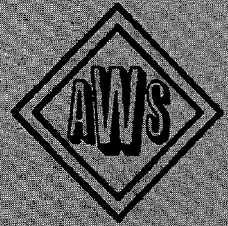


CHAPTER 9:

WELDING, BRAZING AND CUTTING PROCESSES



Introduction

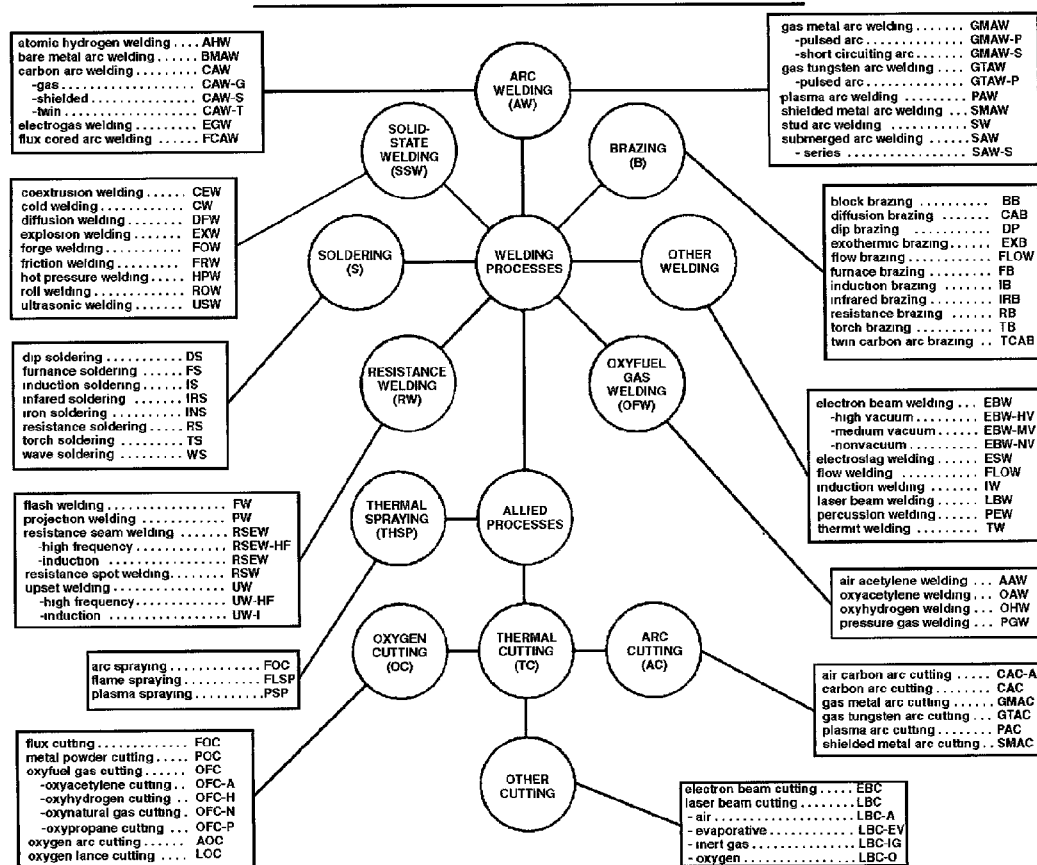
This chapter covers the relevance of welding, brazing and cutting processes to inspection. The information in the previous chapters will be summarized for each of the welding, brazing and cutting processes named in ANSI/AWS QC-1, *Standard for AWS Certification of Welding Inspectors*. Other limiting factors associated with each process will also be covered. Each of the processes will be treated as follows:

- Weldability
- Welding metallurgy
- Welding chemistry
- Limiting factors
- Discontinuities
- Inspection processes

Limiting Factors

In addition to the considerations covered in previous chapters, each welding process has certain other limiting factors which make it a

MASTER CHART OF WELDING AND ALLIED PROCESSES



better choice for some applications than others. It may have been the obvious choice, but usually the selection is a compromise chosen because of cost and quality factors.

Whatever process is specified by the engineer, both the welding inspector and the welder must also be aware of the limiting factors for the specific job, so that both can anticipate and overcome the factors that could cause discontinuities or other more serious problems. In addition to weldability, these other factors influence the selection of a welding process:

- Dimensions of material being welded, especially thickness, and its shape and form
- The position in which welding must be done
- Requirements for the weld root
- Back side accessibility
- Joint preparation
- Availability of welding equipment, power sources, and fixtures
- Availability of welding consumables
- Availability of qualified welders and operators
- Quality level required
- Economics
- Safety

Dimensions of Material

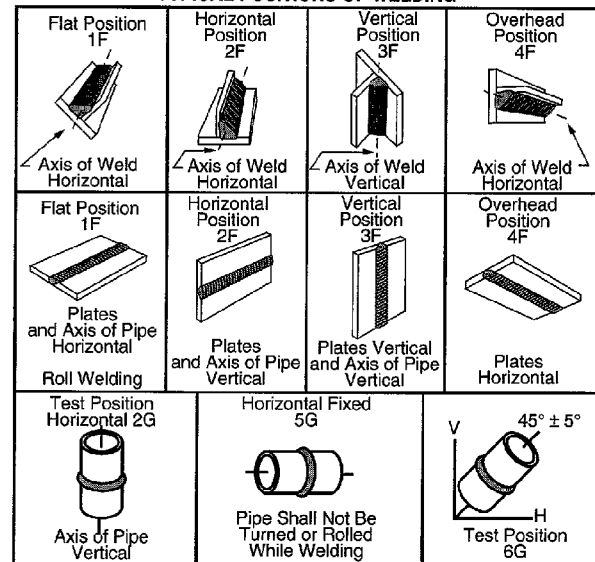
The dimensions of a metal limit the use of some processes and encourage use of others. For heavy sections, the engineer may select flux cored arc, submerged arc or electroslag welding. However, sheet metal is brazed, soldered, oxy-acetylene welded, resistance welded, gas tungsten arc welded, or gas metal arc welded.

Welding Position

When the position of the joints cannot be located for flat position welding, limits on the application of arc and gas welding processes are imposed by the force of gravity. The small weld

pool that must be used has little penetration, and the inspector may find slag inclusions and incomplete fusion as a result.

TYPICAL POSITIONS OF WELDING



Root Requirements

The root of the weld joint must be fused by one technique or another, unless partial penetration welds have been specified by the design. Processes with deep penetration such as submerged arc, flux cored arc and spray transfer gas metal arc welding are chosen by the engineer in preference to shielded metal arc welding if that will simplify the joint preparation.

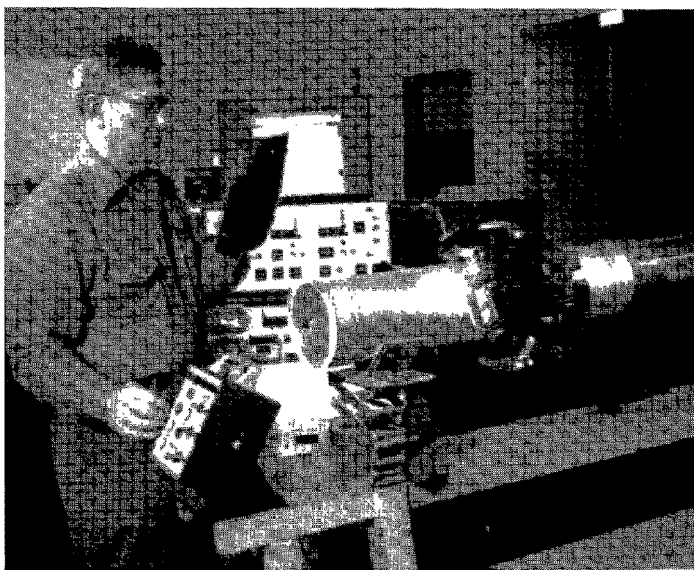
Root penetration in a tight butt joint welded by submerged arc welding in one pass from each side cannot be visually inspected. A joint which is backgouged to sound metal can be inspected with more confidence that the new root pass will fuse properly. The inspector relies on radiography and ultrasonic examination for volumetric inspection of such welds.

Back Side Accessibility

The accessibility of the back side of a joint strongly influences the choice of process. If inadequate aid is provided to the welder, he will

need superb skill in making a root pass from one side of the joint. Such a weld made carelessly commonly displays incomplete fusion, incomplete joint penetration, excessive melt-thru, or other discontinuities.

Inaccessible roots are often welded using backing rings, consumable inserts, or automatic welding equipment. The inspector should expect to see good fit of the parts prior to welding from one side of the joint. A familiar example is the pipeline weld, traditionally deposited with E6010 type shielded metal arc electrodes. Radiographic inspection detects discontinuities in the root of many such welds.

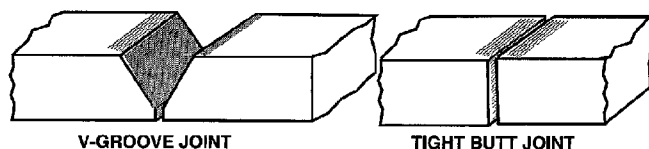


UNION CARBIDE LINDE DIVISION

Joint Preparation

The suitability of available joint preparation also influences the process choice. The square-groove butt joint of an electroslog weld is unsuited for manual welding. Suppose the equipment fails midway through an electroslog weld. Does the fabricator have standby equipment? A double-V-groove preparation may be welded manually with no difficulty.

The groove angle of V-groove welds in heavy plate must be opened wider for gas metal arc welding than for covered electrodes, to accommodate the nozzle of the gun. Unsuitable joint preparations in any of these cases spell trouble for the welder and possibly will create imperfections which the inspector must catch.



Availability of Welding Equipment

The availability of welding equipment obviously limits the choice of welding or cutting processes that can be considered for use, particularly in the field. Portability of the

equipment would determine the availability in field situations. In remote areas, the process to be used is dictated by the availability of fixtures, power sources and consumables.

To name some specific examples, gas tungsten arc welding without high frequency starting requires another welder skill level, using copper starting tabs or striking the arc within the joint. Arc decay is more of a problem without a foot-controlled rheostat. Gas metal arc welding in the short circuiting mode requires a special power supply. Pulsed arc welding requires a pulse generator. Thin sheets subject to warping need hold-down fixtures and chill bars unless welding speeds are high.

Consumables

Consumable materials, such as bare electrodes or proper chemical composition and shielding gases needed for gas metal arc welding, may not be available. Covered electrodes are more readily supplied, with alloying elements added through the coating; they require no external shielding.

Availability of Welding Talent

The availability of the best welding equipment does not guarantee the success of a weldment.

Welders trained and qualified to use the equipment and apply the best techniques must also be available. If the desired talent is not available, a less sophisticated process will have to do; for example, manual shielded metal arc instead of gas tungsten arc. Maintenance work frequently is done by oxyacetylene welding. Root pass gas tungsten arc welds may require less skill than gas metal arc root pass welds.

Quality Level Required

The quality level required for a weldment may rule out certain processes. For this reason, it is not practical to weld reactive metals with the oxyacetylene welding process, because excessive oxidation would result in an unacceptable weldment. In conditions where the highest quality level is required gas tungsten arc welding would be used for root passes in lieu of shielded metal arc or gas metal arc welding.

Economics

Cost analysis is the "bottom line" in selecting a welding process. Economics favor the efficiency gained from automatic and semiautomatic equipment over manual processes.

Safety

Although safety is the last factor to be covered here, it should be the first to be considered. Safety is linked to economic considerations because of the cost of unsafe situations in loss of life and equipment, and because of insurance and legal considerations.

