosphere, the length of the arc, and the welding current. Operators, fitters, and those working nearby need protection against arc radiation. The intensity of the light from the arc increases with increasing current and arc voltage. Arc radiation, like all light radiation, decreases with the square of the distance. Those processes that produce smoke surrounding the arc have a less bright arc since the smoke acts as a filter. The spectrum of the welding arc is similar to that of the sun. Exposure of the skin and eyes to the arc is the same as exposure to the sun.

(2) Being closest, the welder needs a helmet to protect his eyes and face from harmful light and particles of hot metal. The welding helmet (fig. 2-1) is generally constructed of a pressed fiber insulating material. It has an adjustable headband that makes it usable by persons with different head sizes. To minimize reflection and glare produced by the intense light, the helmet is dull black in color. It fits over the head and can be swung upward when not welding. The chief advantage of the helmet is that it leaves both hands free, making it possible to hold the work and weld at the same time.

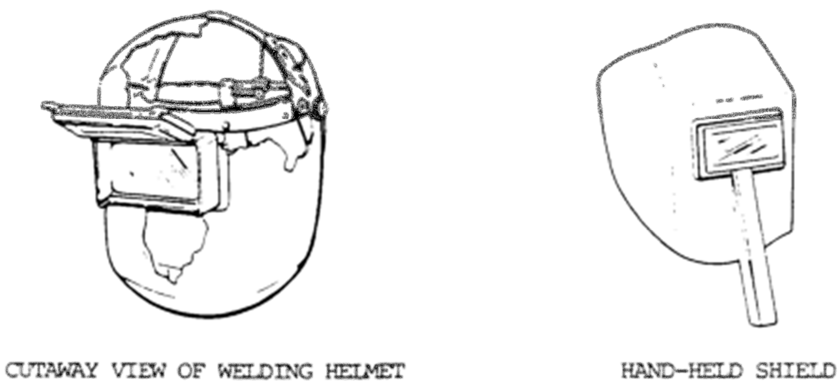


Figure 2-1. Welding helmet and hand-held shield.

(3) The hand-held shield (fig. 2-1) provides the same protection as the helmet, but is held in position by the handle. This type of shield is frequently used by an observer or a person who welds for a short period of time.

(4) The protective welding helmet has lens holders used to insert the cover glass and the filter glass or plate. Standard size for the filter plate is 2 x 4-1/4 in. (50 x 108 mm). In some helmets lens holders open or flip upwards. Lenses are designed to prevent flash burns and eye damage by absorption of the infrared and ultraviolet rays produced by the arc. The filter glasses or plates come in various optical densities to filter out various light intensities, depending on the welding process, type of base metal, and the welding current. The color of the lens, usually green, blue, or brown, is an added protection against the intensity of white light or glare. Colored lenses make it possible to clearly see the metal and weld. Table 2-1 lists the proper filter shades to be used. A magnifier lens placed behind the filter glass is sometimes used to provide clear vision.

Table 2-1. Lens Shades for Welding and Cutting

Welding or Cutting Operation	Electrode Size Metal Thickness or Welding Current	Filter Shade Number
Torch soldering	-	2
Torch brazing	-	3 or 4
Oxygen cutting		
Light	Under 1 in., 25 mm	3 or 4
Medium	1 to 6 in., 25 to 150 mm	4 or 5
Heavy	Over 6 in., 150 mm	5 or 6
Gas welding		
Light	Under 1/8 in., 3 mm	4 or 5
Medium	1/8 to 1/2 in., 3 to 12 mm	5 or 6
Heavy	Over 1/2 in., 12 mm	6 or 8
Shielded metal-arc welding (stick) electrodes	Under 5/32 in., 4 mm	10
	5/32 to 1/4 in., 4 to 6.4 mm	12
	Over 1/4 in., 6.4 mm	14
Gas metal-arc welding (MIG)		
Non-ferrous base metal	All	11
Ferrous base metal	All	12
Gas tungsten arc welding (TIG)	All	12
Atomic hydrogen welding	All	12
Carbon arc welding	All	12
Plasma arc welding	All	12
Carbon arc air gouging		
Light	-	12
Heavy	-	14
Plasma arc cutting		
Light	Under 300 Amp	9
Medium	300 to 400 Amp	12
Heavy	Over 400 Amp	14

A cover plate should be placed outside the filter glass to protect it from weld spatter. The filter glass must be tempered so that is will not break if hit by flying weld spatter. Filter glasses must be marked showing the manufacturer, the shade number, and the letter "H" indicating it has been treated for impact resistance.

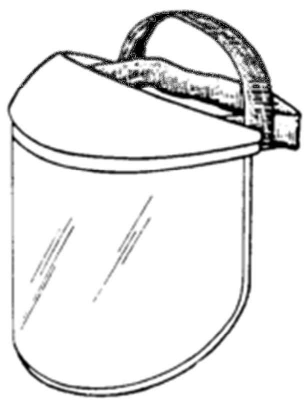
NOTE

Colored glass must be manufactured in accordance with specifications detailed in the "National Safety Code for the Protection of Hands and Eyes of Industrial Workers", issued by the National Bureau of Standards, Washington DC, and OSHA Standards, Subpart Q, "Welding, Cutting, and Brazing", paragraph 1910.252, and American National Standards Institute Standard (ANSI) Z87.1-1968, "American National Standard Practice for Occupational and Educational Eye and Face Protection".

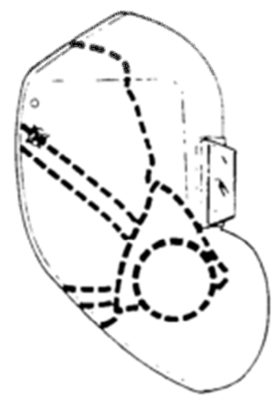
(5) Gas metal-arc (MIG) welding requires darker filter lenses than shielded metal-arc (stick) welding. The intensity of the ultraviolet radiation emitted during gas metal-arc welding ranges from 5 to 30 times brighter than welding with covered electrodes.

(6) Do not weld with cracked or defective shields because penetrating rays from the arc may cause serious burns. Be sure that the colored glass plates are the proper shade for arc welding. Protect the colored glass plate from molten metal spatter by using a cover glass. Replace the cover glass when damaged or spotted by molten metal spatter.

(7) Face shields (fig. 2-2) must also be worn where required to protect eyes. Welders must wear safety glasses and chippers and grinders often use face shields in addition to safety glasses.



CLEAR FACE SHIELD

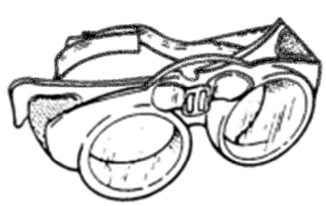


HELMET WITH RESPIRATOR

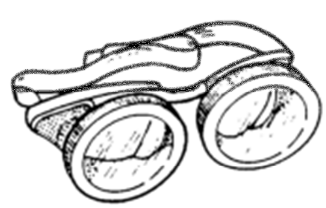
Figure 2-2. Welding helmets and shields.

(8) In some welding operations, the use of mask-type respirators is required. Helmets with the "bubble" front design can be adapted for use with respirators.

c. Safety Goggles. During all electric welding processes, operators must wear safety goggles (fig. 2-3) to protect their eyes from weld spatter which occasionally gets inside the helmet. These clear goggles also protect the eyes from slag particles when chipping and hot sparks when grinding. Contact lenses should not be worn when welding or working around welders. Tinted safety glasses with side shields are recommended, especially when welders are chipping or grinding. Those working around welders should also wear tinted safety glasses with side shields.



TYPE GC-2 CHIPPER'S GOGGLES



TYPE GC CHIPPER'S GOGGLES

Figure 2-3. Safety goggles.

d. Protective Clothing.

(1) Personnel exposed to the hazards created by welding, cutting, or brazing operations shall be protected by personal protective equipment in accordance with OSHA standards, Subpart I, Personal Protective Equipment, paragraph 1910.132. The appropriate protective clothing (fig. 2-4) required for any welding operation will vary with the size, nature, and location of the work to be performed. Welders should wear work or shop clothes without openings or gaps to prevent arc rays from contacting the skin. Those working close to arc welding should also wear protective clothing. Clothing should always be kept dry, including gloves.

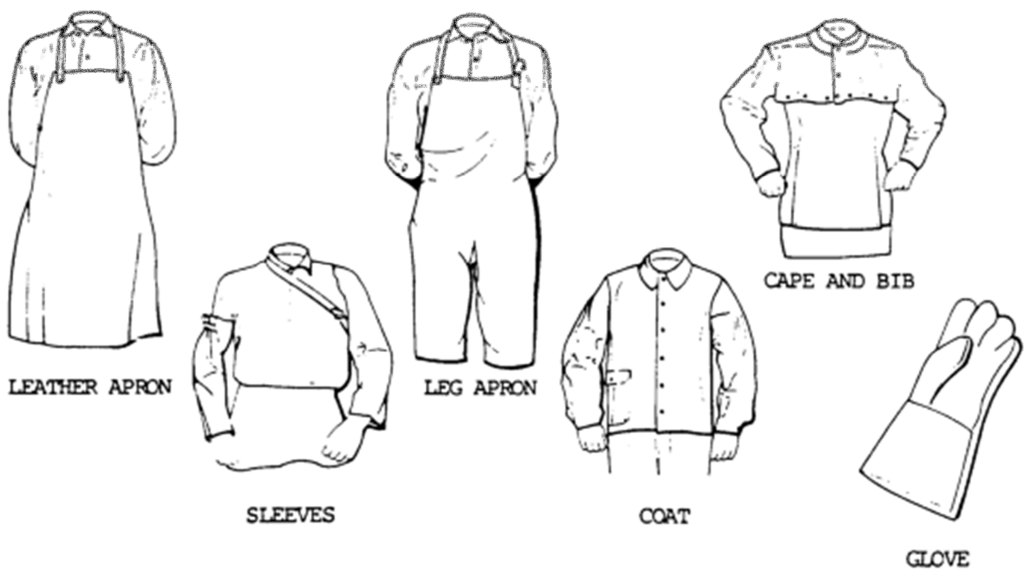


Figure 2-4. Protective clothing.

(2) Woolen clothing should be worn instead of cotton since wool is not easily burned or damaged by weld spatter and helps to protect the welder from changes in temperature. Cotton clothing, if used, should be chemically treated to reduce its combustibility. All other clothing, such as jumpers or overalls, should be reasonably free from oil or grease.

(3) Flameproof aprons or jackets made of leather, fire resistant material, or other suitable material should be worn for protection against spatter of molten metal, radiated heat, and sparks. Capes or shoulder covers made of leather or other suitable materials should be worn during overhead welding or cutting operations. Leather skull caps may be worn under helmets to prevent head burns.

(4) Sparks may lodge in rolled-up sleeves, pockets of clothing, or cuffs of overalls and trousers. Therefore, sleeves and collars should be kept buttoned and pockets should be eliminated from the front of overalls and aprons. Trousers and overalls should not be turned up on the outside. For heavy work, fire-resisant leggings, high boots, or other equivalent means should be used. In production work, a sheet metal screen in front of the worker's legs can provide further protection against sparks and molten metal in cutting operations.

(5) Flameproof gauntlet gloves, preferably of leather, should be worn to protect the hands and arms from rays of the arc, molten metal spatter, sparks, and hot metal. Leather gloves should be of sufficient thickness so that they will not shrivel from the heat, burn through, or wear out quickly. Leather gloves should not be used to pick up hot items, since this causes the leather to become stiff and crack. Do not allow oil or grease to cane in contact with the gloves as this will reduce their flame resistance and cause them to be readily ignited or charred.

e. Protective Equipment.

(1) Where there is exposure to sharp or heavy falling objects or a hazard of bumping in confined spaces, hard hats or head protectors must be used.

(2) For welding and cutting overhead or in confined spaces, steel-toed boots and ear protection must also be used.

(3) When welding in any area, the operation should be adequately screened to protect nearby workers or passers-by froman the glare of welding. The screens should be arranged so that no serious restriction of ventilation exists. The screens should be mounted so that they are about 2.0 ft above the floor unless the work is performed at such a low level that the screen must be extended closer to the floor to protect adjacent workers. The height of the screen is normally 6.0 ft (1.8 m) but may be higher depending upon the situation. Screen and surrounding areas must be painted with special paints which absorb ultraviolet radiation yet do not create high contrast between the bright and dark areas. Light pastel colors of a zinc or titanium dioxide base paint are recommended. Black paint should not be used.

2-3. FIRE HAZARDS

a. Fire prevention and protection is the responsibility of welders, cutters, and supervisors. Approximately six percent of the fires in industrial plants are caused by cutting and welding which has been done primarily with portable equipment or in areas not specifically designated for such work. The elaboration of basic precautions to be taken for fire prevention during welding or cutting is found in the Standard for Fire Prevention in Use of Cutting and Welding Processes, National Fire Protection Association Standard 51B, 1962. Some of the basic precautions for fire prevention in welding or cutting work are given below.

b. During the welding and cutting operations, sparks and molten spatter are formal which sometimes fly considerable distances. Sparks have also fallen through cracks, pipe holes, or other small openings in floors and partitions, starting fires in other areas which temporarily may go unnoticed. For these reasons, welding or cutting should not be done near flammable materials unless every precaution is taken to prevent ignition.

c. Hot pieces of base metal may come in contact with combustible materials and start fires. Fires and explosions have also been caused when heat is transmitted through walls of containers to flammable atmospheres or to combustibles within containers. Anything that is combustible or flammable is susceptible to ignition by cutting and welding.

d. When welding or cutting parts of vehicles, the oil pan, gasoline tank, and other parts of the vehicle are considered fire hazards and must be removed or effectively shielded from sparks, slag, and molten metal.

e. Whenever possible, flammable materials attached to or near equipment requiring welding, brazing, or cutting will be removed. If removal is not practical, a suitable shield of heat resistant material should be used to protect the flammable material. Fire extinguishing equipment, for any type of fire that may be encountered, must be present.