Some of the safety factors to be considered include the mandatory use of various types of

LENS SHADE SELECTOR	
Operation	Shade number
Soldering	2
Torch brazing	3 or 4
Oxygen cutting	
Up to 25.4 mm (1 in.)	3 or 4
25.4 mm to 152.4 mm (1 to 6 in.)	4 or 5
152.4 mm (6 in.) and over	5 or 6
Gas welding	
Up to 3.2 mm (1/8 in.)	4 or 5
3.2 mm to 12.7 mm (1/8 in. to 1/2 in.)	5 or 6
12.7 mm (1/2 in.) and over	6 or 8
Shielded metal arc welding: 1.6 mm (1/16 in.), 2.4 mm (3/32 in.), 3.2 mm (1/8 in.), 4.0 mm (5/32 in.) electrodes	10
Gas tungsten arc welding (nonferrous)	
Gas metal arc welding (nonferrous): 1.6 mm (1/16 in.), 2.4 mm (3/32 in.), 3.2 mm (1/8 in.), 4.0 mm (5/32 in.) electrodes	11
Gas tungsten arc welding (ferrous)	
Gas metal arc welding (ferrous): 1.6 mm (1/16 in.), 2.4 mm (3/32 in.), 3.2 mm (1/8 in.), 4.0 mm (5/32 in.) electrodes	12
Shielded metal arc welding	
4.7 mm (3/16 in.), 5.6 mm (7/32 in.), 6.4 mm (1/4 in.) electrodes	12
7.9 mm (5/16 in.), 9.5 mm (3/8 in.) electrodes	14
Atomic hydrogen welding	10 to 14
Carbon arc welding	14

protective equipment such as: safety glasses, hardhats, steel-toed safety shoes, welding and cutting filter lenses, leather welding garments, etc.

Welding Processes

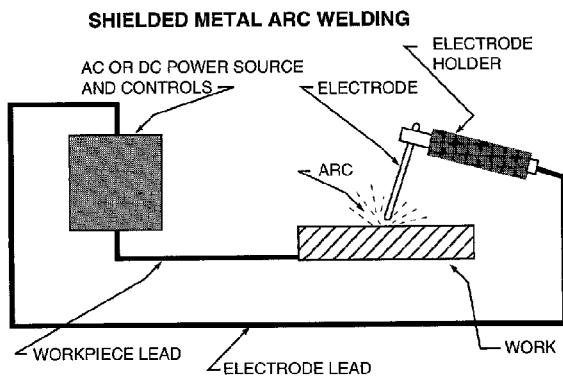
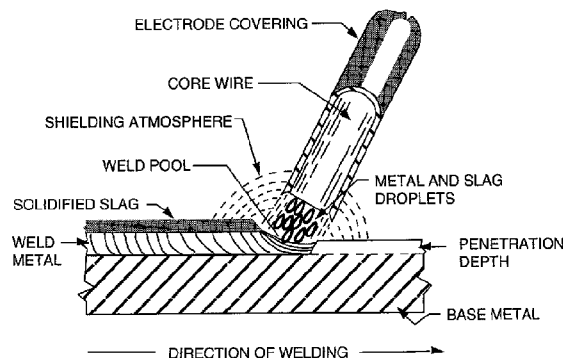
Welding is a process which results in the joining of metals through their melting together by application of heat, with or without the application of pressure, and with or without the addition of filler metal. The welding processes discussed here are those with which the welding inspector must be familiar for the AWS CWI examination. These processes include:

- Shielded Metal Arc Welding (SMAW)
- Gas Metal Arc Welding (GMAW)
- Flux Cored Arc Welding (FCAW)
- Gas Tungsten Arc Welding (GTAW)
- Plasma Arc Welding (PAW)
- Submerged Arc Welding (SAW)
- Electroslag Welding (ESW)
- Oxyacetylene Welding (OAW)
- Stud Welding (SW)

Shielded Metal Arc Welding (SMAW)

Shielded metal arc welding uses the heat of an electric arc between a covered metal electrode and the work. Shielding comes from the decomposition of the electrode flux coating. Filler metal is supplied by the electrode core wire and covering (iron powder and alloys).

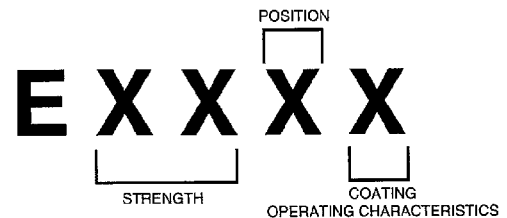
This process is usually manually applied, but it has sometimes been automated with a machine or gravity stick feeder. The basic equipment comprises a power source, cables, an electrode holder, a work clamp, and the electrode. Electrodes for shielded metal arc welding operate variously on alternating current, direct current electrode positive (reverse polarity) or direct current electrode negative (straight polarity)



TYPICAL WELDING CIRCUIT FOR SHIELDED METAL ARC WELD

Welding Metallurgy: A shielded metal arc weld is strengthened by adding alloying elements and by incorporating iron powder in the electrode covering. Unfortunately, some ingredients and the

binder in the covering may attract and hold moisture, a source of hydrogen, which causes cracking in certain welds. A group of electrodes specifically formulated to result in weld deposits having very low levels of hydrogen are referred to as "low hydrogen." Those electrode classifications considered to be low hydrogen have identifications ending with the numbers 5, 6 or 8. Once removed from their sealed shipping containers, they require electrically-heated storage in a vented oven capable of holding the electrodes at temperatures between 250-350° F.



SMAW ELECTRODE IDENTIFICATION SYSTEM

Welding Chemistry: The inspector should understand the many functions of the electrode covering:

- Arc stabilization from ionizing elements (which dictate the usability of the electrode on AC, DCEP or DCEN)
- Gas shielding from decomposition of such ingredients as cellulose and limestone
- Fluxing of oxides from the work surface
- Deoxidation of deposited weld metal to reduce the tendency for porosity
- Slag protection over the cooling weld metal, resulting in slower cooling rates to improve weld properties
- Strengthening the weld metal by supplying alloying elements
- Increased weld metal deposition by incorporation of iron powder (up to 50% of covering)

Limiting Factors: All of the welding manipulations are controlled by the welder:

Classification	Current	Arc	Penetration	Covering & Slag	Iron Powder
F3 EXX10	DCEP	Digging	Deep	Cellulose-sodium	0-10%
F3 EXXX1	AC & DCEP	Digging	Deep	Cellulose-potassium	0
F2 EXXX2	AC & DCEN	Medium	Medium	Rutile-sodium	0-10%
F2 EXXX3	AC & DC	Light	Light	Rutile-potassium	0-10%
F2 EXXX4	AC & DC	Light	Light	Rutile-iron powder	25%-40%
F4 EXXX5	DCEP	Medium	Medium	Low hydrogen-sodium	0
F4 EXXX6	AC or DEEP	Medium	Medium	Low hydrogen-potassium	0
F4 EXXX7	AC or DCEP	Medium	Medium	Low hydrogen-iron powder	25%-40%
F1 EXX20	AC or DC	Medium	Medium	Iron oxide-sodium	0
F1 EXX24	AC or DC	Light	Light	Rutile-iron powder	50%
F1 EXX27	AC or DC	Medium	Medium	Iron oxide-iron powder	50%
F1 EXX28	AC or DCEP	Medium	Medium	Low hydrogen-iron powder	50%

Note: Iron powder percentage based on weight of covering.

Significance of Last Digit of SMAW Identification

electrode inclination, arc length, travel speed, weaving, or backstepping. The welder must set the proper welding current at his power source and select the polarity (if direct current).

For safety, the inspector must not watch the electric arc without the protection of No. 10 or 12 filter lenses (No. 14 if the welder is using more than 400 amperes). Safety glasses with side shields are needed for protection from slag when being removed from the weld face. The inspector and the welder need forced ventilation when working in confined areas.

Discontinuities: Almost any discontinuity can be produced by the shielded metal arc welding process, if not applied properly. Porosity is most likely caused by faulty technique, or by contaminated base metal or electrode (moisture). Cluster porosity (sometimes referred to as starting porosity) often occurs at the initiation and termination of the arc. Back stepping at the start permits the experienced welder to remelt his cold start area and float the gas out of the weld metal. Piping porosity (also called wormhole or elongated porosity) is often found in both single pass fillet welds and groove welds produced at high welding speeds, especially if the joint is contaminated.

Slag inclusions are most often the result of improper welding technique, through insufficient

interpass cleaning or faulty manipulation of the electrode. If the designer has provided insufficient access for welding within the joint, slag inclusions could result.

Incomplete fusion suggests inadequate welding current or difficult access to the joint, especially in multiple pass welds. It may also be a consequence of improper joint preparation, such as insufficient groove angle.

Incomplete joint penetration is normally the result of an excessive root face, insufficient welding current or insufficient root opening. Joint designs should not overestimate the penetration ability of the process.

Undercut, underfill and overlap are all due to welder errors. Traveling too fast will cause undercut, as will excessive welding currents. Travelling too slow will produce overlap.

Lamellar tearing is not the fault of the welder. This discontinuity normally results from low quality steel plates or an improper joint design for joining heavy sections. Use of massive amounts of weld metal in a joint design which results in high shrinkage stresses in the through-thickness direction of rolled plate or structural shapes will often cause lamellar tearing.

Shielded metal arc welds may fail by either hot or cold cracking. Hot cracks include crater, root and throat (or longitudinal) cracks. They result from the high stresses associated with weld

shrinkage when cooling from welding temperatures. Materials susceptible to "hot-shortness" are particularly prone to these types of cracks. When they appear, changes in technique (perhaps a thicker bead) or changes in materials are needed.

Toe and underbead cracks are forms of cold cracks. Toe cracks often arise when a weldment is subjected to fatigue loads, especially when the presence of excessive weld reinforcement or convexity results in an acute reentrant angle at the toe. Underbead cracks (and toe cracks, at times) are the result of hydrogen being present in the weld zone. They are also referred to as delayed cracks because they may not appear until many hours after the weld has cooled to room temperature. Sources of the hydrogen that contributes to these cracks include damp electrodes, humid conditions and dirty surfaces.

Inspection Processes: All of the usual inspection processes are used to detect discontinuities in shielded metal arc welds.

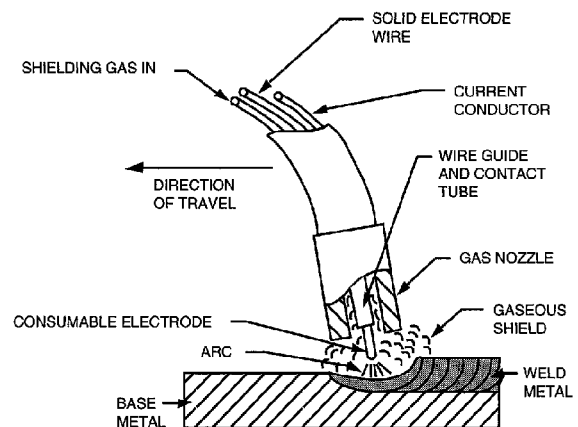
Gas Metal Arc Welding (GMAW)

Gas metal arc welding (sometimes called metal inert gas or MIG) uses the heat of an electric arc between a continuous bare wire filler metal electrode and the work. Shielding is obtained entirely from an externally supplied gas or gas mixture.

This can be a semiautomatic, machine, automatic, or automated process. In the semiautomatic mode, the welder controls the inclination and distance of his gun from the work, and the travel speed and manipulation of the arc. Arc length and electrode feed are controlled automatically by the power source and wire feeder controller.

The gas metal arc process deposits the weld metal in the joint by one of the following modes: spray transfer, globular, short circuiting transfer, and pulsed arc welding.