HEALTH PROTECTION AND VENTILATION

a. General.

(1) All welding and thermal cutting operations carried on in confined spaces must be adequately ventilated to prevent the accumulation of toxic materials, combustible gases, or possible oxygen deficiency. Monitoring instruments should be used to detect harmful atmospheres. Where it is impossible to provide adequate ventilation, air-supplied respirators or hose masks approved for this purpose must be used. In these situations, lookouts must be used on the outside of the confined space to ensure the safety of those working within. Requirements in this section have been established for arc and gas welding and cutting. These requirements will govern the amount of contamination to which welders may be exposed:

(a) Dimensions of the area in which the welding process takes place (with special regard to height of ceiling).

(b) Number of welders in the room.

(c) Possible development of hazardous fumes, gases, or dust according to the metals involved.

(d) Location of welder's breathing zone with respect to rising plume of fumes.

(2) In specific cases, there are other factors involved in which respirator protective devices (ventilation) should be provided to meet the equivalent requirements of this section. They include:

(a) Atomspheric conditions.

(b) Generated heat.

(c) Presence of volatile solvents.

(3) In all cases, the required health protection, ventilation standards, and standard operating procedures for new as well as old welding operations should be coordinated and cleaned through the safety inspector and the industrial hygienist having responsibility for the safety and health aspects of the work area.

b. Screened Areas. When welding must be performed in a space entirely screened on all sides, the screens shall be arranged so that no serious restriction of ventilation exists. It is desirable to have the screens mounted so that they are about 2.0 ft (0.6 m) above the floor, unless the work is performed at such a low level that the screen must be extended closer to the floor to protect workers from the glare of welding. See paragraph 2-2 e (3).

c. Concentration of Toxic Substances. Local exhaust or general ventilating systems shall be provided and arranged to keep the amount of toxic frees, gas, or dusts below the acceptable concentrations as set by the American National Standard Institute Standard 7.37; the latest Threshold Limit Values (TLV) of the American Conference of Governmental Industrial Hygienists; or the exposure limits as established by Public Law 91-596, Occupational Safety and Health Act of 1970. Compliance shall be determined by sampling of the atmsphere. Samples collected shall reflect the exposure of the persons involved. When a helmet is worn, the samples shall be collected under the helmet.

NOTE

Where welding operations are incidental to general operations, it is considered good practice to apply local exhaust ventilation to prevent contamination of the general work area.

d. Respiratory Protective Equipment. Individual respiratory protective equipment will be well retained. Only respiratory protective equipment approved by the US Bureau of Mines, National Institute of Occupational Safety and Health, or other government-approved testing agency shall be utilized. Guidance for selection, care, and maintenance of respiratory protective equipment is given in Practices for Respiratory Protection, American National Standard Institute Standard 788.2 and TB MED 223. Respiratory protective equipment will not be transferred from one individual to another without being disinfected.

e. Precautionary Labels. A number of potentially hazardous materials are used in flux coatings, coverings, and filler metals. These materials, when used in welding and cutting operations, will become hazardous to the welder as they are released into the atmosphere. These include, but are not limited to, the following materials: fluorine compounds, zinc, lead, beryllium, cadmium, and mercury. See paragraph 2-4 i through 2-4 n. The suppliers of welding materials shall determine the hazard, if any, associated with the use of their materials in welding, cutting, etc.

(1) All filler metals and fusible granular materials shall carry the following notice, as a minimum, on tags, boxes, or other containers:

CAUTION

Welding may produce fumes and gases hazardous to health. Avoid breathing these fumes and gases. Use adequate ventilation. See American National Standards Institute Standard Z49.1-1973, Safety in Welding and Cutting published by the American Welding Society.

(2) Brazing (welding) filler metals containing cadmium in significant amounts shall carry the following notice on tags, boxes, or other containers:

WARNING
CONTAINS CADMIUM - POISONOUS FUMES MAY BE FORMED ON HEATING

Do not breathe fumes. Use only with adequate ventilation, such as fume collectors, exhaust ventilators, or air-supplied respirators. See American National Standards Institute Standard Z49.1-1973. If chest pain, cough, or fever develops after use, call physician immediately.

(3) Brazing and gas welding fluxes containing fluorine compounds shall have a cautionary wording. One such wording recommended by the American Welding Society for brazing and gas welding fluxes reads as follows:

CAUTION
CONTAINS FLUORIDES

This flux, when heated, gives off fumes that may irritate eyes, nose, and throat. Avoid fumes--use only in well-ventilated spaces. Avoid contact of flux with eyes or skin. Do not take internally.

Ventilation for General Welding and Cutting.

(1) General. Mechanical ventilation shall be provided when welding or cutting is done on metals not covered in subparagraphs i through p of this section, and under the following conditions:

(a) In a space of less than 10,000 cu ft (284 cu m) per welder.

(b) In a roan having a ceiling height of less than 16 ft (5 m).

(c) In confined spaces or where the welding space contains partitions, balconies, or other structural barriers to the extent that they significantly obstruct cross ventilation.

(2) Minimum rate. Ventilation shall be at the minimum rate of 200 cu ft per minute (57 cu m) per welder, except where local exhaust heeds, as in paragraph 2-4 g below, or airline respirators approved by the US Bureau of Mines, National Institute of Occupational Safety and Health, or other government-approved testing agency, are used. When welding with rods larger than 3/16 in. (0.48 cm) in diameter, the ventilation shall be higher as shown in the following:

Rod diameter (inches)	Required ventilation (cfm)
1/4 (0.64 cm)	3500
3/8 (0.95 cm)	4500

Natural ventilation is considered sufficient for welding or cutting operations where the conditions listed above are not present. Figure 2-5 is an illustration of a welding booth equipped with mechanical ventilation sufficient for one welder.

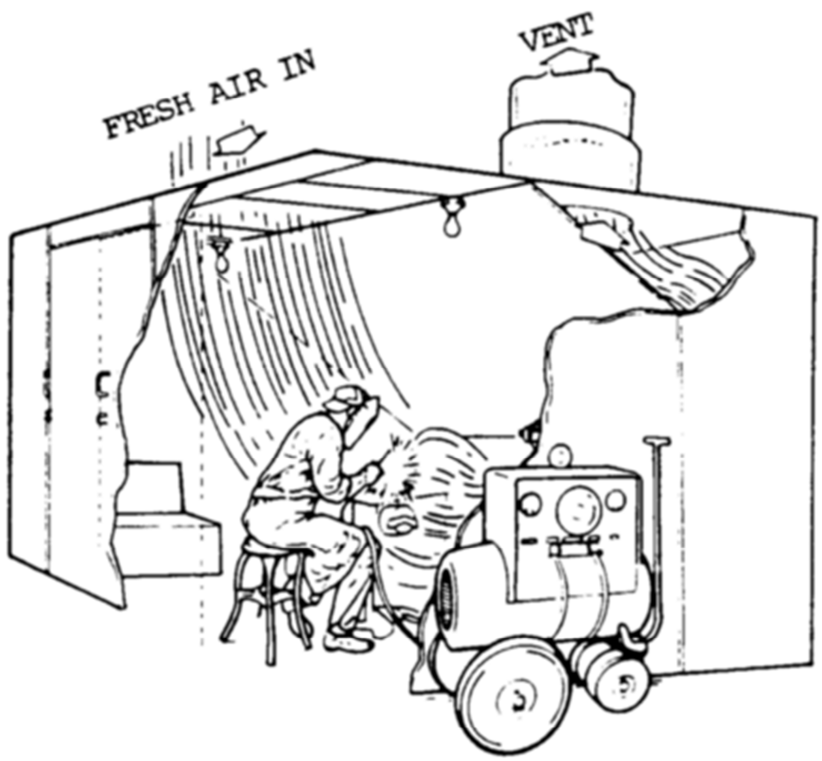


Figure 2-5. Welding booth with mechanical ventilation.

g. Local Exhaust Ventilation. Mechanical local exhaust ventilation may be obtained by either of the following means:

(1) Hoods. Freely movable hoods or ducts are intended to be placed by the welder as near as practicable to the work being welded. These will provide a rate of airflow sufficient to maintain a velocity the direction of the hood of 100 in linear feet per minute in the zone of welding. The ventilation rates required to accomplish this control velocity using a 3-in. wide flanged suction opening are listed in table 2-2.

Table 2-2. Required Exhaust Ventilation

Welding zone	Minimum air flow, cu ft per min	Duct diameter, in.
4 to 6 in. from arc or torch	150	3
6 to 8 in. from arc or torch	275	3-1/2
8 to 10 in. from arc or torch	425	4-1/2
10 to 12 in. from arc or torch	600	6-1/2

(2) Fixed enclosure. A fixed enclosure with a top and two or more sides which surrounds the welding or cutting operations will have a rate of airflow sufficient to maintain a velocity away from the welder of not less than 100 linear ft per minute. Downdraft ventilation tables require 150 cu ft per minute per square foot of surface area. This rate of exhausted air shall be uniform across the face of the grille. A low volume, high-density fume exhaust device attached to the welding gun collects the fumes as close as possible to the point of origin or at the arc. This method of fume exhaust has become quite popular for the semiautomatic processes, particularly the flux-cored arc welding process. Smoke exhaust systems incorporated in semiautomatic guns provide the most economical exhaust system since they exhaust much less air they eliminate the need for massive air makeup units to provide heated or cooled air to replace the air exhausted. Local ventilation should have a rate of air flow sufficient to maintain a velocity away from the welder of not less than 100 ft (30 m) per minute. Air velocity is measurable using a velometer or air flow inter. These two systems can be extremely difficult to use when welding other than small weldments. The down draft welding work tables are popular in Europe but are used to a limited degree North America. In all cases when local ventilation is used, the exhaust air should be filtered.

h. Ventilation in Confined Spaces.

(1) Air replacement. Ventilation is a perquisite to work in confined spaces. All welding and cutting operations in confined spaces shall be adequately ventilated to prevent the accumulation of toxic materials -or possible oxygen deficiency. This applies not only to the welder but also to helpers and other personnel in the immediate vicinity.

(2) Airline respirators. In circumstances where it is impossible to provide adequate ventilation in a confined area, airline respirators or hose masks, approved by the US Bureau of Mines, National Institute of Occupational Safety and Health, or other government-approved testing agency, will be used for this purpose. The air should meet the standards established by Public Law 91-596, Occupational Safety and Health Act of 1970.

(3) Self-contained units. In areas immediately hazardous to life, hose masks with blowers or self-contained breathing equipment shall be used. The breathing equipment shall be approved by the US Bureau of Mines or National Institute of Occupational Safety and Health, or other government-approved testing agency.

(4) Outside helper. Where welding operations are carried on in confined spaces and where welders and helpers are provided with hose masks, hose masks with blowers, or self-contained breathing equipment, a worker shall be stationed on the outside of such confined spaces to ensure the safety of those working within.

(5) Oxygen for ventilation. Oxygen must never be used for ventilation.

i. Fluorine Compounds.

(1) General. In confined spaces, welding or cutting involving fluxes, coverings, or other materials which fluorine compounds shall be done in accordance with paragraph 2-4 h, ventilation in confined spaces. A fluorine compound is one that contains fluorine as an element in chemical combination, not as a free gas.

(2) Maximum allowable concentration. The need for local exhaust ventilation or airline respirators for welding or cutting in other than confined spaces will depend upon the individual circumstances. However, experience has shown that such protection is desirable for fixed-location production welding and for all production welding on stainless steels. When air samples taken at the welding location indicate that the fluorides liberated are below the maximum allowable concentration, such protection is not necessary.

j. Zinc.

(1) Confined spaces. In confined spaces, welding or cutting involving zinc-bearing filler metals or metals coated with zinc-bearing materials shall be done in accordance with paragraph 2-4 h, ventilation in confined spaces.

(2) Indoors. Indoors, welding or cutting involving zinc-bearing metals or filler metals coated with zinc-bearing materials shall be done in accordance with paragraph 2-4 g.

k. Lead.

(1) Confined spaces. In confined spaces, welding involving lead-base metals (erroneously called lead-burning) shall be done in accordance with paragraph 2-4 h.

(2) Indoors. Indoors, welding involving lead-base metals shall be done in accordance with paragraph 2-4 g, local exhaust ventilation.

(3) Local ventilation. In confined spaces or indoors, welding or cutting involving metals containing lead or metals coated with lead-bearing materials, including paint, shall be done using local exhaust ventilation or airline respirators. Outdoors, such operations shall be done using respirator protective equipment approved by the US Bureau of Mines, National Institute of Occupational Safety and Health, or other government-approved testing agency. In all cases, workers in the immediate vicinity of the cutting or welding operation shall be protected as necessary by local exhaust ventilation or airline respirators.

l. Beryllium. Welding or cutting indoors, outdoors, or in confined spaces involving beryllium-bearing material or filler metals will be done using local exhaust ventilation and airline respirators. This must be performed without excep-tion unless atmospheric tests under the most adverse conditions have established that the workers' exposure is within the acceptable concentrations of the latest Threshold Limit Values (TLV) of the American Conference of Governmental Industrial Hygienists, or the exposure limits established by Public Law 91-596, Occupational Safety and Health Act of 1970. In all cases, workers in the immediate vicinity of the welding or cutting operations shall be protected as necessary by local exhaust ventilation or airline respirators.

m. Cadmium.

(1) General. Welding or cutting indoors or in confined spaces involving cadmium-bearing or cadmium-coated base metals will be done using local exhaust ventilation or airline respirators. Outdoors, such operations shall be done using respiratory protective equipment such as fume respirators, approved by the US Bureau of Mines, National Institute of Occupational Safety and Health, or other government-approved testing agency, for such purposes.

(2) Confined space. Welding (brazing) involving cadmium-bearing filler metals shall be done using ventilation as prescribed in paragraphs 2-4 g, local exhaust ventilation, and 2-4 h, ventilation in confined spaces, if the work is to be done in a confined space.

NOTE

Cadmium-free rods are available and can be used in most instances with satisfactory results.

n. Mercury. Welding or cutting indoors or in a confined space involving metals coated with mercury-bearing materials, including paint, shall be done using local exhaust ventilation or airline respirators. Outdoors, such operations will be done using respiratory protective equipment approved by the National Institute of Occupational Safety and Health, US Bureau of Mines, or other government-approved testing agency.

o. Cleaning Compounds.

(1) Manufacturer's instructions. In the use of cleaning materials, because of their toxicity of flammability, appropriate precautions listed in the manufacturer's instructions will be followed.

(2) Degreasing. Degreasing or other cleaning operations involving chlorinated hydrocarbons will be located so that no vapors from these operations will reach or be drawn into the area surrounding any welding operation. In addition, trichloroethylene and perchloroethylene should be kept out of atmospheres penetrated by the ultraviolet radiation of gas-shielded welding operations.

p. Cutting of Stainless Steels. Oxygen cutting, using either a chemical flux or iron powder, or gas-shielded arc cutting of stainless steel will be done using mechanical ventilation adequate to remove the fumes generated.

q. First-Aid Equipment. First-aid equipment will be available at all times. On every shift of welding operations, there will be personnel present who are trained to render first-aid. All injuries will be reported as soon as possible for medical attention. First-aid will be rendered until medical attention can be provided.

WELDING IN CONFINED SPACES

a. A confined space is intended to mean a relatively small or restricted space such as a tank, boiler, pressure vessel, or small compartment of a ship or tank.

b. When welding or cutting is being performed in any confined space, the gas cylinders and welding machines shall be left on the outside. Before operations are started, heavy portable equipment mounted on wheels shall be securely blocked to prevent accidental movement.

c. Where a welder must enter a confined space through a manhole or other all opening, means will be provided for quickly removing him in case of emergency. When safety belts and life lines are used for this purpose, they will be attached to the welder's body so that he cannot be jammed in a small exit opening. An attendant with a preplanned rescue procedure will be stationed outside to observe the welder at all times and be capable of putting rescue operations into effect.

d. When arc welding is suspended for any substantial period of time, such as during lunch or overnight, all electrodes will be removed from the holders with the holders carefully located so that accidental contact cannot occur. The welding machines will be disconnected from the power source.

e. In order to eliminate the possibility of gas escaping through leaks or improperly closed valves when gas welding or cutting, the gas and oxygen supply valves will be closed, the regulators released, the gas and oxygen lines bled, and the valves on the torch shut off when the equipment will not be used for a substantial period of time. Where practical, the torch and hose will also be removed from the confined space.

f. After welding operations are completed, the welder will mark the hot metal or provide some other means of warning other workers.

Defects in welding&Remidies

A **welding defect** is any flaw that compromises the usefulness of a weldment. There is a great variety of welding defects. Welding imperfections are classified according to ISO 6520[1] while their acceptable limits are specified in ISO 5817 and ISO 10042.

Major causes

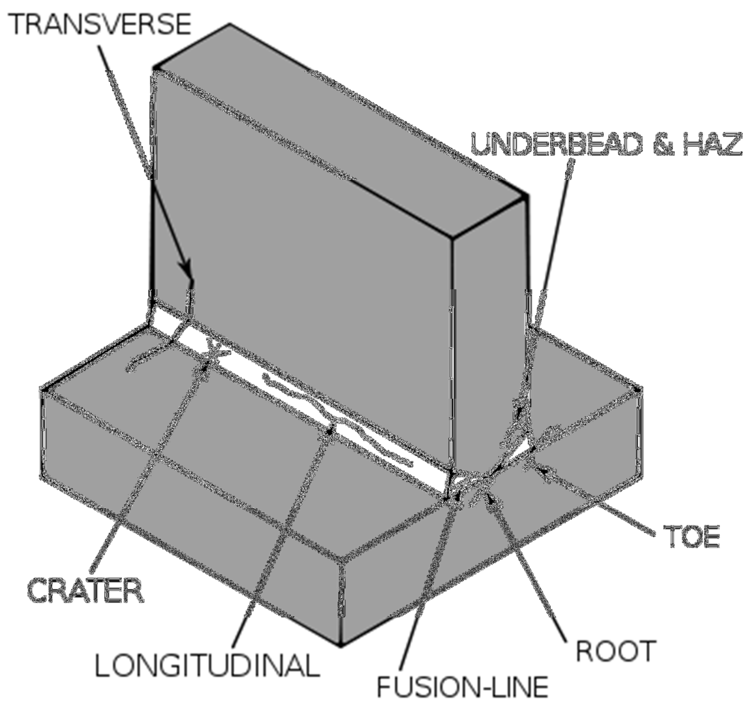
According to the American Society of Mechanical Engineers (ASME), causes of welding defects can be broken down as follows: 45 percent poor process conditions, 32 percent operator error, 12percent wrong technique, 10 percent incorrect consumables, and 5 percent bad weld grooves.[4]

Hydrogen embrittlement

Residual stresses

The magnitude of stress that can be formed from welding can be roughly calculated using

Cracks



Defects related to fracture.

Arc strike cracking

Arc strike cracking occurs when the arc is struck but the spot is not welded. This occurs because the spot is heated above the material's upper critical temperature and then essentially quenched. This forms martensite, which is brittle and may lead to higher chances of micro-cracks. Usually the arc is struck in the weld groove so this type of crack does not occur, but if the arc is struck outside of the weld groove then it must be welded over to prevent the cracking. If this is not an option then the arc spot can be postheated, that is, the area is heated with an oxy-acetylene torch, and then allowed to cool slowly.[6]

Cold cracking

Residual stresses can reduce the strength of the base material, and can lead to catastrophic failure through cold cracking. Cold cracking is limited to steels and is associated with the formation of martensite as the weld cools. The cracking occurs in the heat-affected zone of the base material. To reduce the amount of distortion and residual stresses, the amount of heat input should be limited, and the welding sequence used should not be from one end directly to the other, but rather in segments.[7]

Cold cracking only occurs when all the following preconditions are met:[*citation needed*]

- susceptible microstructure (*e.g.* martensite)
- hydrogen present in the microstructure (hydrogen embrittlement)
- service temperature environment (normal atmospheric pressure): -100 to +100 °F
- high restraint

Eliminating any one of these will eliminate this condition.

Crater crack

Crater cracks occur when a crater is not filled before the arc is broken. This causes the outer edges of the crater to cool more quickly than the crater, which creates sufficient stresses to form a crack. Longitudinal, transverse and/or multiple radial cracks may form.[8]

Hat crack

Hat cracks get their name from the shape of the cross-section of the weld, because the weld flares out at the face of the weld. The crack starts at the fusion line and extends up through the weld. They are usually caused by too much voltage or not enough speed.[8]

Hot cracking

Hot cracking, also known as solidification cracking, can occur with all metals, and happens in the fusion zone of a weld. To diminish the probability of this type of cracking, excess material restraint should be avoided, and a proper filler material should be utilized.[7] Other causes include too high welding current, poor joint design that does not diffuse heat, impurities (such as sulfur and phosphorus), preheating, speed is too fast, and long arcs.[9]

Underbead crack

An undercut crack, also known as a heat-affected zone (HAZ) crack,[10] is a crack that forms a short distance away from the fusion line; it occurs in low alloy and high alloy steel. The exact causes of this type of crack are not completely understood, but it is known that dissolved hydrogen must be present. The other factor that affects this type of crack is internal stresses resulting from: unequal contraction between the base metal and the weld metal, restraint of the base metal, stresses from the formation of martensite, and stresses from the precipitation of hydrogen out of the metal.[11]

Longitudinal crack

Longitudinal cracks run along the length of a weld bead. There are three types: *check cracks*, *root cracks*, and *full centerline cracks*. Check cracks are visible from the surface and extend partially into the weld. They are usually caused by high shrinkage stresses, especially on final passes, or by a hot cracking mechanism. Root cracks start at the root and extent part way into the weld. They are the most common type of longitudinal crack because of the small size of the first weld bead. If this type of crack is not addressed then it will usually propagate into subsequent weld passes, which is how full cracks (a crack from the root to the surface) usually form.[8]

Reheat cracking

Reheat cracking is a type of cracking that occurs in HSLA steels, particularly chromium, molybdenum and vanadium steels, during postheating. The phenomenon has also been observed in austenitic stainless steels. It is caused by the poor creep ductility of the heat affected zone. Any existing defects or notches aggravate crack formation. Things that help prevent reheat cracking include heat treating first with a low temperature soak and then with a rapid heating to high temperatures, grinding or peening the weld toes, and using a two layer welding technique to refine the HAZ grain structure.[12][13]

Root and toe cracks

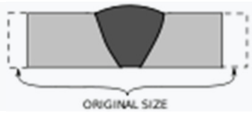
A root crack is the crack formed by the short bead at the root(of edge preparation) beginning of the welding, low current at the beginning and due to improper filler material used for welding.Major reason for happening of these types of cracks is hydrogen embrittlement. These types of defects can be eliminated using high current at the starting and proper filler material. Toe crack occurs due to moisture content present in the welded area,it as a part of the surface crack so can be easily detected. Preheating and proper joint formation is must for eliminating these types of defects.

Transverse crack

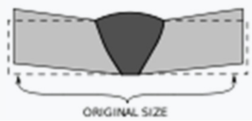
Transverse cracks are perpendicular to the direction of the weld. These are generally the result of longitudinal shrinkage stresses acting on weld metal of low ductility. Crater cracks occur in the crater when the welding arc is terminated prematurely. Crater cracks are normally shallow, hot cracks usually forming single or star cracks. These cracks usually start at a crater pipe and extend longitudinal in the crater. However, they may propagate into longitudinal weld cracks in the rest of the weld.

Distortion

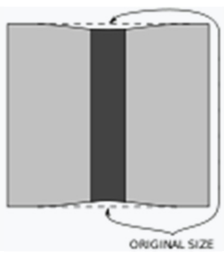
Welding methods that involve the melting of metal at the site of the joint necessarily are prone to shrinkage as the heated metal cools. Shrinkage then introduces residual stresses and distortion. Distortion can pose a major problem, since the final product is not the desired shape. To alleviate certain types of distortion the workpieces can be offset so that after welding the product is the correct shape.[14] The following pictures describe various types of welding distortion:[15]

- 

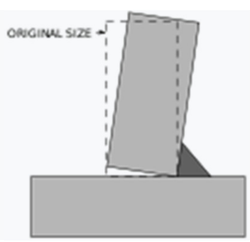
  Transverse shrinkage

- 

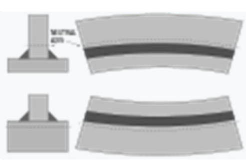
  Angular distortion

- 

  Longitudinal shrinkage

- 

  Fillet distortion

- 

  Neutral axis distortion

Gas inclusion

Gas inclusions is a wide variety of defects that includes *porosity*, *blow holes*, and *pipes* (or *wormholes*). The underlying cause for gas inclusions is the entrapment of gas within the solidified weld. Gas formation can be from any of the following causes: high sulphur content in the workpiece or electrode, excessive moisture from the electrode or workpiece, too short of an arc, or wrong welding current or polarity.[10]

Inclusions

There are two types of inclusions: *linear inclusions* and *rounded inclusions*. Inclusions can be either *isolated* or *cumulative*. Linear inclusions occur when there is slag or flux in the weld. Slag forms from the use of a flux, which is why this type of defect usually occurs in welding processes that use flux, such as shielded metal arc welding, flux-cored arc welding, and submerged arc welding, but it can also occur in gas metal arc welding. This defect usually occurs in welds that require multiple passes and there is poor overlap between the welds. The poor overlap does not allow the slag from the previous weld to melt out and rise to the top of the new weld bead. It can also occur if the previous weld left an undercut or an uneven surface profile. To prevent slag inclusions the slag should be cleaned from the weld bead between passes via grinding, wire brushing, or chipping.[16]

Isolated inclusions occur when rust or mill scale is present on the base metal.[17]

Lack of fusion and incomplete penetration

Lack of fusion is the poor adhesion of the weld bead to the base metal; incomplete penetration is a weld bead that does not start at the root of the weld groove. Incomplete penetration forms channels and crevices in the root of the weld which can cause serious issues in pipes because corrosive substances can settle in these areas. These types of defects occur when the welding procedures are not adhered to; possible causes include the current setting, arc length, electrode angle, and electrode manipulation.[18] Defects can be varied and classified as critical or non critical. Porosity (bubbles) in the weld are usually acceptable to a certain degree. Slag inclusions, undercut, and cracks are usually non acceptable. Some porosity, cracks, and slag inclusions are visible and may not need further inspection to require their removal. Small defects such as these can be verified by Liquid Penetrant Testing (Dye check). Slag inclusions and cracks just below the surface can be discovered by Magnetic Particle Inspection. Deeper defects can be detected using the Radiographic (X-rays) and/or Ultrasound (sound waves) testing techniques.