Spray transfer occurs with high current and voltage combinations, when there is at least 80% argon present in the shielding gas. For each electrode size, there is a threshold current above which the metal pinches off in fine droplets many times a second. The current propels the droplets axially down the center of the arc, away from the



GAS METAL ARC WELDING PROCESS

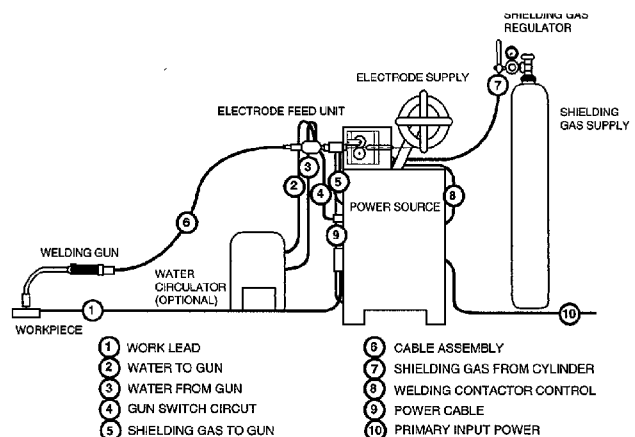
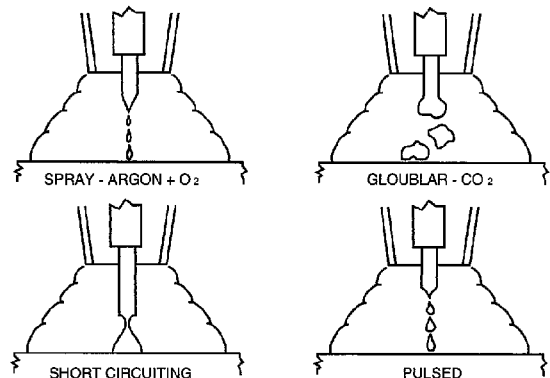


DIAGRAM OF GAS METAL ARC WELDING EQUIPMENT



THE FOUR TYPES OF METAL TRANSFER

electrode, straight into the pool. Spray transfer mode best defines the arc and the pool for the welder. It requires high current relative to the diameter of the electrode. Due to its high heat capacity, this mode of transfer is best suited for flat and horizontal position welding.

Globular transfer occurs at low currents compared to spray transfer—low, that is, in relation to the size of the electrode. Low current density at the electrode tip produces large, irregular drops of metal that transfer to the pool without much direction. The result is increased amounts of spatter compared to spray transfer.

Short circuiting transfer requires a power source having sufficient secondary inductance to prevent excessive spatter. As the electrode melts, each drop shorts out the arc during its transfer to the pool, but the electrical impedance built into the power source prevents the welding current from spattering the bridging drop. The short circuiting mode is a relatively cold process, and its misapplication may result in incomplete fusion. It readily bridges gaps. Sheet metal can be welded without excessive melt-through and welds may be made in all positions.

Pulsed Arc welding maintains a low current arc as the background condition and injects high current pulses upon that current. Transfer of filler metal is by spray of droplets during each pulse. Pulsing the power lowers the average heat input from the current. Out-of-position welding then becomes possible using larger wire sizes.

Welding Chemistry: Shielding gases protect gas metal arc welds from the atmosphere. Fluxes are not used in this process. All deoxidizers and

alloying elements are incorporated into the electrode wire.

Limiting Factors: The semiautomatic features of gas metal arc welding simplify the training of the welder and should make his work more consistent. However, the short circuiting mode may lead to incomplete fusion. The welding inspector should recognize that joints welded by this process are not prequalified under AWS D1.1, Structural Welding Code- Steel. The contractor must demonstrate that the welding procedure to be used under short circuiting conditions will indeed produce satisfactory welds, with adequate fusion.

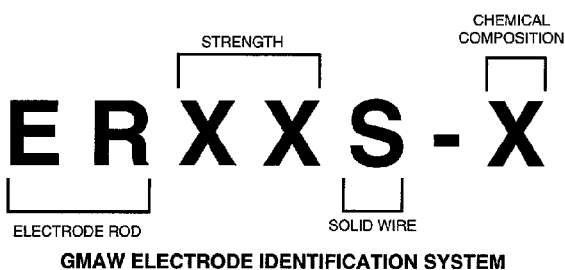
For safety, the inspector exposed to a nearby welding arc must have protective clothing against arc burn, and he must not watch the arc without eye protection from No. 12 filter lenses (No. 14 if welding current exceeds 400 amperes). The lens may be in a helmet or hand-held shield. When the welder is welding in a confined area, ventilation must be provided; however, that ventilation must not be such that it disrupts the gas shielding.

Discontinuities: Gas metal arc welding may result in any of the common weld discontinuities, with the exception of slag inclusions.

Porosity, which is caused by gas trapped in the weld, is often caused by improper gas shielding. The shielding gas must displace the surrounding atmosphere, which contains oxygen and nitrogen. Welding without adequate shielding permits atmospheric oxygen and nitrogen to dissolve in the molten metal. Use of excessive shielding gas flow rates will also lead to the production of porosity due to the vortex action produced which tends to draw atmospheric gases into the arc region.

Incomplete fusion is possible, especially in welds made with short circuiting transfer. It may occur with globular transfer or even with pulsed or spray transfer at low current levels if the welder fails to properly manipulate the welding arc.

Incomplete joint penetration is more likely to occur with short circuiting and globular transfer



than with spray conditions. The spray arc in argon results in good penetration when properly directed into the joint.

The presence of undercut and underfill reflect poor technique by the welder. Overlap is more prevalent in globular transfer and with the short circuiting arc.

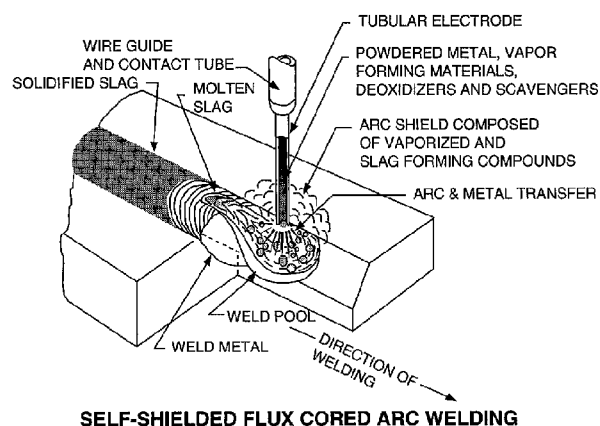
Opening up of seams, laps, laminations, and lamellar tears is to be expected where welds are constrained. High stresses occur because of the rapid heating and cooling that accompany arc welding.

Cracks are to be expected in the weld metal if improper joint designs are used. Moreover, there is one type of crack peculiar to gas metal arc welding. It occurs beside the deeply penetrating finger of weld metal under a weld made with argon shielding, and it is strictly due to the unusual stress pattern created by the shape of the bead and the rapid heating and cooling that occur.

Inspection Processes: The inspection processes for evaluation of discontinuities in gas metal arc welds include nondestructive test methods for cracks in the heat affected zone, visual, magnetic particle and penetrant examination of cracks open to the surface, and radiographic, ultrasonic and magnetic particle inspection for sub-surface cracks. Radiography and ultrasonic testing are also utilized for the discovery of other types of subsurface discontinuities.

Flux Cored Arc Welding (FCAW)

Flux cored arc welding uses the heat of an arc between a continuous filler metal electrode and the work, as in gas metal arc welding. However, shielding is obtained, in whole or in part, from a flux contained within the tubular electrode. Self-shielded electrodes require no external gas protection, while other flux cored electrodes use additional external gas shielding, commonly carbon dioxide, supplied through the welding gun.



NOTE: GAS SHIELDING IS OPTIONAL

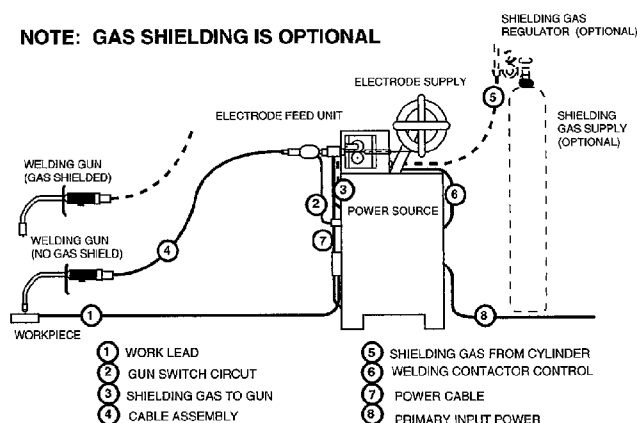
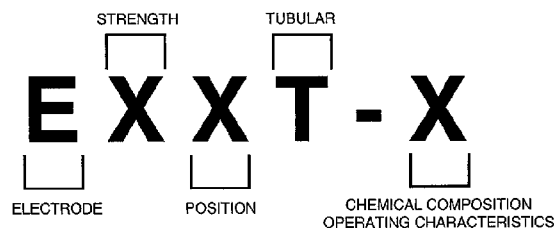


DIAGRAM OF FLUX CORED ARC WELDING EQUIPMENT

Welding Chemistry: The flux cored arc welding electrode contains flux, deoxidizers, alloying elements, and sometimes denitrifiers within the tubular wire. If external shielding is provided, the choice of shielding gas is usually carbon dioxide (CO_2) because of its low cost plus its ability to improve the penetration characteristics of the weld pass. Carbon dioxide is an active gas (rather than being inert like argon or helium); strong deoxidizers must be present in the electrode to produce a sound weld. Under self-shielding conditions even more protection must be



FCAW ELECTRODE IDENTIFICATION SYSTEM

built into the flux core. Gas mixtures are used to combine the separate advantages of two or more gases. Thus 75% argon-25% carbon dioxide may be used to improve the operating characteristics of the arc plus provide excellent mechanical properties of the finished weld.

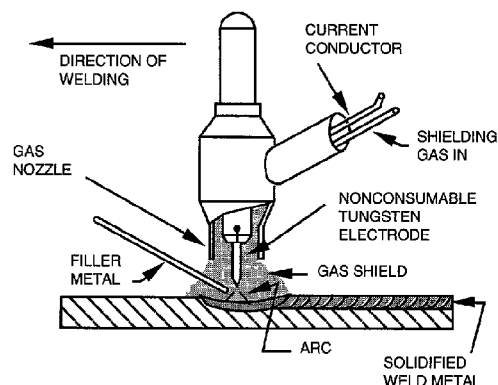
Limiting Factors: Uniform quality is required in the flux cored electrodes. Any undesired irregularity in the structure of the flux cored electrode will introduce faults into the weld deposit. Since the wire is tubular and the absorption of moisture by the flux is possible, weld porosity may result if the electrode is improperly stored. Evidence of poor storage of the electrode coils in the shop should alert the inspector to this possibility.

Normal safety precautions, including eye protection (No. 12 filter lens) and sufficient ventilation, are necessary for the welding process. Safety goggles with side shields are also required when working in the vicinity where slag is being chipped from beads.

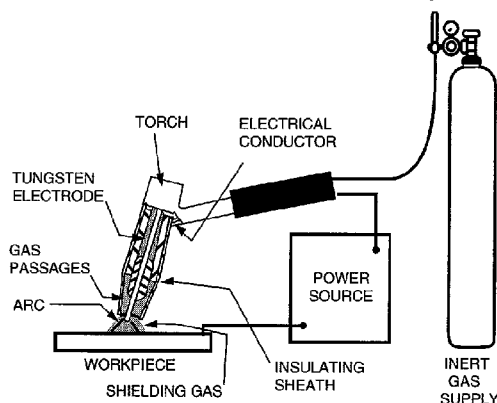
Discontinuities: Discontinuities mainly involve porosity and slag inclusions. Any unexpected porosity or bead irregularity that the welder cannot acknowledge as his fault may indicate a void in the flux core, deficiency of some ingredient in the flux, or improper storage conditions. The slag produced by the internal flux naturally increases the chance for slag inclusions, especially when the welder tends to travel too slowly for a given set of operating conditions.

Gas Tungsten Arc Welding (GTAW)

Gas tungsten arc welding (sometimes referred to as tungsten inert gas, or TIG welding) uses an electric arc between a nonconsumable electrode and the work. Shielding is obtained from an inert gas or inert gas mixture, except in the case where argon-hydrogen gas mixtures are used for some stainless steel applications. Filler metal may be added as needed. The torch is usually water-



GAS TUNGSTEN ARC WELDING OPERATION



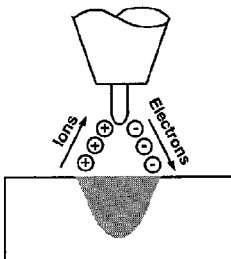
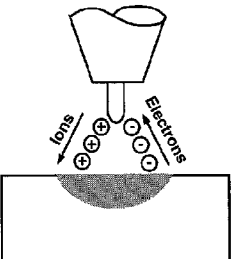
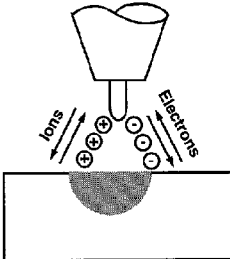
GAS TUNGSTEN ARC WELDING EQUIPMENT

cooled, but may be air-cooled for low current applications.

This type of welding may be accomplished by manual, mechanized or automatic methods. When filler metal is added, the process calls for a two-handed technique, as in oxyacetylene welding. Cold-wire and hot-wire feeds are automated versions of that technique.

Welding Metallurgy: The slow heating and lower temperatures combined with slower cooling rates characteristic of GTAW will result in improved weld metal and heat-affected zone mechanical properties. Welds may be made without filler metal when the edges of the joint provide sufficient material and deoxidizers.

Welding Chemistry: The tungsten electrode contributes neither deoxidation nor fluxing, so it is fortunate that the melting is essentially slow and

CURRENT - TYPE	DC	DC	AC (balanced)
ELECTRODE POLARITY	Negative	Positive	
ELECTRON AND ION FLOW			
PENETRATION CHARACTERISTICS			
OXIDE CLEANING ACTION	NO	YES	YES - Once every half cycle
HEAT BALANCE IN THE ARC (approx.)	70% At work end 30% At electrode end	30% At work end 70% At electrode end	50% At work end 50% At electrode end
PENETRATION	Deep; narrow	Shallow; wide	Medium
ELECTRODE CAPACITY	Excellent (e.g. 3.18 mm [1/8 in.] - 400 A)	Poor (e.g. 6.35mm [1/4 in.] - 120 A)	Good (e.g. 3.18 mm [1/8 in.] - 225 A)

EFFECT OF WELDING CURRENT TYPE ON PENETRATION FOR GAS TUNGSTEN ARC WELDING

that most of the gases evolved can escape from the weld pool before it freezes. The corrosion resistant oxide film on aluminum and aluminum alloys, and on magnesium and its alloys, can be removed by the argon-shielded gas tungsten arc or gas metal arc using direct current, electrode positive. In alternating current operation, this occurs every half cycle, and arc re-ignition is normally accomplished by a superimposed high frequency current.

Filler rod containing the needed deoxidizers may be added manually or by the use of a wire feeder for mechanized applications.

When fully shielded by argon or helium, the tungsten electrode is not noticeably consumed, although some evaporation occurs while it is hot. The hot tip may become molten. Thoriated or zirconia-treated tungsten more readily emits

electrons and has a smaller molten spot. This tends to improve the life expectancy of these types of electrodes compared to that of pure tungsten electrodes.

Limiting Factors: The outstanding feature of the gas tungsten arc welding process is the exceptional cleanliness that can be obtained in the weld deposits, producing crack-free welds in alloys that are difficult to weld by other processes. However, the process has its limiting factors. For example, the skill level necessary to produce high quality welds is only acquired by long experience in manipulating the electrode and feeding the filler wire (when used).

Without skillful control, incomplete fusion, incomplete joint penetration, overlap, and cracking are possible. Another drawback is the possibility of tungsten from the electrode entering the weld,

AWS TUNGSTEN ELECTRODE CLASSIFICATIONS		
AWS CLASSIFICATION	ALLOY	COLOR
EWP	Pure Tungsten	Green
EWTh-1	0.8-1.2% Thoria	Yellow
EWTh-2	1.7-2.2% Thoria	Red
EWTh-3	0.35-0.55% Thoria	Blue
EWZr	0.15-0.40% Zirconia	Brown
EWCe-2	1.8%-2.2% Ceria	Orange

through inadvertent touching of the electrode to the molten puddle by the welder.

Specialized equipment and consumables are available for automated welding. Thoriated or zirconia-treated tungsten electrodes are used for improved arc stability. Argon and helium are the preferred shielding gases.

For safety from the brilliant visible arc of this process, the inspector must have protective clothing against arc burn and a shield with No. 12 filter lenses (No. 14 for over 400 amperes). Ventilation is needed in confined areas, but it should not disturb the shielding gas.

Discontinuities: All of the common types of discontinuities are possible with gas tungsten arc welding, with the exception of slag inclusions.

Porosity is a common discontinuity due to the process' low tolerance for contamination. Impurities on the surface or within the base metal readily lead to porosity if no deoxidizers are introduced into the weld pool. Loss of shielding gas will also result in the creation of porosity.

Tungsten inclusions may result from accidental touching of the tungsten electrode to the weld pool. The hot tip may have a molten spot to which the arc is attached. The molten drop is readily transferred to the pool, thus producing a tungsten inclusion in the weld. Use of excessive welding currents for a given electrode diameter can also contribute to the deterioration of the electrode and result in tungsten inclusions. The use of a "scratch-start" technique in the absence of high frequency current may also result in the production of this discontinuity. Whether such inclusions are rejectable depends on the governing specifications.

Incomplete fusion or incomplete joint penetration may be encountered if the welder's technique is poor. The penetration of the arc in gas tungsten arc welding is relatively low; arc voltage and penetration can be increased by helium additions to the shielding gas. For this

reason, only those joints designed especially for gas tungsten arc welding should be specified.

Undercut, underfill and overlap as well as trouble with laminations, seams and laps can occur as with other welding processes.

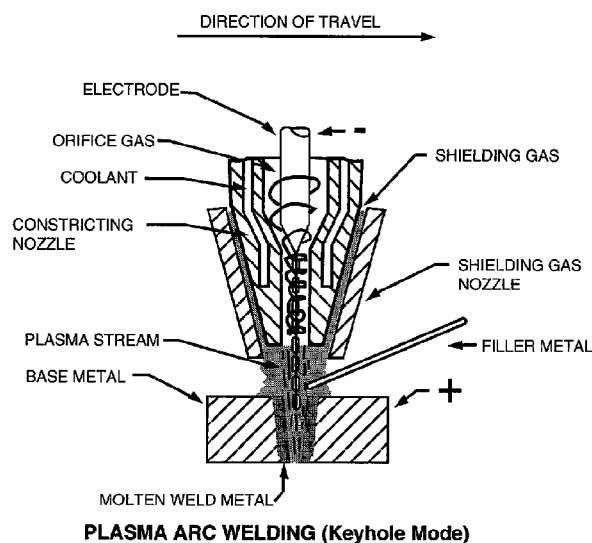
Cracks are usually hot cracks in gas tungsten arc welds. Longitudinal cracking may occur in deposits made at high travel speeds. Crater cracks are prevalent due to improper control of the welding current at the termination of the weld. A hand- or foot-operated current control is usually used to provide proper welding and slope control.

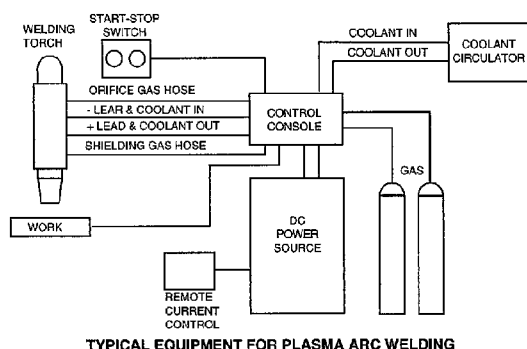
Cold cracking due to hydrogen in the weld metal could be caused by the presence of moisture or contamination which produces hydrogen. This type of cracking could also result from the presence of high stresses in the weld zone.

Inspection Processes: All inspection processes are used, especially radiography when tungsten inclusions are to be detected.

Plasma Arc Welding (PAW)

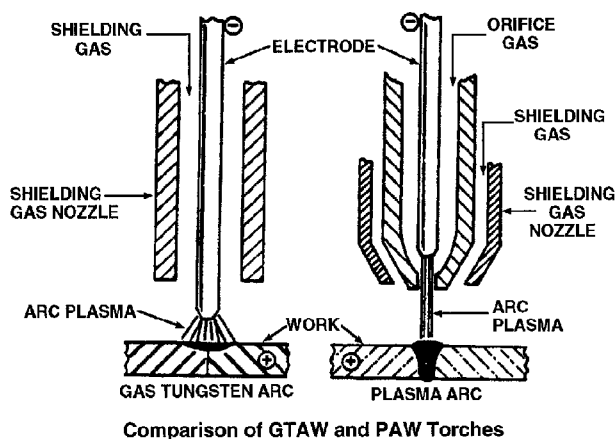
Plasma arc welding is a process which utilizes a constricted arc between the electrode and the workpiece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc). In many respects, this process is quite similar to gas





tungsten arc welding; however, the constricted arc provides a much more localized heat source.

Shielding for this process is obtained from the hot, ionized gas issuing from the torch which may be supplemented by an auxiliary source of shielding gas. This shielding gas may be inert gas or a mixture of gases. There is no pressure utilized and filler metal may or may not be required.



Like the gas tungsten arc process, plasma arc welding uses a tungsten electrode, but it is recessed into the torch. In most respects, the application of this process is identical to gas tungsten arc welding, so the previous comments relative to GTAW will be applicable.

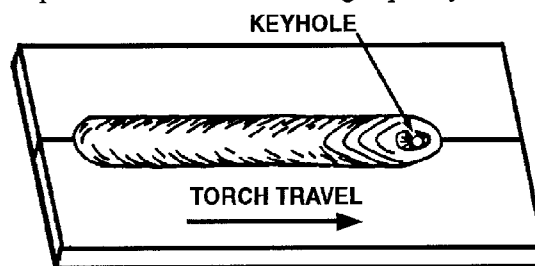
Welding Metallurgy: The constricted arc produces a more localized heat source which results in the ability to weld materials at higher travel speeds than those obtainable with gas tungsten arc welding. This will tend to reduce the

heat input which will result in faster heat affected zone cooling rates. This might increase the heat affected zone hardness in some materials to the degree that cracking might result. Like gas tungsten arc welding, filler metal addition may not be necessary if the edges of the base metals are melted and fused together.

Welding Chemistry: Since the tungsten electrode is not intended to be consumed, it contributes neither deoxidation nor fluxing to the molten metal. Filler metals to be used should contain deoxidizers to reduce the tendency for the production of porosity. Base and filler metal cleanliness is also important for this process, as with gas tungsten arc welding.

Limiting Factors: All those items mentioned for gas tungsten arc welding are appropriate for plasma arc welding as well. The constricted arc is less sensitive to changes in arc length, plus the distance from the torch to the work is longer than that for gas tungsten arc welding. Both of these factors tend to make the plasma arc welding process slightly easier to control manually.

One variation of plasma arc welding used for producing complete joint penetration groove welds is referred to as the "keyhole" technique. With this method, welding is performed on a square-groove butt joint with zero root opening. The concentrated heat of the arc penetrates through the material thickness to form a small keyhole. As welding progresses, the keyhole moves along the joint melting the edges of the base metal which then flow together and solidify after the welding arc passes. This creates a high quality weld, with



Keyhole Technique for Plasma Arc Welding

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no elaborate joint edge geometry and faster welding travel speeds compared to gas tungsten arc welding. The application of this technique is limited to materials 1 inch and less in thickness.

The faster welding speeds obtainable with this method will tend to reduce the amount of distortion present after welding.

Discontinuities: All of the discontinuities mentioned in the previous discussion of gas tungsten arc welding are also applicable for plasma arc welding.

There is a reduced tendency for tungsten inclusions with plasma arc welding due to the fact that the tungsten is recessed in the torch. Use of excessive welding currents may cause overheating of the copper constricting nozzle, resulting in copper inclusions in the weld.