Lamellar tearing

Lamellar tearing is a type of welding defect that occurs in rolled steel plates that have been welded together due to shrinkage forces perpendicular to the faces of the plates.[19]Since the 1970s, changes in manufacturing practices limiting the amount of sulfur used have greatly reduced the incidence of this problem.[20]

Lamellar tearing is caused mainly by sulfurous inclusions in the material. Other causes include an excess of hydrogen in the alloy. This defect can be mitigated by keeping the amount of sulfur in the steel alloy below 0.005%.[20] Adding rare earth elements, zirconium, or calcium to the alloy to control the configuration of sulfur inclusions throughout the metal lattice can also mitigate the problem.[21]

Modifying the construction process to use casted or forged parts in place of welded parts can eliminate this problem, as Lamellar tearing only occurs in welded parts

Undercut

Undercutting is when the weld reduces the cross-sectional thickness of the base metal and which reduces the strength of the weld and workpieces. One reason for this type of defect is excessive current, causing the edges of the joint to melt and drain into the weld; this leaves a drain-like impression along the length of the weld. Another reason is if a poor technique is used that does not deposit enough filler metal along the edges of the weld. A third reason is using an incorrect filler metal, because it will create greater temperature gradients between the center of the weld and the edges. Other causes include too small of an electrode angle, a dampened electrode, excessive arc length, and slow speed.

Special Welding Techniques

CO_2 WELDING

CO2 Arc Welding

In CO2 arc welding, the welding wire wound in coil is fed into the welding torch by the feeding motor automatically. The welding wire that is electrified through the contact tip becomes the electrode to strike an arc between itself and the base metal. The arc heat melts the wire and the base metal to join two pieces of base metal. In this case, in order that the weld metal will not be affected by oxygen and nitrogen in the atmosphere, CO2 gas is supplied from the nozzle of the welding torch to shield the weld pool. Its schematic is shown below.

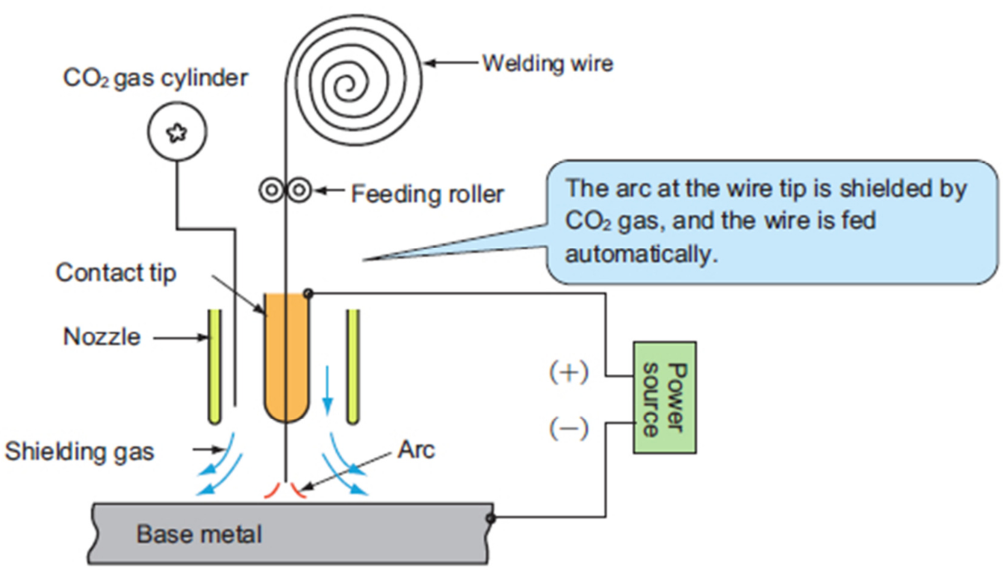
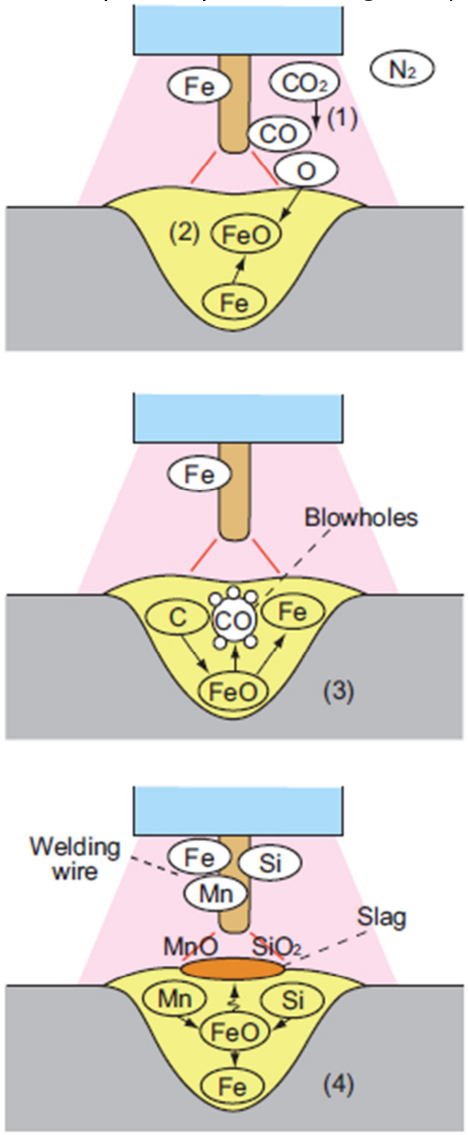


Fig. 1 Schematic diagram of semiautomatic CO2 arc welding

Principles

Iron becomes brittle when it combines with nitrogen that exists much in the atmosphere. CO2 gas, therefore, is often used to shield the weld pool from the atmosphere. CO2 gas can be decomposed by the ultra−high temperature arc heat into CO and O near the arc.



$$CO_2 \rightleftarrows CO + O \quad \cdots \ (1)$$

The decomposed O combines with molten iron to form FeO.

$$Fe + O \rightleftarrows FeO \quad \cdots \ (2)$$

Sequentially, C that is contained in steel is easier to combine with O than Fe deprives O from FeO to generate CO gas, which is apt to left in the weld metal to form blowholes. A weld metal that contains blowholes cannot be deemed to be sound.

$$FeO + C \rightleftarrows Fe + CO \quad \cdots \ (3)$$

To improve the soundness, a welding wire that contains Si and Mn that have stronger affinity with O is used ; in this case, O in FeO combines not with C but with Si and Mn and floats up on the surface of the weld pool to form slag of SiO2 and MnO. Though slag is formed, the weld metal becomes sound without blowholes.

$$\left.\begin{array}{l} FeO + Mn \rightleftarrows Fe + MnO \\ 2FeO + Si \rightleftarrows 2Fe + SiO_2 \end{array}\right. \cdots (4)$$

Besides Si and Mn that prevent blowholes, various other chemical elements are added to the welding wire in order to let the weld metal possess required strength, impact toughness, corrosion resistance and other properties.

Features

As compared with shielded metal arc welding, CO2 arc welding has the following advantages and disadvantages.

(1) Advantages

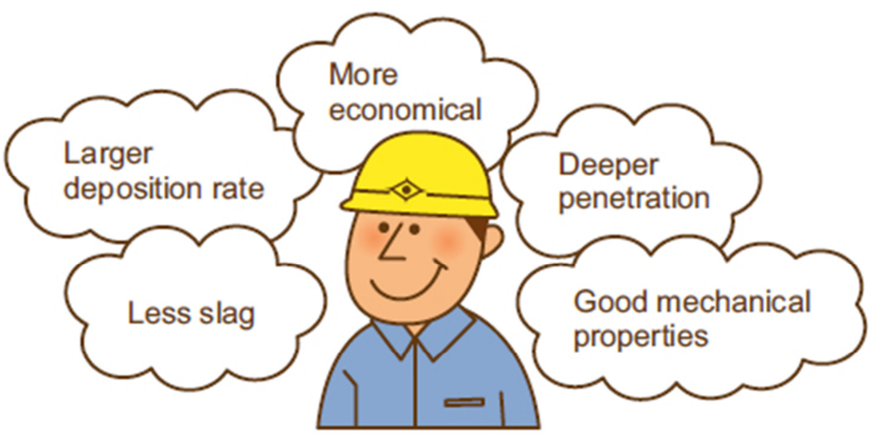
①As the diameter of the wire is small, the welding current density is high and thus the deposition rate is big.

②Good concentration of the arc realizes deep penetration.

③The deposition efficiency is high and formation of slag is little, which makes it unnecessary to remove slag after each pass.

④The arc generation rate is high, thereby lowering the welding cost and making the process to be more economical.

⑤Hydrogen in the weld metal is low, which contributes to good crack resistance and mechanical properties.



Disadvantages

①Windbreak screen is needed against high wind at a velocity of 2m/sec. or higher.

②Even if a long conduit cable is used, welder's movable area is limited.

③The price of the power source is high.

If you compare such advantages and disadvantages with those of the shielded metal arc welding process, it is evident that CO2 arc welding offers higher efficiency, lower welding costs and better economy. Such advantageous effects can be maximized in automatic welding, particularly in robotic welding

C.I WELDING

A cast iron is an alloy of iron, carbon, and silicon, in which the amount of carbon is usually more than 1.7 percent and less than 4.5 percent. The overall weldability of cast iron is low and depends on the material type, complexity, thickness, casting complexity and need for machinability. Ductile and malleable irons have good weldability while grey cast iron and white cast iron are only weldable for small attachments.

The most widely used type of cast iron is known as gray iron. Gray iron has a variety of compositions, but is usually such that it is primarily perlite with many graphite flakes dispersed throughout.

There are also alloy cast irons which contain small amounts of chromium, nickel, molybdenum, copper, or other elements added to provide specific properties.

Another alloy iron is austenitic cast iron, which is modified by additions of nickel and other elements to reduce the transformation temperature so that the structure is austenitic at room or normal temperatures. Austenitic cast irons have a high degree of corrosion resistance.

In white cast iron, almost all the carbon is in the combined form. This provides a cast iron with higher hardness, which is used for abrasion resistance.

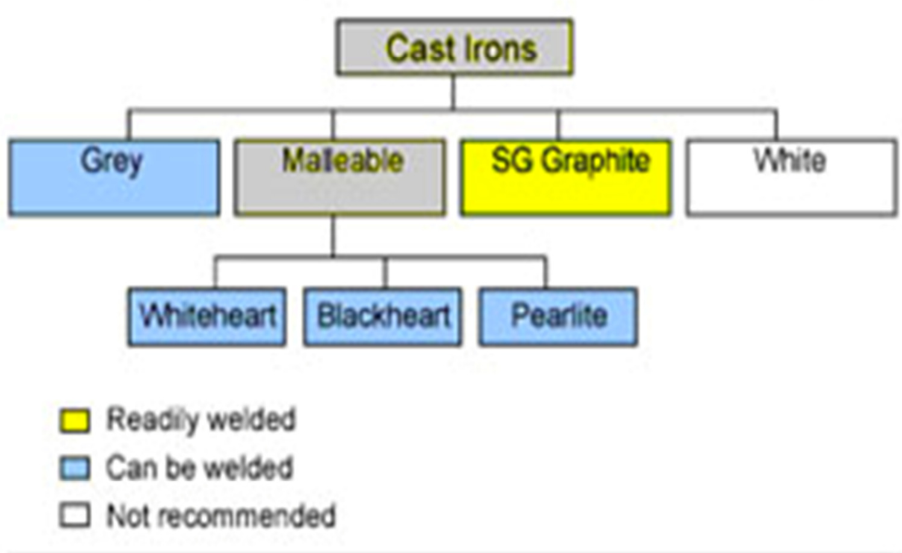
Malleable cast iron is made by giving white cast iron a special annealing heat treatment to change the structure of the carbon in the iron. The structure is changed to perlitic or ferritic, which increases its ductility.

Nodular iron and ductile cast iron are made by the addition of magnesium or aluminum which will either tie up the carbon in a combined state or will give the free carbon a spherical or nodular shape, rather than the normal flake shape in gray cast iron. This structure provides a greater degree of ductility or malleability of the casting.

A major factor contributing to the difficulty of welding cast iron is its lack of ductility. If cast irons are loaded beyond their yield points, they break rather than deform to any significant extent. Weld filler metal and part configuration should therefore be selected to minimize welding stresses.

MMA, flux cored arc, MIG, TIG and gas welding processes are normally used with nickel-based welding consumables to produce high-quality welds, but cast iron and steel electrodes can also produce satisfactory welds in certain alloys.

Weldability by Metal Type



TIG WELDING

TIG welding (GTAW or gas tungsten) is an arc welding process that operates at high temperature (over 6,000 degrees Fahrenheit) to melt and heat metals. While it is more expensive than stick welding, it is cleaner and more versatile (works on steel, aluminum, brass and many other metals).It results is high quality welds.

On the downside the equipment is more expensive and the process is slower than other welding processes. Unlike GMAW or MIG welding, a non-consumable (doesn't get melted) tungsten electrode is used. The electrode creates an electrical arc which produces the required heat. The Tig torch is cooled by air or water and the process uses a filler metal in rod form.

GTAW also requires a shielding gas such as argon or helium to protect the weld from the atmosphere.

The gas tungsten arc welding process is generally not commercially competitive with other processes for welding heavier gauges of metal if they can be readily welded by the shielded metal arc, submerged arc, or gas metal arc welding processes with adequate quality.

Gas tungsten arc welding (GTAW) is a process in which the joining of metals is produced by heating therewith an arc between a tungsten (non-consumable) electrode and the work.

A shielding gas is used, normally argon.

normally done with a pure tungsten or tungsten alloy rod, but multiple electrodes are sometimes used.

The heated weld zone, molten metal, and tungsten electrode are shielded from the atmosphere by a covering of inert gas fed through the electrode holder.

Filler metal may or may not be added. A weld is made by applying the arc so that the touching workpiece and filler metal are melted and joined as the weld metal solidifies.