Since the arc is constricted, mis-tracking of the joint is quite possible, resulting in incomplete fusion, especially when the keyhole technique is being used.

Another discontinuity unique to plasma arc welding with the keyhole technique is commonly referred to as "tunneling." This is simply a pore oriented through the weld throat at the termination of a keyhole weld. It results when the welder fails to properly fill the keyhole at the weld termination.

Inspection Processes: All inspection processes are used for examination of plasma arc welds.

Submerged Arc Welding (SAW)

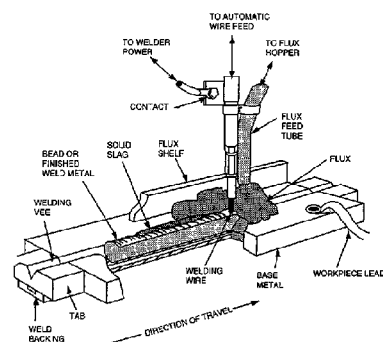
Submerged arc welding uses the heat of an electric arc or arcs between the electrode or electrodes and the work, all buried beneath a shielding blanket of granular flux.

Welding under a granular flux is a semiautomatic, mechanized or automatic process in which electrode feed and arc length are controlled by the wire feeder and power supply. In automatic welding, a travel mechanism moves

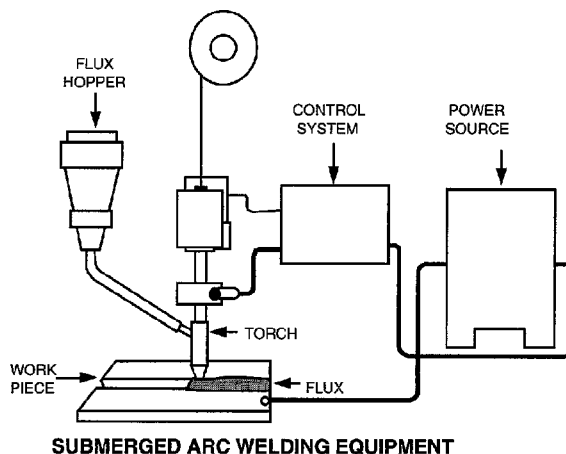
either the torch or the work, and normally a flux recovery system recirculates the unfused granular flux back to the flux hopper for reuse.

The arc is hidden in submerged arc welding, which frees the welder or operator from his helmet but hides the path he must follow. For machine or automatic welding, the path is prealigned or a seam-tracking apparatus controls the orientation of the torch relative to the joint centerline. In semiautomatic submerged arc welding, the gun is actually moved along the joint in contact with the faces of the work (usually a T-joint or groove weld) to control the location of the weld. This process may produce deep penetration by the arc. Straight butt joints may be welded in metal 1 inch thick in one pass from each side with complete joint penetration if the joint is accurately followed and the current density is high.

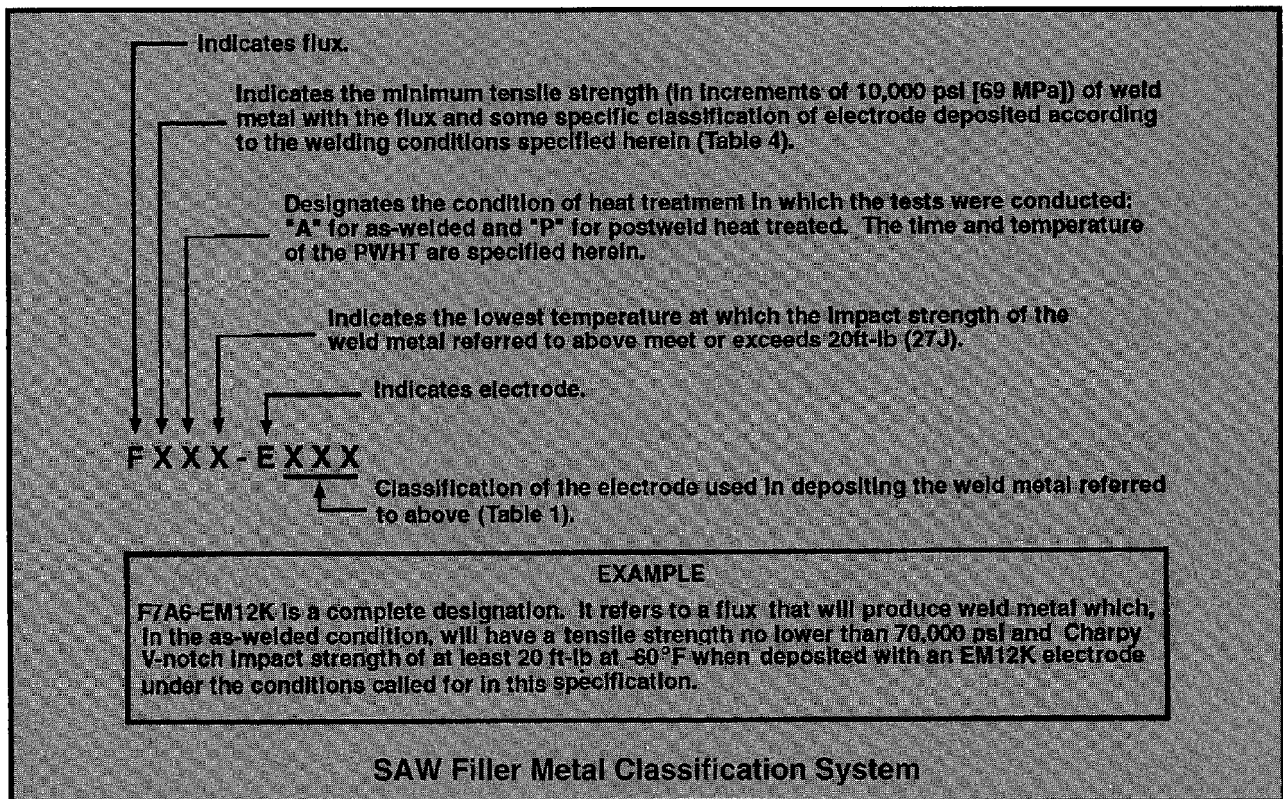
Welding Metallurgy: The high heat input of this process produces rapid heating and cooling.



SCHEMATIC VIEW OF SUBMERGED ARC WELDING PROCESS



SUBMERGED ARC WELDING EQUIPMENT



Sound welds are deposited rapidly and economically, with excellent metallurgical properties.

Welding Chemistry: The weld composition results from contributions from the melted base metal and the electrode, modified by chemical reactions with the flux and alloys added through the flux. Since the flux and filler wire are independently dispensed in this process, great flexibility in obtaining weld properties is possible. The inspector must make sure that the proper wire and flux combination is used to obtain the correct weld composition. Shop dirt, grease or moisture can contaminate the flux, resulting in cracks. Some fluxes require heated storage containers and hoppers to assure that the flux is dry when used.

Limiting Factors: Cleaning of the work surfaces and aligning of the machine travel with the joint are particularly important in submerged arc welding. Improper alignment will result in

offset beads with incomplete joint penetration. In a highly restrained joint, joint misalignment may also cause cracks.

Welding operators are needed who are trained in controlling the variables of the process. For example, a change in the proportion of flux or arc voltage will change the weld composition.

For safety, goggles are required, but filter plates are not necessary because the arc is not visible.

Discontinuities: Welds may exhibit all of the common discontinuities. Porosity is often encountered in submerged arc welds because of the high travel speeds and rapid freezing which results. Related discontinuities, perhaps of only minor importance but hard to overlook because they are so visible, are gas dents on the bead surface. They are caused by large bubbles of gas trapped beneath the solidified slag while the metal is still molten. Changes in flux granulation (fewer fines), changes in composition, or reduction in the

height of the granular flux blanket will tend to reduce this occurrence. Cleaning the work surfaces, slowing the travel speed or using a more highly deoxidized electrode may cure internal porosity.

Slag inclusions are found in many submerged arc welds. Convex bead profiles in multiple pass welds are frequently the cause. Convex beads leave narrow pockets against prior beads and along the groove faces in which slag will cling or within which new slag will become trapped under the next bead.

Incomplete fusion may occur in attempting too large a weld in one pass or in welding too fast. Incomplete joint penetration also occurs when the welding arc is carelessly aligned with the joint.

Undercut is not uncommon in submerged arc welding when high welding currents are used.

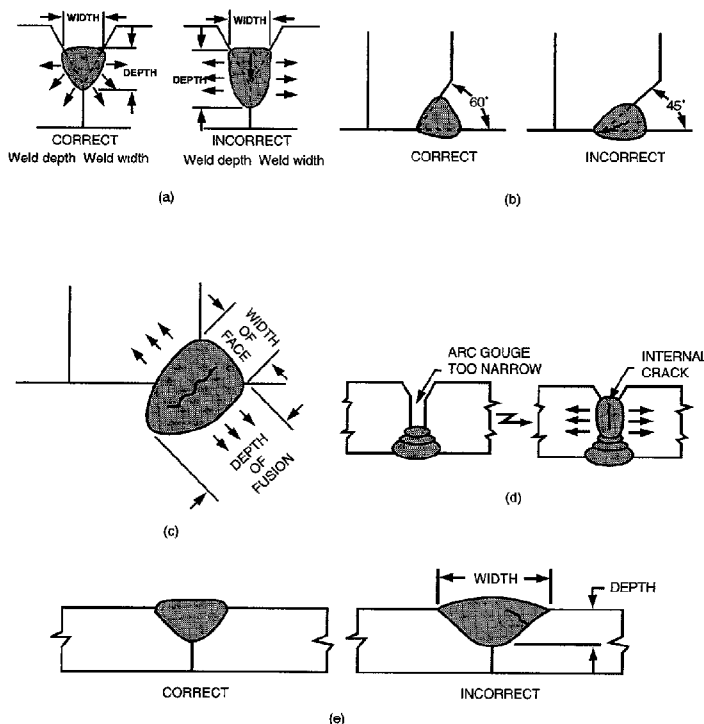
Laminations, seams and laps in the base metal may lead to cracks in submerged arc welds. The notch provided by these plate discontinuities tends to initiate cracks in the weld metal. The high

stresses in the weld may also cause lamellar tearing in susceptible materials.

Cracks in submerged arc welds may occur when the material is hot or cold. Crater cracks may be anticipated unless the operator has perfected a crater-filling technique. Run-off tabs are commonly used to put starts and stops outside the weld joint area. Throat cracks in small root pass weld beads between heavy sections are typical in a highly restrained joint. In situations where the weld penetration is much greater than the width of the weld bead, centerline cracking may occur due to the undesirable solidification pattern which results.

Toe cracks and root cracks are often a form of delayed cracking attributed to hydrogen. Moisture in the flux is the prime suspect in these occurrences.

Inspection Processes: The inspection processes used for submerged arc welding include visual, radiographic, ultrasonic, magnetic particle and penetrant testing.



SOLIDIFICATION CRACKING BECAUSE OF WELD PROFILE

Electroslag Welding (ESW)

Electroslag welding uses an electrically melted metallurgical flux that melts the filler metal and the surfaces of the work. The heat is created by the electrical resistance of the flux. There is no arc except at the start of the weld before the granular flux melts and becomes conductive. The slag is then kept molten by its resistance to the flow of electric current passing between the electrode and the work.

Electroslag welding is purely a mechanized or automatic process. The melted base metal, electrode and guide tube (in consumable guide welding) collect at the bottom of the flux pool. Welding is done essentially in the flat position with welding progressing from the bottom to top of a weld joint positioned vertically. Water-cooled backing shoes in contact with the joint sides contain the

molten weld metal and the molten flux. The weld surface is molded by the contour of the shoes. The vertical progression of welding provides directional solidification of the molten pool and ready flotation of all nonmetallic impurities into the floating slag layer. As the molten metal slowly solidifies in upward progression, it joins the plates together. A substantial amount of base metal is melted to form part of the weld in this process.