This process is similar to other arc welding processes in that the heat is generated by an arc between a nonconsumable electrode and the workpiece, but the equipment and electrode type distinguish itfrom other arc welding processes.

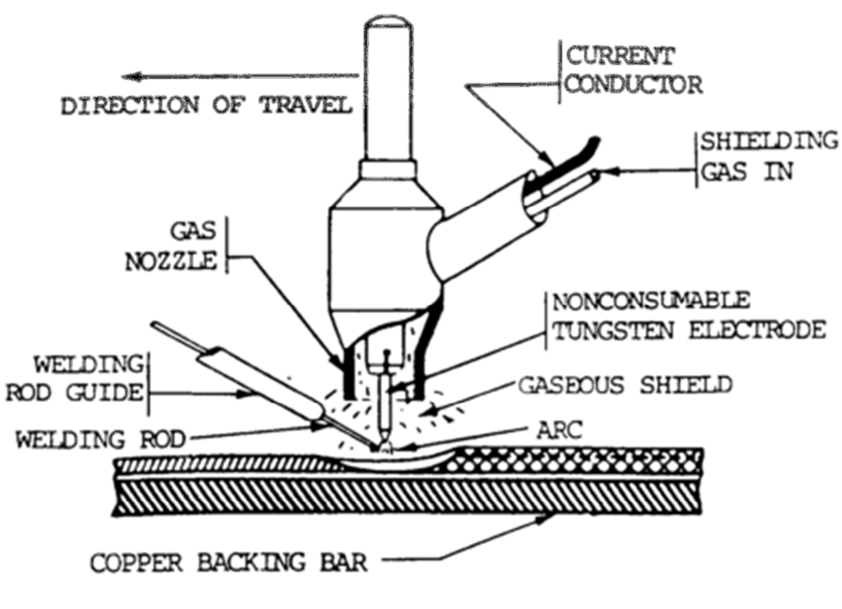


Figure 10-32. Gas tungsten arc (TIG) welding (GTAW).

Advantages and Disadvantages

Advantages

- Works on almost all types of metals with higher melting points. Gas tungsten arc welding is the most popular method for welding aluminum stainless steels, and nickel-base alloys. It is generally not used for the very low melting metals such as solders, or lead, tin, or zinc alloys.

  It is especially useful for joining aluminum and magnesium which form refractory oxides, and also for the reactive metals like titanium and zirconium, which dissolve oxygen and nitrogen and become embrittled if exposed to air while melting.
- Pinpoint accuracy and control. The process provides more precise control of the weld than any other arc welding process, because the arc heat and filler metal are independently controlled.
- Good looking weld beads
- For metals of varying thickness including very thin metals (amperage range of 5 to 800, which is the amount of electricity created by the welding machine). The gas tungsten arc welding process is very good for joining thin base metals because of excellent control of heat input.
- creates strong joints. It produces top quality welds in almost all metals and alloys used by industry.
- clean process with minimal amount of of fumes, sparks, spatter and smoke
- High level of visibility when working due to low levels of smoke. Visibility is excellent because no smoke or fumes are produced during welding, and there is no slag or spatter that must be cleaned between passes or on a completed weld.
- Minimal finishing required. In very critical service applications or for very expensive metals or parts, the materials should be carefully cleaned of surface dirt, grease, and oxides before welding.
- Works in any position
- TIG welding also has reduced distortion in the weld joint because of the concentrated heat source.
- As in oxyacetylene welding, the heat source and the addition of filler metal can be separately controlled.
- Because the electrode is non-consumable, the process can be used to weld by fusion alone without the addition of filler metal.

Disadvantages

- Brighter UV rays when compared to other welding processes
- Slower process than consumable electrode arc welding processes.
- Takes practice
- More expensive process overall. Expensive welding supplies (vs. other processes) because the arc travel speed and weld metal deposition rates are lower than with some other methods.

  Inert gases for shielding and tungsten electrode costs add to the total cost of welding compared to other processes. Argon and helium used for shielding the arc are relatively expensive.

Equipment costs are greater than that for other processes, such as shielded metal arc welding, which require less precise controls.

- Not easily portable, best for a welding shop
- Transfer of molten tungsten from the electrode to the weld causes contamination. The resulting tungsten inclusion is hard and brittle.
- Exposure of the hot filler rod to air using improper welding techniques causes weld metal contamination.

MIG WELDING

Gas metal arc welding (GMAW), sometimes referred to by its subtypes, metal inert gas (MIG) welding or metal active gas (MAG) welding, is a semi-automatic or automatic arc welding process in which a continuous and consumable wire electrode and a shielding gas are fed through a welding gun.

A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used.

There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.

Shielding is obtained from an externally supplied gas or gas mixture.

History

Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it allowed for lower welding time compared to other welding processes.

The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common.

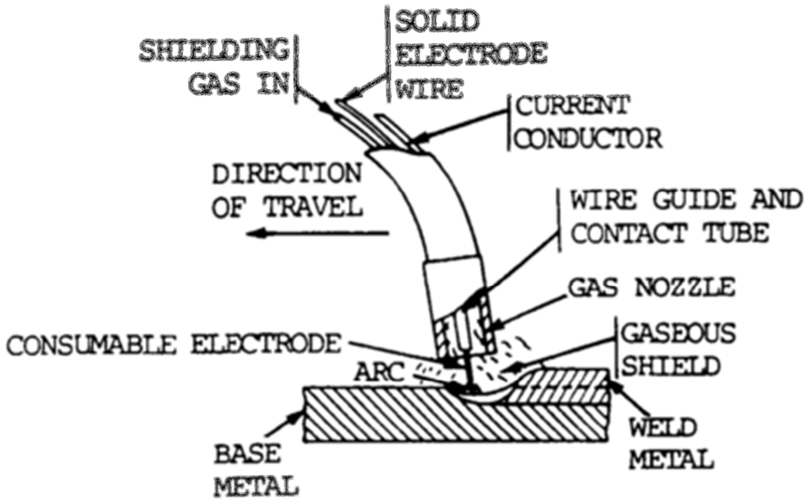


Figure 10-44. Gas metal arc welding process.

Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it allowed for lower welding time compared to other welding processes.

The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common.

MIG Welding Basics

MIG welding is operated in semiautomatic, machine, and automatic modes. It is utilized particularly in high production welding operations.

All commercially important metals such as carbon steel, stainless steel, aluminum, and copper can be welded with this process in all positions by choosing the appropriate shielding gas, electrode, and welding conditions.

Equipment

Gas metal arc welding equipment consists of a welding gun, a power supply, a shielding gas supply, and a wire-drive system which pulls the wire electrode from a spool and pushes it through a welding gun.

A source of cooling water may be required for the welding gun.

In passing through the gun, the wire becomes energized by contact with a copper contact tube, which transfers current from a power source to the arc.

While simple in principle, a system of accurate controls is employed to initiate and terminate the shielding gas and cooling water, operate the welding contractor, and control electrode feed speed as required.

The basic features of MIG welding equipment are shown in figure 10-45.

The MIG process is used for semiautomatic, machine, and automatic welding. Semiautomatic MIG welding is often referred to as manual welding.

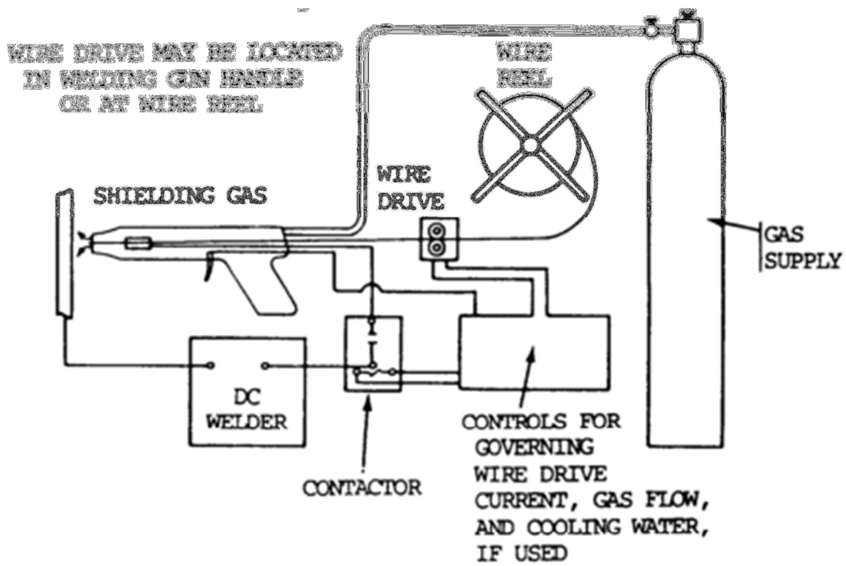


Figure 10-45. MIG welding process.

Developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process.

Today, GMAW is commonly used in industries such as the automobile industry, where it is preferred for its versatility and speed.

Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility.

A related Mig process, flux cored arc welding, often does not utilize a shielding gas, instead employing a hollow electrode wire that is filled with flux on the inside.

Power Supply

Two types of power sources are used for MIG welding: constant current and constant voltage.

(a) Constant current power supply

With this type, the welding current is established by the appropriate setting on the power supply.

Arc length (voltage) is controlled by the automatic adjustment of the electrode feed rate.

This type of welding is best suited to large diameter electrodes and machine or automatic welding, where very rapid change of electrode feed rate is not required.

Most constant current power sources have a drooping volt-ampere output characteristic.

However, true constant current machines are available.

Constant current power sources are not normally selected for MIG welding because of the control needed for electrode feed speed. The systems are not self-regulating.

(b) Constant voltage power supply

The arc voltage is established by setting the output voltage on the power supply.

The power source will supply the necessary amperage to melt the welding electrode at the rate required to maintain the present voltage or relative arc length.

The speed of the electrode drive is used to control the average welding current.

This characteristic is generally preferred for the welding of all metals.

The use of this type of power supply in conjunction with a constant wire electrode feed results in a self-correcting arc length system.

Motor generator or dc rectifier power sources of either type may be used.

With a pulsed direct current power supply, the power source pulses the dc output from a low background value to a high peak value.

Because the average power is lower, pulsed welding current can be used to weld thinner sections than those that are practical with steady dc spray transfer.

SEAM WELDING

Seam welding is a variation of resistance spot welding. In **resistance seam welding**, however, the welding electrodes are motor driven wheels as opposed to stationary rods. The result is a 'rolling' resistance weld or non-hermetic seam weld. This process is most often used to join two sheets of metal together.

Typical Amada Miyachi equipment used for resistance seam welding include our STA Series AC weld controls, HF2 high frequency inverter weld control, SM8500 seam welding system and AF8500 lid placement, tacking and sealing system.

For more information about the resistance welding process read our Fundamentals of Resistance Welding.

In **laser seam welding**, the part to be welded is moved or rotated under the laser focus head allowing laser spot welds to overlap. Key parameters for laser seam welding are the pulse repetition rate, measured in pulses per second (Hz) and the linear part travel rate or welding speed. Spot overlap percentage (a function of speed), pulse repetition rate and focused spot diameter are also used in the equation for determining the best laser for the job and for determining the total weld cycle time. Laser welding is used to make hermetic seam welds: Laser seam welding applications include sensors, radar components, battery housing, conductors for thin film cells, pacemaker cases, and insulin pump cases. All of Amada Miyachi's welding lasers may be used for seam welding applications; the model selected depends on the application success requirements.

Submerged arc welding

Submerged arc welding is a process in which the joining of metals is produced by heating with an arc or arcs between a bare metal electrode or electrodes and the work.

The arc is shielded by a blanket of granular fusible material on the work.

Pressure is not used. Filler metal is obtained from the electrode or from a supplementary welding rod.

Equipment

The SAW equipment components required for submerged arc welding are shown by figure 10-59.

Equipment consists of a welding machine or power source, the wire feeder and control system, the welding torch for automatic welding or the welding gun and cable assembly for semiautomatic welding, the flux hopper and feeding mechanism, usually a flux recovery system, and a travel mechanism for automatic welding.

The power source for submerged arc welding must be rated for a 100 percent duty cycle, since the submerged arc welding operations are continuous and the length of time for making a weld may exceed 10 minutes.

If a 60 percent duty cycle power source is used, it must be derated according to the duty cycle curve for 100 percent operation.

When constant current is used, either ac or dc, the voltage sensing electrode wire feeder system must be used.

When constant voltage is used, the simpler fixed speed wire feeder system is used. The CV system is only used with direct current.

Both generator and transformer-rectifier power sources are used, but the rectifier machines are more popular.

Welding machines for submerged arc welding range in size from 300 amperes to 1500 amperes.

They may be connected in parallel to provide extra power for high-current applications.

Direct current power is used for semiautomatic applications, but alternating current power is used primarily with the machine or the automatic method.

Multiple electrode systems require specialized types of circuits, especially when ac is employed.

For semiautomatic application, a welding gun and cable assembly are used to carry the electrode and current and to provide the flux at the arc.

A small flux hopper is attached to the end of the cable assembly.

The electrode wire is fed through the bottom of this flux hopper through a current pickup tip to the arc.

The flux is fed from the hopper to the welding area by means of gravity.

The amount of flux fed depends on how high the gun is held above the work.

The hopper gun may include a start switch to initiate the weld or it may utilize a "hot" electrode so that when the electrode is touched to the work, feeding will begin automatically.

For automatic welding, the torch is attached to the wire feed motor and includes current pickup tips for transmitting the welding current to the electrode wire.

The flux hopper is normally attached to the torch, and may have magnetically operated valves which can be opened or closed by the control system.

Other pieces of equipment sometimes used may include a travel carriage, which can be a simple tractor or a complex moving specialized fixture. A flux recovery unit is normally provided to collect the unused submerged arc flux and return it to the supply hopper.

Submerged arc welding system can become quite complex by incorporating additional devices such as seam followers, weavers, and work rovers.

SAW Welding Diagram

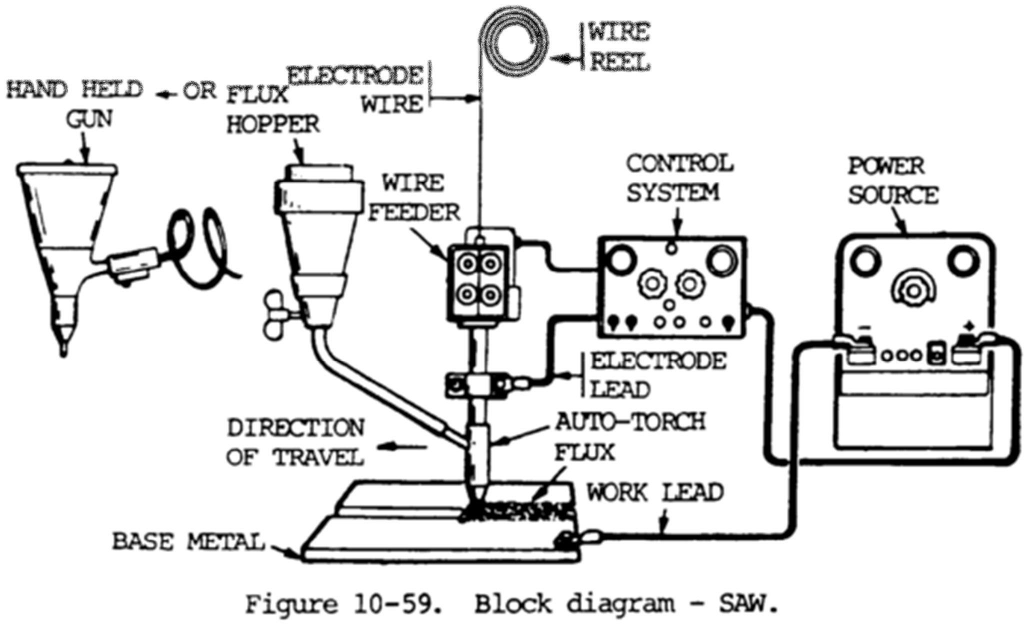


Figure 10-59. Block diagram of SAW (submerged arc welding) Equipment.

Advantages

The major advantages of the SAW or submerged arc welding process are:

1. high quality metal weld.
2. extremely high speed and deposition rate
3. smooth, uniform finished weld with no spatter.
4. little or no smoke.
5. no arc flash, thus minimal need for protective clothing.
6. high utilization of electrode wire.
7. easy automation for high-operator factor.
8. normally, no involvement of manipulative skills.

Principles of Operation

Process

The submerged arc welding process is shown by figure 10-60. It utilizes the heat of an arc between a continuously fed electrode and the work.

Submerged Arc Welding Process Diagram

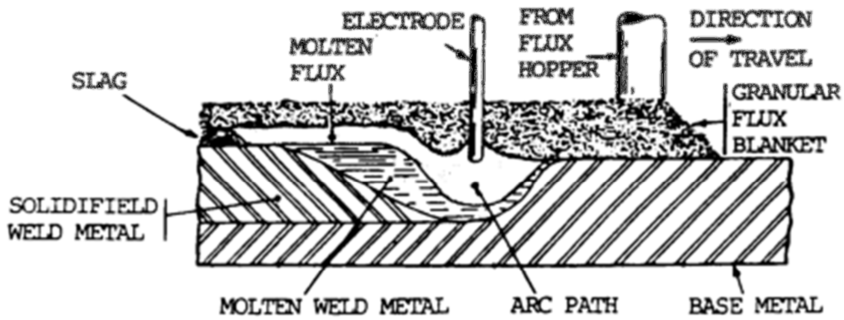


Figure 10-60. Process diagram--submerged arc welding..

Figure 10-60: Process Diagram for SAW (submerged arc welding)

The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted off the electrode is transferred through the arc to the workpiece, where it becomes the deposited weld metal.

Shielding is obtained from a blanket of granular flux, which is laid directly over the weld area. The flux close to the arc melts and intermixes with the molten weld metal, helping to purify and fortify it.

The flux forms a glass-like slag that is lighter in weight than the deposited weld metal and floats on the surface as a protective cover.

The weld is submerged under this layer of flux and slag, hence the name submerged arc welding. The flux and slag normally cover the arc so that it is not visible.

The unmelted portion of the flux can be reused. The electrode is fed into the arc automatically from a coil. The arc is maintained automatically.

Travel can be manual or by machine. The arc is initiated by a fuse type start or by a reversing or retrack system.

FLASH BUTT WELDING

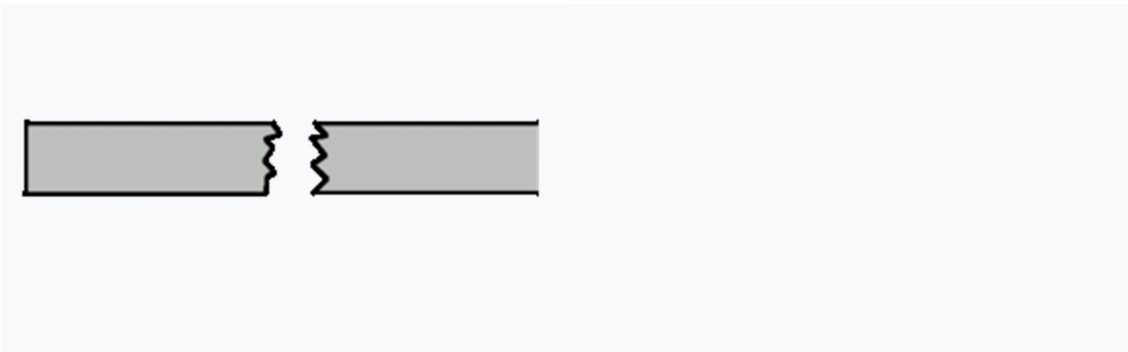
Flash butt welding is a type of resistance welding without using any filler metal. It is used for joining two metal parts together using heat and force. Each of the two parts to be joined are clamped against an electrode, usually a copper alloy. The electrodes themselves being connected to the secondary side of a transformer. The ends are brought slowly together until they just touch. At this point a high current flows through the touching points, rapidly heating and melting the metal at the points of contact. The molten metal is then expelled by its own rapid expansion. This part of the welding cycle is called the flashing and generally creates a spectacular shower of sparks. Voltage used is generally low (typically between 4 and 20 volts) but the current usually very high, often in the tens of thousands of amps. The heat generated raises the temperature of either side of the joint. Once the temperature is above the forging temperature (typically around 1,250°C for steel) the ends are rapidly pushed together with great force. The high speed expels any remaining molten metal and the high force generates enough pressure at the joint (around 90 megapascals for steel) to 'forge weld' the ends together.

THE DIFFERENT CYCLES USED

Pre-Heating

Sometimes an optional pre-heating operation is used to heat the joint area using Joules energy from passing a current through the joint area directly without any flashing. This heats the whole area between the electrodes. Pre-heating itself is sometime preceded by a 'Burnoff' cycle which prepares the ends for better contact in the pre-heating cycle.

Flashing



An important parameter is to attain the proper forging temperature around the joint. This is generally dependent on the amount of heat generated by the flashing cycle. Flashing is typically determined by either a pre-set amount of time (seconds) or a pre-set distance to be flashed away (mm). Whereas pre-heating will heat the whole joint area that is between the electrodes, flashing will instead generate heat only at the joint interface. Heat will then be conducted back into the joint parent metal.

Butting a.k.a. Upsetting

Once the correct temperature profile has been generated then the ends of the joint are rapidly forced together. Initially a high velocity 'squirts' out any impure molten metal at the joint interface before it solidifies. Further movement as the joint cools swells the joint area through an upsetting action until the pressure at the joint, along with the temperature is sufficient to 'forge-weld' the ends together.

Hold Time

At the end of upsetting there is commonly a 'hold time' during which the joint is held still to allow the joint to cool and the two pieces of metal to completely bond.

Applications

Railway Lines (Flash butt welding machines are often transported to the work site on a road-rail vehicle)

Chains

Steel wheels

Sheets or rods of steel in rolling mills

Starter Rings

Gas cutting –Procedure &Precautions

In **oxy-fuel cutting**, a torch is used to heat metal to its kindling temperature. A stream of oxygen is then trained on the metal, burning it into a metal oxide that flows out of the kerf as slag.[5]

Torches that do not mix fuel with oxygen (combining, instead, atmospheric air) are not considered oxy-fuel torches and can typically be identified by a single tank (oxy-fuel cutting requires two isolated supplies, fuel and oxygen). Most metals cannot be melted with a single-tank torch. Consequently, single-tank torches are typically suitable for soldering and brazing but not for welding.

Plasma and the plasma arc cutting process uses heated gas to cut through metal (30,000 degrees Fahrenheit). The process works by heating gas to temperatures that causes it to ionize or conduct electricity. The gas is pressurized and shot over a tungsten electrode. The welding machine adds electricity which forms a circuit with the metal to be cut. The process produces heat which turns the gas into plasma, which can cut metal.

The process can be used to both cut and gouge metal. When gouging the process offers lower cost, lower fume and noise levels vs. carbon arc gouging.

Overview

The plasma arc cutting process cuts metal by melting a section of metal with a constricted arc. A high velocity jet flow of hot ionized gas melts the metal and then removes the molten material to form a kerf. The basic arrangement for a plasma arc cutting torch, similar to the plasma arc welding torch, is shown in figure 10-71.

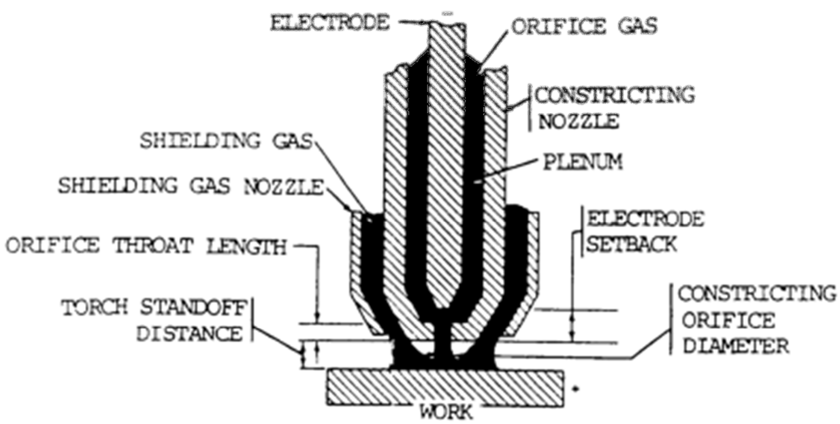
Three variations of the process exist:

- low current plasma cutting
- high current plasma cutting
- cutting with water added

Low current arc cutting, which produces high-quality cuts of thin materials, uses a maximum of 100 amperes and a much smaller torch than the high current version. Modifications of processes and equipment have been developed to permit use of oxygen in the orifice gas to allow efficient cutting of steel.

All plasma torches constrict the arc by passing it through an orifice as it travels away from the electrode toward the workpiece. As the orifice gas passes through the arc, it is heated rapidly to a high temperature, expands and accelerates as it passes through the constricting orifice. The intensity and velocity of the arc plasma gas are determined by such variables as the type of orifice gas and its entrance pressure, constricting orifice shape and diameter, and the plasma energy density on the work.

Plasma Arc Torch Diagram



The constriction of the nozzle focuses the arc. The flow of gas controls the velocity of the plasma.

Advantages and Disadvantages

Advantages

There are many advantages for the plasma arc cutting process:

- small risk of changing the shape of the metal (called distortion)
- precise cutting
- slag-free cuts when working with aluminum, stainless stell and carbon steel
- works in all positions
- fast process
- works across many types of metals
- do not require gas cylinders

Disadvantages

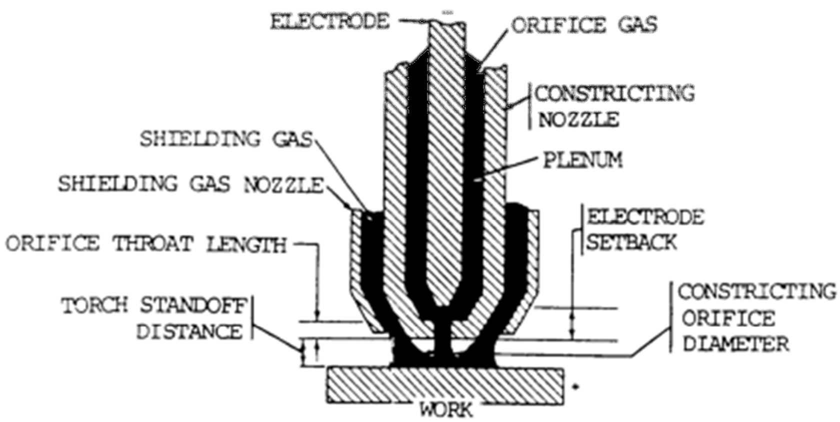
Some disadvantages of plasma arc cutting:

- creates a small bevel (7 degrees - approximate)
- electrical shock risk when not operating safely
- requires clean air source
- needs electricity to operate so not completely portable
- not cost effective for very thick steel

Plasma Arc Cutting Operation

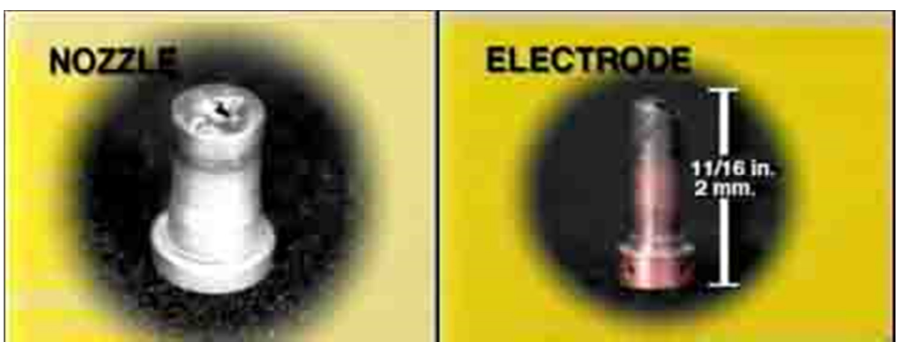
The basic plasma arc cutting circuitry is shown in figure 10-72. The process operates on direct current, straight polarity (dcsp), electrode negative, with a constricted transferred arc. In the transferred arc mode, an arc is struck between the electrode in the torch and the workpiece. The arc is initiated by a pilot arc between the electrode and the constricting nozzle. The nozzle is connected to ground (positive) through a current limiting resistor and a pilot arc relay contact. The pilot arc is initiated by a high frequency generator connected to the electrode and nozzle. The welding power supply then maintains this low current arc inside the torch. Ionized orifice gas from the pilot arc is blown through the constricting nozzle orifice. This forms a low resistance path to ignite the main arc between the electrode and the workpiece. When the main arc ignites, the pilot arc relay may be opened automatically to avoid unnecessary heating of the constricting nozzle.