Welding Metallurgy: Two metallurgical factors are important in electroslag welding: symmetrical stress patterns which result in no angular distortion and large weld metal grain sizes resulting from slow cooling. The stresses induced

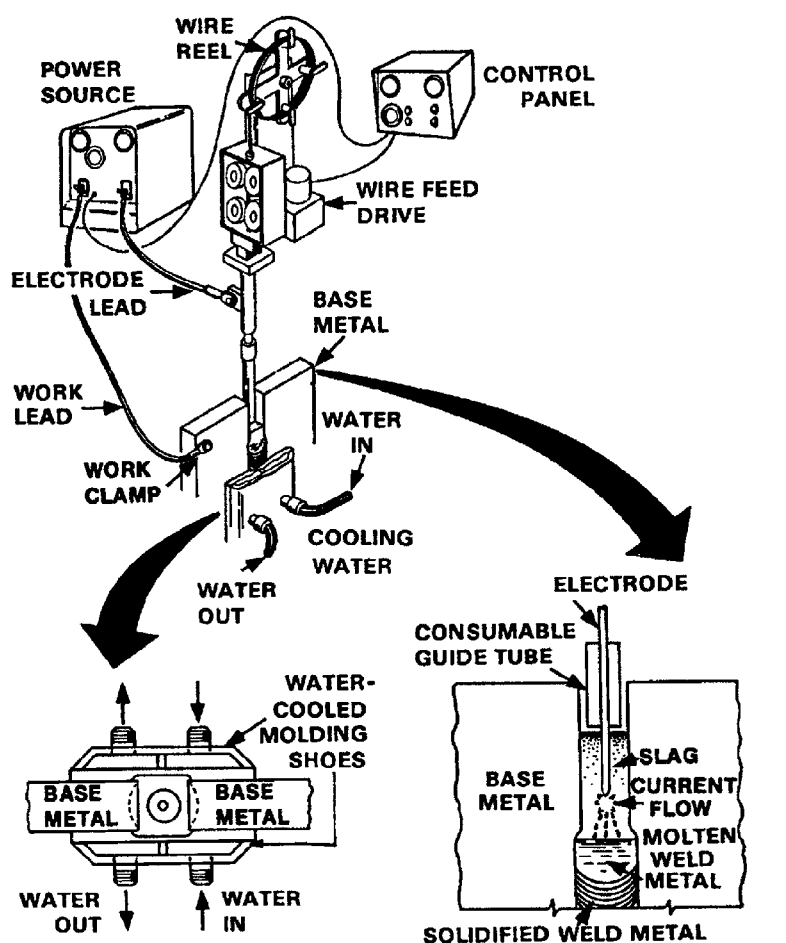
during the slow cooling of the weld is symmetrical with no distortion, which is different from the result when groove welds are welded from one side of a joint using some other welding processes. The large grains associated with electroslag welding tend to reduce the mechanical properties of the weld metal and cracking may result, especially if the weld joint is highly restrained.

Welding Chemistry: The welding composition is controlled by a combination of base metal, electrode and consumable guide tubes, if used, and the metal is protected from oxidation and refined by the molten slag. The slag used in this process is a metallurgical flux that refines both the fused base metal and the filler metal. As welding progresses, the slag also shields the weld pool along the full cross section of the joint.

Limiting Factors: Electroslag welding now has the reputation for producing the cleanest weld metal, being comparable to vacuum arc remelted steel. The only limiting factor of note is the skill level required to set up the machine. Due to the extensive time required for this setup, only thicker sections can be economically joined using this process.

Preweld preparation is simple. Faces of the joint must be aligned, but this is not as critical as with some other processes. The plate edges must be smooth and fairly uniform in thickness for proper positioning of the backing shoes.

For safety, the white-hot electroslag pool should not be watched without No. 5 filter lens protection (or darker). Safety goggles are needed when slag is being removed from weld deposits.



Electroslag Welding Equipment

Hobart Brothers Company

Discontinuities: All of the common discontinuities may appear in electroslog welds.

Porosity is usually gross when it occurs, and in the form of piping porosity. This can be caused by moisture in the flux or by the "sweating" of the water-cooled backing shoes.

Slag inclusions are uncommon but may exist. They normally result from improper operating parameters that may allow solidified slag to become mechanically trapped. They may also result if the weld is nearly lost or is lost and restarted. The welding process depends on building up a pool of molten slag heated to about 3100° F. An inadequate starting sump (joint extension) will leave poorly melted metal and slag in the weld. Shallow run-off tabs at the top of the joint may fail to allow the joint to be completely filled, resulting in underfill.

Incomplete fusion often occurs in welds with poor shape of the pool. Welds in thick plates in which the heat is distributed by oscillating the electrode(s) may have incomplete fusion in the central portion, or near the shoes. The cooling effect of the shoe may prevent melting of the base metal out to the surface. The resulting indication resembles an undercut.

Overlap may occur if the shoes do not ride smoothly and closely on the plates, allowing the pool to grow outward from the surface plane. Ultimately, this condition leads to a run-out of the pool unless the gap is patched with insulating material or another dam. Again, this does not occur as readily in consumable guide welding because the shoes are fixed.

Laminations and delaminations in the plate are not as great a concern in an electroslog weld. The metallurgical slag floats out any inclusions in the lamination and seals such discontinuities alongside the weld.

Lamellar tearing has not been observed in electroslog welding because no through-thickness tensile stress is imposed on the base metal, at least not in butt joints. Tearing might occur in T-joints, but its occurrence is minimal.

Cracking, often severe, may occur in electroslog welds made in a deep, narrow pool at high welding speeds, due to the undesirable solidification patterns which result.

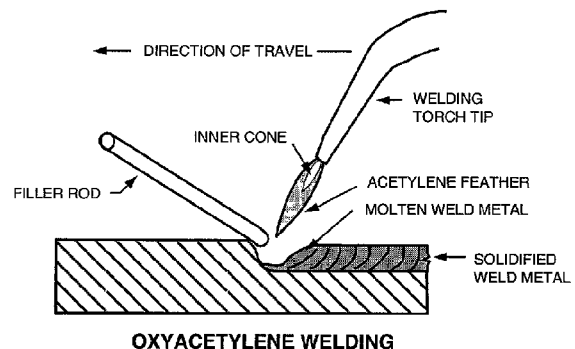
Fissures are commonly found. This is a term used to describe a discontinuity that particularly occurs in these welds. It is a small or moderately-sized separation along grain boundaries. It is readily formed here because of the large size of the grains. High restraint stresses caused by solidification of the weld metal cause the separation.

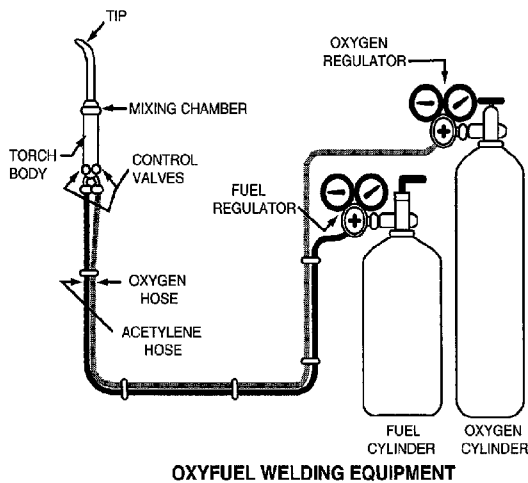
Inspection Processes: Inspection processes commonly used for electroslog welding are visual and radiographic testing. Ultrasonic testing is difficult because of the large grains typically present in electroslog welds.

Oxyacetylene Welding (OAW)

Oxyacetylene welding is a chemical welding process which relies on the chemical reaction between the oxyacetylene flame and the base metal to produce the necessary heat for melting the base and filler metals, if filler metal is used.

The oxyacetylene flame is produced by burning acetylene gas with pure oxygen fed through a torch, completing the combustion with oxygen in the air. Oxyacetylene welding is usually a manual process, although it may be mechanized for machine or automatic operation. While other fuel gases are effective for cutting operations, only acetylene provides sufficient heat to produce a satisfactory weld.





Welding Metallurgy: The temperature of the oxyacetylene flame is about 5600° F, which is sufficient to melt the commonly used metals. The flame provides both the heat and the necessary shielding of the molten metal for most applications; however, fluxes are available to improve the cleaning action on some materials. Both the heat and shielding are provided by the chemical reaction of the flame with the base metal.

An important variable is the size of the torch tip, which must be large enough to preheat the weldment and maintain a molten pool.

Welding Chemistry: The main welding chemistry consideration is what effect the nitrogen, oxygen and hydrogen in the air will have with the base metal and weld metal during the welding process.

The welder must regulate the torch flame to burn under neutral conditions, with the primary reaction exactly balanced, yielding only carbon monoxide and hydrogen. The flame atmosphere is then neither carburizing nor oxidizing, although it is chemically reducing. This flame adjustment must be learned from the appearance of the inner flame cone and the noise of the flame. The hot metal is then protected from the atmosphere by the combustion products in the neutral flame, and fluxes, if used.

Limiting Factors: The primary limitation of oxyacetylene welding is the level of skill required to minimize discontinuities. Adjustment of the heat source is totally controlled by the welder. He must set it for neutral conditions. There are no absolute guides; to secure the right flame, the welder must read the color and shape of the inner cone. He has pressure gages to set, but the size of the flame and the fuel ratio are set by judgment only.

The primary combustion area at the center of the flame has an intense white color, while the secondary combustion area varies from light orange to blue.

The welder must also control the application of heat to the work, the position and direction of the flame, and the manipulation of the filler rod (if needed). For safety, the eyes must be protected from the brilliance of the hot weld pool with No. 4 or 5 filter lenses in goggles.

In pre-weld preparation, the joint opening must be sufficiently large for oxyacetylene weld penetration. Also, joints in the vertical and overhead positions require appropriate technique to overcome the effects of gravity. The joint must be cleaned properly to avoid contaminating the weld.

Discontinuities: The most commonly found discontinuities are porosity, incomplete fusion, incomplete joint penetration, undercut, underfill, overlap, and various forms of cracks. Proper welding technique will eliminate most of these problems.

Uniformly scattered porosity generally betrays faulty welding technique, improper filler metal or contaminated base metal.

Incomplete fusion of the base metal edges frequently occurs when they are inadvertently oxidized. It occurs even with the best flame adjustment if improper manipulation is used.

Undercut, underfill and overlap are other weld faults attributed directly to the welder.

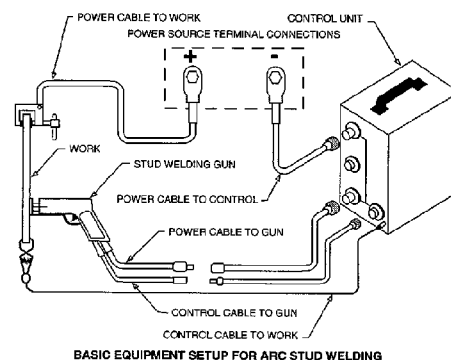
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Cracks are generally hot cracks in oxyacetylene welds. The process does not lead to cold cracking because the slow application of heat provides adequate preheat and makes the weld cool slowly. Throat cracks may result if the weld deposit is too thin to resist weld shrinkage stresses.

Inspection Processes: The inspection processes for oxyacetylene welding include visual, penetrant, magnetic particle, radiographic and ultrasonic testing.

Stud Welding (SW)

Stud welding is a two-step process used to join attachments to metal surfaces. It heats a metal stud or similar part and a workpiece by drawing an arc between them, and then rapidly forces the



heated surfaces together under pressure until they have united.