Plasma Arc Torch Diagram



Principles of Operation

Plasma Cutting Consumables



The quality and cut speed will decline when the electrode or nozzle tip becomes damaged

The basic plasma arc cutting circuitry is shown in figure 10-72. The process operates on direct current, straight polarity (dcsp), electrode negative, with a constricted transferred arc. In the transferred arc mode, an arc is struck between the electrode in the torch and the workpiece. The arc is initiated by a pilot arc between the electrode and the constricting nozzle. The nozzle is connected to ground (positive) through a current limiting resistor and a pilot arc relay contact. The pilot arc is initiated by a high frequency generator connected to the electrode and nozzle.

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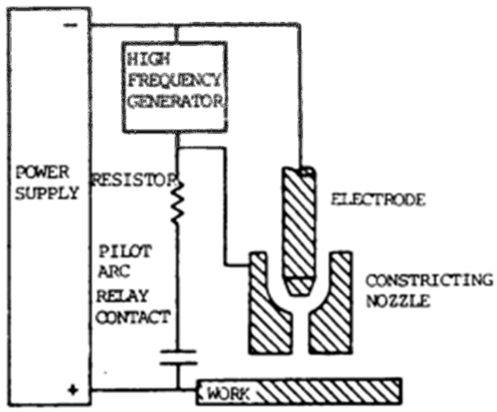
Basic Plasma Arc Cutting Circuitry - Figure 10-72



Because the plasma constricting nozzle is exposed to the high plasma flare temperatures (estimated at 18,032 to 25,232°F (10,000 to 14,000°C)), the nozzle must be made of water-cooled copper. In addition, the torch should be de-signed to produce a boundary layer of gas between the plasma and the nozzle.

Precautions

On a cargo vessel, fire occurred in the mast house where oxygen and acetylene cylinders were stored. The crew had arranged two gas torches in tandem for carrying out hot work on the windlass drum. Both the torches were connected in parallel from the same pair of gas cylinders by temporarily fitting "standard" t-joints at the regulator valves. At sometime during the hot work, it was decided to use one gas torch to carryout brazing repair work on the other torch while it was connected to the pressurized gas hoses.

Flashback from the torch being heated travelled through the hoses up to the mast house, rupturing the hoses at the regulator valve connections and causing a fire inside. Fortunately, the backfire arrestors on the regulators prevented a major explosion of the cylinders.

Such hazardous accidents can take place on any kind of ship if proper precautions are not taken while handling gas welding/cutting on board ships.

Precautions In Gas Cutting Operation.

When performing gas welding or cutting operation, following practical tips must be considered for safety and efficiency of operations .

1. Secure in Vertical Position: Compressed gas cylinders must be handled with utmost care and always be secured in vertical position even if they are full or empty. Full and empty cylinders to be segregated and marked clearly.

2. Store in Right Spaces: Never store oxygen and acetylene cylinder together in one space whenever possible. Keep them separately in well ventilated spaces. Ensure when not in use, their caps should always be on them.

3. Keep Grease and Oil Away: Control valves and fittings should be kept free of oil and grease. Never operate cylinder valves and parts with oily and greasy hands.

4. Ensure Flame Arresters Are Properly Fitted: Ensure non-return valves and flame arresters are fitted in the acetylene and oxygen cylinder lines. One flame arresters is normally fitted in the low pressure side of the regulator near cylinder and other near the torch.

5. Keep Pressure of Oxygen Higher: When performing gas welding, ensure the pressure of oxygen is always higher than the acetylene to avoid acetylene going back to the oxygen line.

6. Handle Acetylene With Care: Acetylene should not be used for welding at a pressure exceeding 1 bar of atmosphere gauge as it is liable to explode, even in the absence of air, when under excessive pressure.

7. Rectify Cause of Backfire: In case of back fire, the first priority should be to close the oxygen valve and then immediately close the acetylene valve. No operation is to be performed until the cause of backfire is rectified.

8. Handle Flashback carefully: In case of flashback or explosion of the gas pipes, first action must be to isolate the cylinder valves for both the cylinders. Further action to be taken as per ship's fire drill procedures.

9. Ensure Proper Connections: The connections between the hose and blowpipe, and between hoses should be securely fixed with fittings to comply with Regulatory Standard.

10. Keep a Steady Watch: A regular watch to be kept on the temperature of acetylene cylinder. If the temperature is elevating, it is to be considered same as flashback or explosion situation for taking action.

11. Prevent Interchange of Hoses: Manifold hose connections including inlet and outlet connections should be such that the hose cannot be interchanged between fuel gases and oxygen manifolds and headers.

12 Replace Old and Faulty Hoses: Any hose in which flashback has occurred must be replaced with new one.

13. Handle Hoses Properly: While performing the job, the hoses should be laid properly and kept out of any moving machinery, sharp corners, high temperature areas etc. Ensure they are not dangled, knitted or tipped over.

14. Use Only Approved leak detection fluid: Only approved leak detection fluid to be used for detection of leak from hose or regulator arrangement. If it is not available, non-detergent soap (Ivory) can be used.

15. Never Use Sealing Tape: Never use sealing tape of metal joining material to prevent leak between metal to metal gas tight joints. With an oxygen cylinder this could result in initiation of a metal- oxygen fire.

16. Never Over Tight Connections: Never try to over tight any nut of regulator connection or cylinder valve spindle to stop the leak. This can lead to damage.

17. Take Proper Steps for Maintenance: Only special tools should be used to clean any clogging in the blow pipe. Before performing any maintenance, complete system to be isolated. Never attempt repairs on pressurized oxy-acetylene equipment nor carry out any unauthorized modification on hot work equipment.

18. Use Safe Ignitors Only: Blowpipe should only be ignited with friction ignitor or other stable flame generator. Avoid using lighter as sudden flame, else blow pipe can hit the lighter body and explode

19. Never Use Oxygen: Oxygen should never be used for ventilation, cooling purpose or for blowing dust off the surface or clothes.

20. Discard Hoses That Had Flashback: Any length of hose in which a flashback has occurred should be discarded immediately.

Last but not the least, make sure before carrying out any kind of hot work, the hot work checklist and risk assessment forms have been duly filled. Also, do not forget to follow all safety procedures while carrying out such jobs in enclosed spaces.

High pressurized gas cylinders carrying highly flammable material are a major threat to the ship and its crew. Special care and attention must therefore be taken while handling such equipment, taking into consideration all safety procedures and manufacturers' notes.

INTRODUCTION TO NON DESTRUCTIVE TESTING

What Is Nondestructive Testing?

Nondestructive testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system. In other words, when the inspection or test is completed the part can still be used.

In contrast to NDT, other tests are destructive in nature and are therefore done on a limited number of samples ("lot sampling"), rather than on the materials, components or assemblies actually being put into service.

These destructive tests are often used to determine the physical properties of materials such as impact resistance, ductility, yield and ultimate tensile strength, fracture toughness and fatigue strength, but discontinuities and differences in material characteristics are more effectively found by NDT.

Today modern nondestructive tests are used in manufacturing, fabrication and in-service inspections to ensure product integrity and reliability, to control manufacturing processes, lower production costs and to maintain a uniform quality level. During construction, NDT is used to ensure the quality of materials and joining processes during the fabrication and erection phases, and in-service NDT inspections are used to ensure that the products in use continue to have the integrity necessary to ensure their usefulness and the safety of the public.

It should be noted that while the medical field uses many of the same processes, the term "nondestructive testing" is generally not used to describe medical applications.

TYPES OF NDT Test Methods

Test method names often refer to the type of penetrating medium or the equipment used to perform that test. Current NDT methods are: Acoustic Emission Testing (AE), Electromagnetic Testing (ET), Guided Wave Testing (GW), Ground Penetrating Radar (GPR), Laser Testing Methods (LM), Leak Testing (LT), Magnetic Flux Leakage (MFL), Microwave Testing, Liquid Penetrant Testing (PT), Magnetic Particle Testing (MT), Neutron Radiographic Testing (NR), Radiographic Testing (RT), Thermal/Infrared Testing (IR), Ultrasonic Testing (UT), Vibration Analysis (VA) and Visual Testing (VT).

The six most frequently used test methods are MT, PT, RT, UT, ET and VT. Each of these test methods will be described here, followed by the other, less often used test methods.

1. Magnetic Particle Testing (MT)
2. Liquid Penetrant Testing (PT)
3. Radiographic Testing (RT)
4. Ultrasonic Testing (UT)
5. Electromagnetic Testing (ET)
6. Visual Testing (VT)
7. Acoustic Emission Testing (AE)
8. Guided Wave Testing (GW)
9. Laser Testing Methods (LM)
10. Leak Testing (LT)
11. Magnetic Flux Leakage (MFL)
12. Neutron Radiographic Testing (NR)
13. Thermal/Infrared Testing (IR)
14. Vibration Analysis (VA)

ULTRASONIC FLAW DETECTION

Of all the applications of industrial ultrasonic testing, flaw detection is the oldest and the most common. Since the 1940s, the laws of physics that govern the propagation of sound waves through solid materials have been used to detect hidden cracks, voids, porosity, and other internal discontinuities in metals, composites, plastics, and ceramics. High frequency sound waves reflect from flaws in predictable ways, producing distinctive echo patterns that can be displayed and recorded by portable instruments. Ultrasonic testing is completely nondestructive and safe, and it is a well established test method in many basic manufacturing, process, and service industries, especially in applications involving welds and structural metals. This paper provides a brief introduction to the theory and practice of ultrasonic flaw detection. It is intended only as an overview of the topic. Additional detailed information may be found in the references listed at the end.

1. **Basic Theory:** Sound waves are simply organized mechanical vibrations traveling through a medium, which may be a solid, a liquid, or a gas. These waves will travel through a given medium at a specific speed or velocity, in a predictable direction, and when they encounter a boundary with a different medium they will be reflected or transmitted according to simple rules. This is the principle of physics that underlies ultrasonic flaw detection.

   Frequency: All sound waves oscillate at a specific frequency, or number of vibrations or cycles per second, which we experience as pitch in the familiar range of audible sound. Human hearing extends to a maximum frequency of about 20,000 cycles per second (20 KHz), while the majority of ultrasonic flaw detection applications utilize frequencies between 500,000 and 10,000,000 cycles per second (500 KHz to 10 MHz). At frequencies in the megahertz range, sound energy does not travel efficiently through air or other gasses, but it travels freely through most liquids and common engineering materials.

Velocity: The speed of a sound wave varies depending on the medium through which it is traveling, affected by the medium's density and elastic properties. Different types of sound waves (see Modes of Propagation, below) will travel at different velocities.

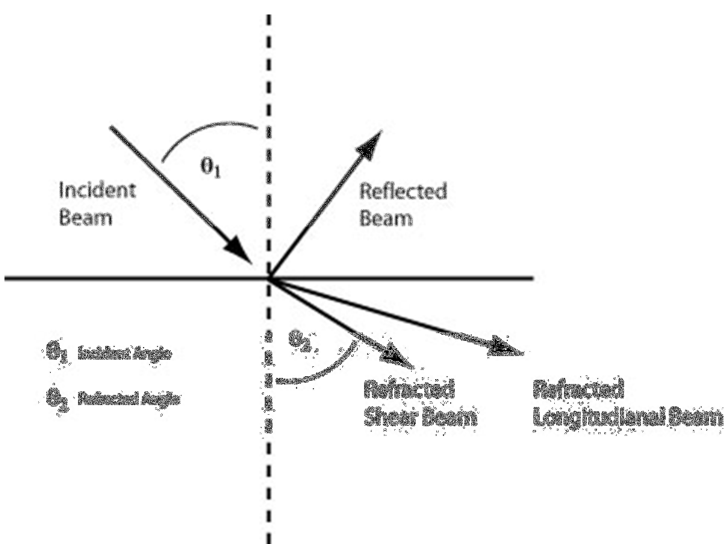
Wavelength: Any type of wave will have an associated wavelength, which is the distance between any two corresponding points in the wave cycle as it travels through a medium. Wavelength is related to frequency and velocity by the simple equation

Wavelength is a limiting factor that controls the amount of information that can be derived from the behavior of a wave. In ultrasonic flaw detection, the generally accepted lower limit of detection for a small flaw is one-half wavelength. Anything smaller than that will be invisible. In ultrasonic thickness gaging, the theoretical minimum measurable thickness one wavelength.