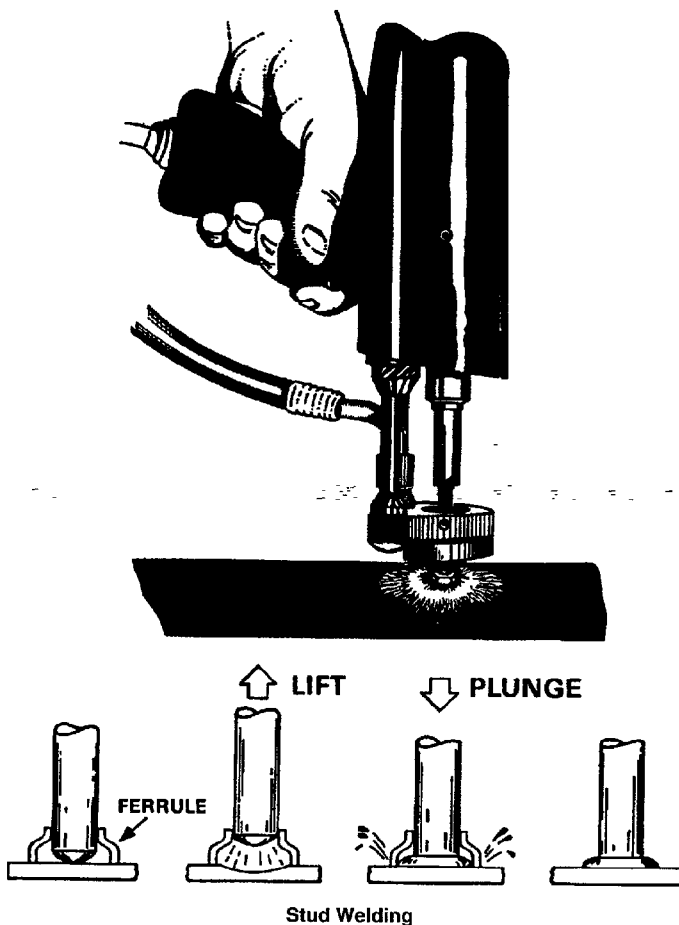
The process may be fully automatic or semiautomatic. A stud gun holds the tip of the stud against the workpiece. It then applies heat by creating an electrical arc between the stud and the underlying spot on the work surface. A timer in the control circuit then cuts off the current, and the stud-holding mechanism in the gun plunges the stud into the molten pool to make a weld. Freezing is almost instantaneous, as the weld is chilled by the surrounding base metal. When the weld is complete, the gun is removed and the ceramic ferrule is removed.

Studs may be welded in all positions. Stud welding is widely used in shipbuilding, bridges, automobiles, railroads, boilers, and industrial equipment.

Welding Chemistry: Partial shielding may be provided by a ceramic ferrule surrounding the stud or by a shielding gas. A flux may also be present on the stud tip.

Limiting Factors: The welding operator must correctly adjust the stud arc equipment. Defective gun action, improper current levels, and arc blow may result in incomplete fusion or undercut.

For safety, goggles must be worn whenever welding operators are knocking ferrules from completed stud welds and when testing the finished stud welds.



Discontinuities: There are only three main discontinuities which may be encountered with this process. Incomplete fusion could occur if the stud is not joined to the base metal across its entire cross section. Undercut may also occur if excessive welding current is used. Finally, the weld is not considered complete unless there is a small reinforcing fillet (or flash) present around the entire circumference of the stud base.

Inspection Processes: The examinations given to stud welds are visual examination for uniform build-up, and mechanical testing by hammer blows to bend the stud and restraighthen it. Studs with defective welds break off or give a "dead" sound.

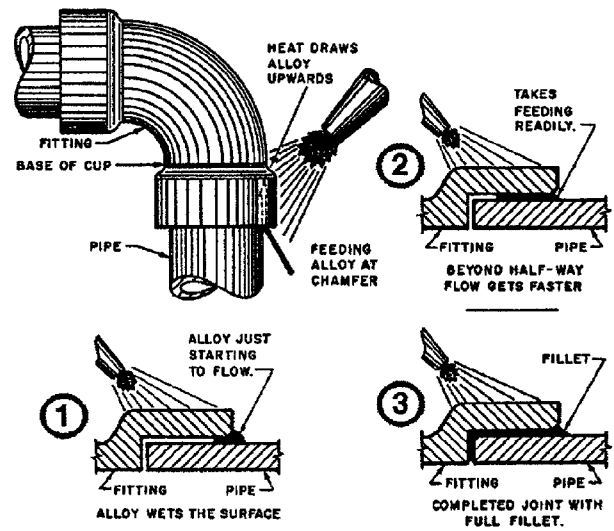
Brazing (B)

Brazing is a group of joining processes that produces coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having a melting point above 840° F and below the melting point of the base metals. The filler metal is distributed between the closely fitted faying surfaces of the joint by capillary action. The major difference between the various brazing methods is the manner in which the heat is applied to the joint. Brazing methods currently of industrial significance include the following:

- Torch brazing (TB)
- Furnace brazing (FB)
- Induction brazing (IB)
- Resistance brazing (RB)
- Dip brazing (DB)
- Infrared brazing (IRB)
- Diffusion brazing (DFB)

Torch Brazing (TB)

Torch brazing is accomplished by heating with a gas torch or torches. The fuel gas (acetylene, propane, natural gas, etc.) may be burned with air, compressed air or oxygen. Brazing filler metal may be preplaced in the forms of rings, washers, strips, slugs, powder, etc., or it may be face-fed,



Brazing Process

that is, fed from hand-held filler metal, usually in the form of wire or rod. Proper cleaning and fluxing before brazing are essential. This process may be performed manually, by machine or automatically.

Manual torch brazing is particularly useful on assemblies involving sections of unequal mass. Machine operations are set up when the rate of production warrants, using one or more torches equipped with single- or multiple-flame tips. The machine may move either the work or the torches, or both.

Torch brazing should be a reliable process. The flux, by its melting, indicates when the work is at a temperature suitable for brazing. The filler metal then flows into the joint by capillary action and should be visible at all exposed edges of the joint.

Furnace Brazing (FB)

Furnace brazing is preferred when the parts to be brazed can be assembled with the filler metal preplaced near or in the joint. The preplaced brazing filler metal may be in the form of wire, foil, powder, paste, or tape. Most high production brazing is done in a reducing gas atmosphere, such as hydrogen, but much furnace brazing is done in a vacuum, which prevents oxidation. Brazing in a

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vacuum assures the clean surfaces needed for good wetting and flow of filler metals without the use of fluxes. However, several base metals and filler metals are harmed by vacuum brazing because the constituents may evaporate.

Induction Brazing (IB)

Induction brazing is an automatic process that uses an induction coil to heat the metal. The parts are placed in or near a coil carrying alternating current. They become heated by an electric current induced in the parts to be joined. The brazing filler metal is usually preplaced. Careful design of the joint and the coil setup are necessary to assure that all surfaces reach brazing temperature at the same time.

Resistance Brazing (RB)

Resistance brazing is an automatic or semiautomatic process that uses the electrical resistance in the joint being welded as the heating device. The brazing filler metal is preplaced or added in some convenient form. Fluxing must take into account the conductivity of the flux. Most fluxes are electrical insulators when solid. The parts being brazed are held between two electrodes, and proper pressure and current are applied. The pressure is maintained until the joint solidifies.

Dip Brazing (DB)

Dip brazing is performed in a chemical bath or a molten metal bath. In chemical bath dip brazing, the brazing filler metal is preplaced and the assemblies are then immersed in a molten salt. The salt bath furnishes the heat necessary for brazing and usually protects against oxidation; if not, suitable flux should be used. In molten metal dip brazing, the parts are immersed in a bath of molten brazing filler metal. A cover of flux is maintained over the molten bath.

Infrared Brazing (IRB)

Infrared brazing uses the high intensity quartz lamp to provide radiant heat to bring the work to brazing temperature. Assemblies to be brazed are supported so that the energy impinges on the joints to be brazed.

Diffusion Brazing (DFB)

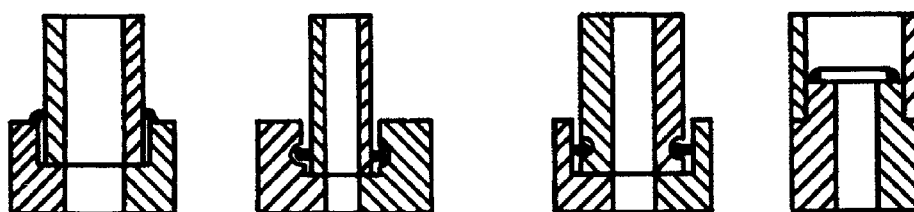
Diffusion brazing uses a filler metal which will diffuse into the base metal to create joint properties approaching those of the base metal. Migration of atoms (in the solid state) away from their home positions in the crystal lattice results in interdiffusion of the filler metal and base metal. This results in partially or completely eliminating any trace of filler metal as a layer in the joint. Such a braze develops increased mechanical properties and a higher remelt temperature. In some joints, a diffusion of atoms is planned that will create a liquid phase, which may be distributed by capillary action as in other brazing methods.

Brazing Chemistry: Brazing compounds are complex alloys with carefully adjusted melting points and flow characteristics. The work must be cleaned of oxides and films, which explains the reason for fluxes used in every type of brazing except furnace brazing. Furnace brazing cleans the surfaces by using reducing type gases or a vacuum.

Limiting Factors: Preparation for brazing requires proper cleaning of each joint and jiggling to hold correct joint alignment during capillary flow of the brazing filler metal.

For safety, all personnel must guard against toxic fumes of volatilized cadmium (from parts and filler metals) and fluorides (from fluxes). Eye protection is essential.

Discontinuities: Typical discontinuities found in brazed joints include voids, erosion and incomplete joint penetration. Voids and



Methods of Preplacing Brazing Filler Metal in Wire Form

incomplete joint penetration are commonly caused by underheating or by improper fluxing (or both). Erosion is a discontinuity resembling undercut. It results from overheating during brazing.

Inspection Processes: Inspection processes for detecting internal defects in brazed joints include torsion or mechanical testing, radiography and leak testing.

Cutting Processes

So far this discussion has dealt exclusively with those methods used to join metals together. However, in the welding environment, there are also needs for metal removal or severing. There are numerous methods available, including both thermal and mechanical types.

Thermal cutting is the standard method of preparing base metal joints for welding, of cutting out defects for weld repair, and of backgouging. The area cut is confined to a narrow, well-defined zone of controlled width called the kerf. Metal is removed by combustion (oxidation) in oxyfuel gas cutting, by simple melting in the plasma jet, or by arc melting in a blast of air.

The cutting process may be manual, semiautomatic or automatic. Standards for quality of cut surfaces vary with the requirements of the structure being welded. If the resulting irregularities are excessive, they can be chipped with a blunt tool or ground back with an abrasive wheel.

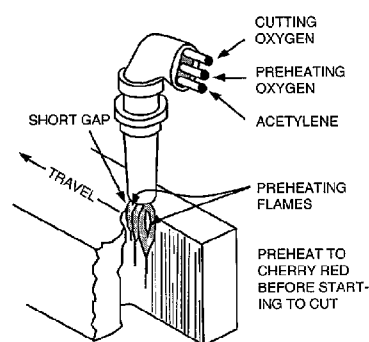
For safety, filter lenses are required for observing thermal cutting operations, and safety goggles with side shields are needed for protection from sparks and spatter.