Modes of Propagation: Sound waves in solids can exist in various modes of propagation that are defined by the type of motion involved. Longitudinal waves and shear waves are the most common modes employed in ultrasonic flaw detection. Surface waves and plate waves are also used on occasion. A longitudinal or compressional wave is characterized by particle motion in the same direction as wave propagation, as from a piston source. Audible sound exists as longitudinal waves. A shear or transverse wave is characterized by particle motion perpendicular to the direction of wave propagation. A surface or Rayleigh wave has an elliptical particle motion and it travels across the surface of a material, penetrating to a depth of approximately one wavelength. A plate or Lamb wave is a complex mode of vibration in thin plates where material thickness is less than one wavelength and the wave fills the entire cross-section of the medium. = Sound waves may be converted from one form to another. Most commonly, shear waves are generated in a test material by introducing longitudinal waves at a selected angle. This is discussion further under **Angle Beam Testing** in Section 4. **Variables Limiting Transmission of Sound Waves:** The distance that a wave of a given frequency and energy level will travel depends on the material through which it is traveling. As a general rule, materials that are hard and homogeneous will transmit sound waves more efficiently than those that are soft and heterogeneous or granular. Three factors govern the distance a sound wave will travel in a given medium: beam spreading, attenuation, and scattering. As the beam travels, the leading edge becomes wider, the energy associated with the wave is spread over a larger area, and eventually the energy dissipates. Attenuation is energy loss associated with sound transmission through a medium, essentially the degree to which energy is absorbed as the wave front moves forward. Scattering is random reflection of sound energy from grain boundaries and similar microstructure. As frequency goes up, beam spreading increases but the effects of attenuation and scattering are reduced. For a given application, transducer frequency should be selected to optimize these variables.

Reflection at a Boundary: When sound energy traveling through a material encounters a boundary with another material, a portion of the energy will be reflected back and a portion will be transmitted through. The amount of energy reflected, or reflection coefficient, is related to the relative acoustic impedance of the two materials. Acoustic impedance in turn is a material property defined as density multiplied by the speed of sound in a given material. For any two materials, the reflection coefficient as a percentage of incident energy pressure may be calculated through the formula

Angle of Reflection and Refraction: Sound energy at ultrasonic frequencies is highly directional and the sound beams used for flaw detection are well defined. In situations where sound reflects off a boundary, the angle of reflection equals the angle of incidence. A sound beam that hits a surface at perpendicular incidence will reflect straight back. A sound beam that hits a surface at an angle will reflect forward at the same angle. Sound energy that is transmitted from one material to another bends in accordance with Snell's Law of refraction. Again, a beam that is traveling straight will continue in a straight direction, but a beam that strikes a boundary at an angle will be bent according to the formula:



In the broadest sense, a transducer is a device that converts energy from one form to another. Ultrasonic transducers convert electrical energy into high frequency sound energy and vice versa. **Cross section of typical contact transducer** Typical transducers for ultrasonic flaw detection utilize an active element made of a piezoelectric ceramic, composite, or polymer. When this element is excited by a high voltage electrical pulse, it vibrates across a specific spectrum of frequencies and generates a burst of sound waves. When it is vibrated by an incoming sound wave, it generates an electrical pulse. The front surface of the element is usually covered by a wear plate that protects it from damage, and the back surface is bonded to backing material that mechanically dampens vibrations once the sound generation process is complete. Because sound energy at ultrasonic frequencies does not travel efficiently through gasses, a thin layer of coupling liquid or gel is normally used between the transducer and the test piece.

There are five types of **ultrasonic transducers** commonly used in flaw detection applications:

- **Contact Transducers** -- As the name implies, contact transducers are used in direct contact with the test piece. They introduce sound energy perpendicular to the surface, and are typically used for locating voids, porosity, and cracks or delaminations parallel to the outside surface of a part, as well as for measuring thickness.

Angle Beam Transducers -- Angle beam transducers are used in conjunction with plastic or epoxy wedges (angle beams) to introduce shear waves or longitudinal waves into a test piece at a designated angle with respect to the surface. They are commonly used in weld inspection.

Delay Line Transducers - Delay line transducers incorporate a short plastic waveguide or delay line between the active element and the test piece. They are used to improve near surface resolution and also in high temperature testing, where the delay line protects the active element from thermal damage.

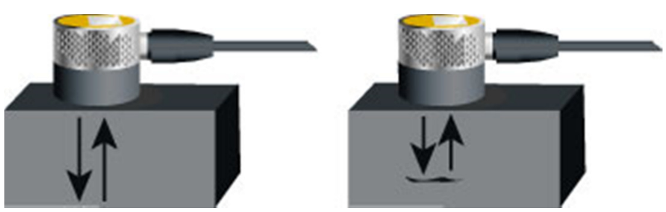
Immersion Transducers - Immersion transducers are designed to couple sound energy into the test piece through a water column or water bath. They are used in automated scanning applications and also in situations where a sharply focused beam is needed to improve flaw resolution.

Dual Element Transducers - Dual element transducers utilize separate transmitter and receiver elements in a single assembly. They are often used in applications involving rough surfaces, coarse grained materials, detection of pitting or porosity, and they offer good high temperature tolerance as well. Further details on the advantages of various transducer types, as well as the range of frequencies and diameters offered, may be found in the **transducer section** of our web site.

Ultrasonic Flaw Detectors Modern **ultrasonic flaw detectors** such as the **EPOCH series** are small, portable, microprocessor-based instruments suitable for both shop and field use. They generate and display an ultrasonic waveform that is interpreted by a trained operator, often with the aid of analysis software, to locate and categorize flaws in test pieces. They will typically include an ultrasonic pulser/receiver, hardware and software for signal capture and analysis, a waveform display, and a data logging module. While some analog-based flaw detectors are still manufactured, most contemporary instruments use digital signal processing for improved stability and precision. The pulser/receiver section is the ultrasonic front end of the flaw detector. It provides an excitation pulse to drive the transducer, and amplification and filtering for the returning echoes. Pulse amplitude, shape, and damping can be controlled to optimize transducer performance, and receiver gain and bandwidth can be adjusted to optimize signal-to-noise ratios. Modern flaw detectors typically capture a waveform digitally and then perform various measurement and analysis function on it. A clock or timer will be used to synchronize transducer pulses and provide distance calibration. Signal processing may be as simple as generation of a waveform display that shows signal amplitude versus time on a calibrated scale, or as complex as sophisticated digital processing algorithms that incorporate distance/amplitude correction and trigonometric calculations for angled sound paths. Alarm gates are often employed to monitor signal levels at selected points in the wave train to flag echoes from flaws. The display may be a CRT, a liquid crystal, or an electroluminescent display. The screen will typically be calibrated in units of depth or distance. Multicolor displays can be used to provide interpretive assistance. Internal data loggers can be used to record full waveform and setup information associated with each test, if required for documentation purposes, or selected information like echo amplitude, depth or distance readings, or presence or absence of alarm conditions.

Procedure

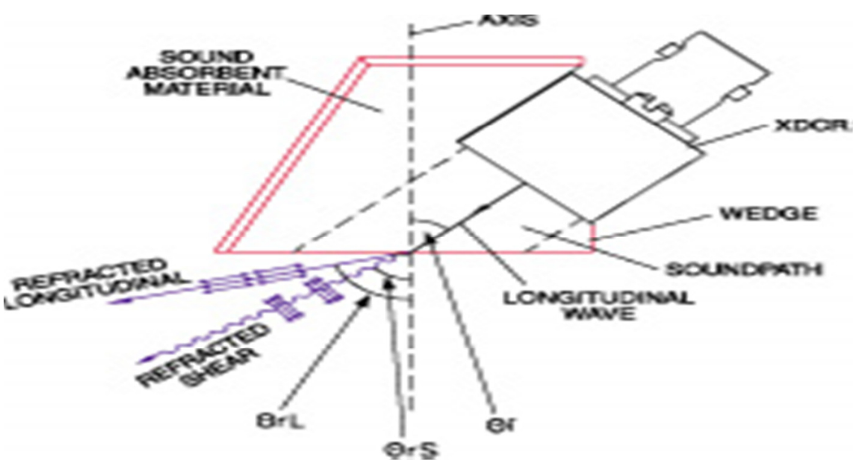
Ultrasonic flaw detection is basically a comparative technique. Using appropriate reference standards along with a knowledge of sound wave propagation and generally accepted test procedures, a trained operator identifies specific echo patterns corresponding to the echo response from good parts and from representative flaws. The echo pattern from an test piece may then be compared to the patterns from these calibration standards to determine its condition. Straight Beam Testing -- Straight beam testing utilizing contact, delay line, dual element, or immersion transducers is generally employed to find cracks or delaminations parallel to the surface of the test piece, as well as voids and porosity. It utilizes the basic principle that sound energy traveling through a medium will continue to propagate until it either disperses or reflects off a boundary with another material, such as the air surrounding a far wall or found inside a crack. In this type of test, the operator couples the transducer to the test piece and locates the echo returning from the far wall of the test piece, and then looks for any echoes that arrive ahead of that backwall echo, discounting grain scatter noise if present. An acoustically significant echo that precedes the backwall echo implies the presence of a laminar crack or void. Through further analysis, the depth, size, and shape of the structure producing the reflection can be determined.

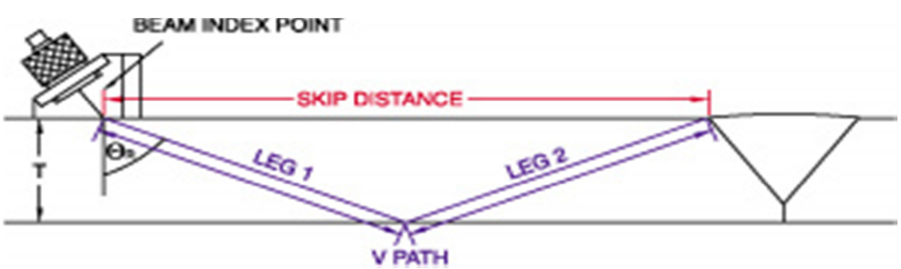


Sound energy will travel to the far side of a part, but reflect earlier if a laminar crack or similar discontinuity is presented. In some specialized cases, testing is performed in a through transmission mode, where sound energy travels between two transducers placed on opposite sides of the test piece. If a large flaw is present in the sound path, the beam will be obstructed and the sound pulse will not reach the receiver.
- Angle Beam Testing - Cracks or other discontinuities perpendicular to the surface of a test piece, or tilted with respect to that surface, are usually invisible with straight beam test techniques because of their orientation with respect to the sound beam. Such defects can occur in welds, in structural metal parts, and many other critical components. To find them,

angle beam techniques are used, employing either common angle beam (wedge) transducer assemblies or immersion transducers aligned so as to direct sound energy into the test piece at a selected angle. The use of angle beam testing is especially common in weld inspection. Typical angle beam assemblies make use of mode conversion and Snell's Law to generate a shear wave at a selected angle (most commonly 30, 45, 60, or 70 degrees) in the test piece. As the angle of an incident longitudinal wave with respect to a surface increases, an increasing portion of the sound energy is converted to a shear wave in the second material, and if the angle is high enough, all of the energy in the second material will be in the form of shear waves. There are two advantages to designing common angle beams to take advantage of this mode conversion phenomenon. First, energy transfer is more efficient at the incident angles that generate shear waves in steel and similar materials. Second, minimum flaw size resolution is improved through the use of shear waves, since at a given frequency, the wavelength of a shear wave is approximately 60% the wavelength of a comparable longitudinal wave**.**

Typical Angel beam assembly





The angled sound beam is highly sensitive to cracks perpendicular to the far surface of the test piece (first leg test) or, after bouncing off the far side, to cracks perpendicular to the coupling surface (second leg test). A variety of specific beam angles and probe positions are used to accommodate different part geometries and flaw types, and these are described in detail in appropriate inspection codes and procedures such as ASTM E-164 and the AWS Structural Welding Code.

Radiography

In Radiography Testing the test-part is placed between the radiation source and film (or detector). The material density and thickness differences of the test-part will attenuate (i.e. reduce) the penetrating radiation through interaction processes involving scattering and/or absorption. The differences in absorption are then recorded on film(s) or through an electronic means. In industrial radiography there are several imaging methods available, techniques to display the final image, i.e. Film Radiography, Real Time Radiography (RTR), Computed Tomography (CT), Digital Radiography (DR), and Computed Radiography (CR).

There are two different radioactive sources available for industrial use; X-ray and Gamma-ray. These radiation sources use higher energy level, i.e. shorter wavelength, versions of the electromagnetic waves. Because of the radioactivity involved in radiography testing, it is of paramount importance to ensure that the Local Rules is strictly adhered during operation.

Computed Tomography (CT) is one of the lab based advanced NDT methods that TWI offers to industry. CT is a radiographic based technique that provides both cross-sectional and 3D volume images of the object under inspection. These images allow the internal structure of the test object to be inspected without the inherent superimposition associated with 2D radiography. This feature allows detailed analysis of the internal structure of a wide range of components.

Benefits

- Can inspect assembled components
- Minimum surface preparation required
- Detects both surface and subsurface defects
- Provides a permanent record of the inspection
- Verify internal flaws on complex structures
- Isolate and inspect internal components
- Automatically detect and measure internal flaws
- Measure dimensions and angles within the sample without sectioning
- Sensitive to changes in thickness, corrosion, flaws and material density changes

Applications

Radiographic Testing is widely used in the;

- Aerospace industries
- Military defence
- Offshore industries
- Marine industries
- Power-gen industries
- Petrochem industries
- Waste Management
- Automotive industries
- Manufacturing industries
- Transport industries