The three primary thermal cutting processes are the following:

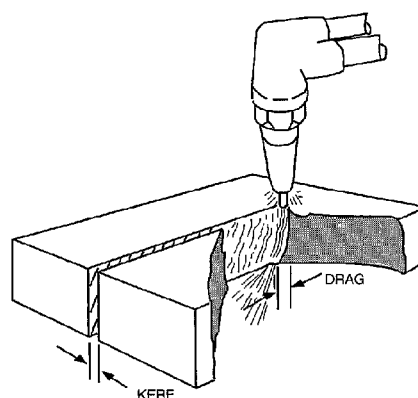
- Oxyfuel gas cutting (OFC)
- Air carbon arc cutting (AAC)
- Plasma arc cutting (PAC)

Oxyfuel Gas Cutting (OFC)

Oxyfuel gas cutting was at one time exclusively oxyacetylene cutting (OFC-A), but today oxyfuel cutting may be with oxygen and natural gas (OFC-N), propane (OFC-P), hydrogen (OFC-H), a proprietary mixture such as stabilized methylacetylene and propadiene, or metal powder



PROCESS DIAGRAM OXYGEN CUTTING



KERF AND DRAG IN OXYFUEL GAS CUTTING

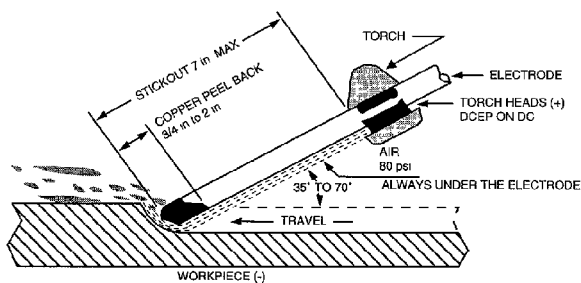
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cutting (POC). Metal powder cutting is used for stainless steel, aluminum and copper alloys. Torch modifications to suit each fuel gas are required.

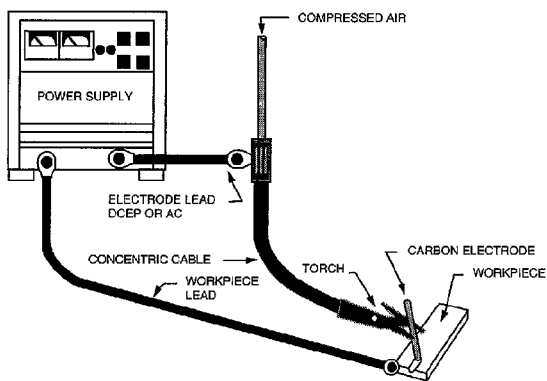
Oxyfuel gas cutting severs ferrous metals by oxidizing the iron in oxygen to form iron oxide. Above the oxidation temperature of about 1700° F, the familiar oxidation of iron (rusting) becomes combustion which is confined to a narrow zone. The metal to be cut is heated to the oxidation temperature by preheat flames disposed around the oxygen cutting jet.

The quality of the cut surface varies over wide limits. The skill of the cutter or operator affects all operations, since the cutting flame must be manually adjusted even for automatic cutting.

The major limitation of this method is the fact that it will only effectively cut those materials which oxidize at a temperature below their melting point. Consequently, it is difficult to produce a quality cut in stainless steels using this method.



TYPICAL OPERATING PROCEDURES FOR AIR CARBON ARC GOUGING



TYPICAL AIR CARBON ARC GOUGING EQUIPMENT

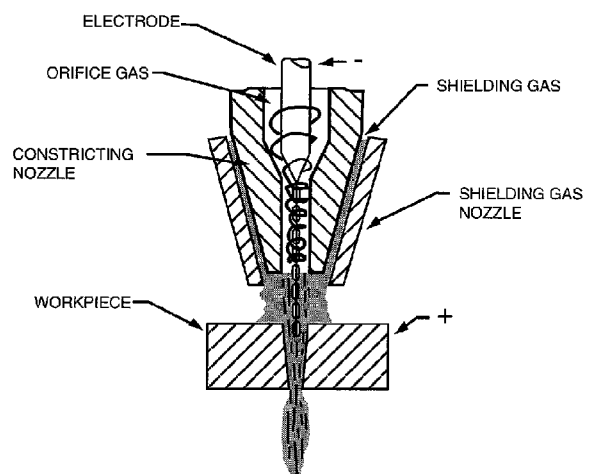
Air Carbon Arc Cutting (AAC)

Air carbon arc cutting melts the metal with an electric carbon arc and then blows it out with a high velocity air jet, traveling parallel to the electrode and striking the weld pool just behind the arc.

Plasma Arc Cutting (PAC)

Plasma arc cutting uses the greater heat of the plasma arc (27,000° F) to cut through any metal, ferrous or nonferrous. It removes the molten material with a high velocity jet of hot ionized gas. The process uses a constricted arc between a water-cooled electrode (direct current electrode negative) and the workpiece. The orifice which constricts the arc is also water-cooled.

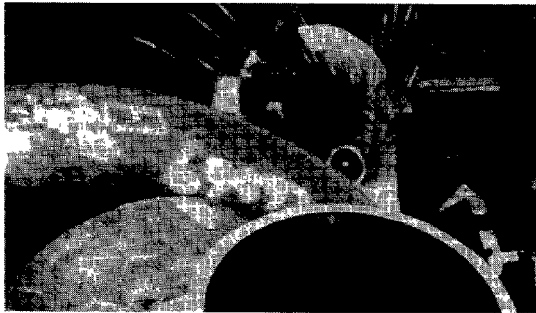
The quality of plasma arc cutting is superior to other types of thermal cutting because of the high temperature of the jet. The kerf is normally slightly unsquare; however, use of water-injected torches will tend to minimize this effect.



TYPICAL PLASMA ARC CUTTING TORCH

Mechanical Cutting

Joints are also prepared for welding by mechanical means such as milling, grinding, shaping, sawing, shearing, and chipping. The major concern after mechanical cutting is the removal of sulfurized cutting oils used to lubricate the cutting tools. Sulfur may cause cracking in welds, and all oils are a source of hydrogen.



Mechanical Cutting

Summary

The welding inspector is primarily responsible for judging the quality of welds produced by numerous processes. Knowledge of the various processes will be extremely helpful in deciding what types of welding problems might be anticipated. Actual welding experience is also quite helpful for the welding inspector; however, this is not a requirement for qualification as a CWI.

REVIEW

CHAPTER 9

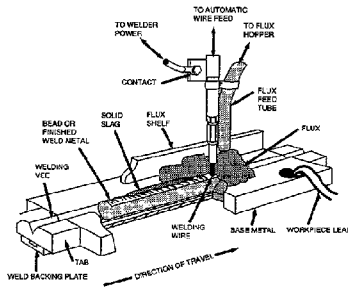
WELDING, BRAZING AND CUTTING PROCESSES

- Q9-1** Of the following, which is not a necessary requirement for a welding process?
- a. source of energy
 - b. electricity
 - c. means of shielding molten metal
 - d. base material
 - e. none of the above
- Q9-2** Which of the following are functions of the flux coating of a SMAW electrode?
- a. insulating
 - b. alloying
 - c. deoxidation
 - d. shielding
 - e. all of the above
- Q9-3** In the AWS system of SMAW electrode designations, the next to the last number refers to:
- a. usability
 - b. electrode coating
 - c. position
 - d. strength
 - e. none of the above
- Q9-4** Which of the following is an incorrect statement about a SMAW electrode designated as an E7024?
- a. It is a low hydrogen type.
 - b. The weld deposit has a minimum tensile strength of 70,000 psi.
 - c. It is suitable for use in the flat and horizontal fillet positions only.
 - d. all of the above
 - e. none of the above

- Q9-5** Which of the following is not essential parts of a typical SMAW system?
- a. constant current power supply
 - b. wire feeder
 - c. covered electrode
 - d. electrode lead
 - e. work lead
- Q9-6** Shielding of the molten metal in GMAW is accomplished through the use of:
- a. granular flux
 - b. inert gas
 - c. reactive gas
 - d. a and b above
 - e. inert and reactive gases
- Q9-7** Which of the following is not considered a type of metal transfer for GMAW?
- a. short circuiting
 - b. spray
 - c. globular
 - d. droplet
 - e. pulsed arc
- Q9-8** Which of the following types of metal transfer in GMAW is considered to be the lowest energy, and therefore prone to incomplete fusion?
- a. short circuiting
 - b. spray
 - c. globular
 - d. droplet
 - e. pulsed arc

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Q9-9 What type of welding process is pictured below?



- a. SMAW
- b. GMAW
- c. FCAW
- d. SAW
- e. ESW

Q9-10 Which of the following is not considered an arc welding process?

- a. SMAW
- b. GMAW
- c. FCAW
- d. ESW
- e. none of the above

Q9-11 In the electrode designation system for FCAW, the second number refers to:

- a. strength
- b. position
- c. chemical composition
- d. usability
- e. none of the above

Q9-12 Which of the following is not always an essential element of a FCAW system?

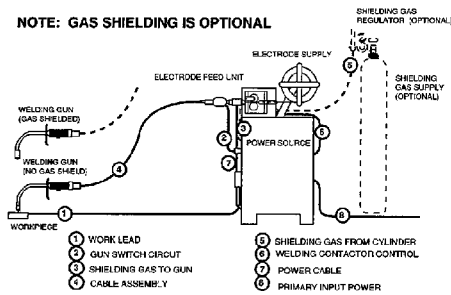
- a. constant voltage power supply
- b. tubular electrode
- c. wire feeder
- d. shielding gas
- e. work (ground) lead

- Q9-13** What aspect of the GTAW and PAW processes is different than for the other arc welding processes?
- a. nonconsumable electrode
 - b. power supply
 - c. shielding
 - d. all of the above
 - e. none of the above
- Q9-14** Shielding for the GTAW and PAW processes is accomplished through the use of:
- a. granular flux
 - b. slag
 - c. inert gas
 - d. reactive gas
 - e. none of the above
- Q9-15** A green stripe on a tungsten electrode designates:
- a. pure tungsten
 - b. 1% thoriated tungsten
 - c. 2% thoriated tungsten
 - d. zirconated tungsten
 - e. none of the above
- Q9-16** When welding aluminum with the GTAW process, what type of welding current is most commonly used?
- a. DCEP
 - b. DCEN
 - c. AC
 - d. a and b above
 - e. b and c above
- Q9-17** SAW and ESW are similar in that:
- a. both are arc welding processes
 - b. both use shielding gases
 - c. both use a granular flux
 - d. a and b above
 - e. a and c above

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Q9-18 The diagram below depicts what welding process?

NOTE: GAS SHIELDING IS OPTIONAL



- a. SMAW
- b. ESW
- c. FCAW
- d. SAW
- e. PAW

Q9-19 Solidification cracking due to improper width-to-depth ratio of the weld nugget may be a problem with which welding process?

- a. OFW
- b. SW
- c. SAW
- d. all of the above
- e. none of the above

Q9-20 Which of the following processes are typically used only in the flat position unless special apparatus is employed?

- a. GMAW
- b. SAW
- c. ESW
- d. a and b above
- e. b and c above

Q9-21 Which of the following are not common to both GTAW and PAW?

- a. nonconsumable tungsten electrode
- b. copper constricting nozzle
- c. shielding gas nozzle
- d. externally-applied filler metal
- e. none of the above

- Q9-22** What technique is employed with PAW to produce full penetration welds?
- a. stringer beads
 - b. weave beads
 - c. keyhole
 - d. backstep
 - e. none of the above
- Q9-23** What welding process produces welds in the flat position, in a single pass, with the progression vertically upward along the joint?
- a. SAW
 - b. ESW
 - c. FCAW
 - d. a and b above
 - e. b and c above
- Q9-24** Which of the following is not an advantage of the ESW process?
- a. high deposition rate
 - b. ease of setup
 - c. capable of joining thick sections
 - d. no tendency for angular distortion
 - e. none of the above
- Q9-25** Which welding process is considered to be a chemical welding process?
- a. SMAW
 - b. ESW
 - c. SAW
 - d. OAW
 - e. none of the above
- Q9-26** Which arc welding process provides a very efficient means of joining attachments to some planar surface?
- a. OAW
 - b. SW
 - c. GMAW
 - d. GTAW
 - e. SMAW

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- Q9-27** Brazing differs from welding in that:
- a. no filler metal is used.
 - b. an oxyfuel flame is used.
 - c. the base metal is not melted.
 - d. all of the above
 - e. none of the above
- Q9-28** For satisfactory results, a braze joint should have:
- a. a large surface area.
 - b. a small gap between pieces to be joined.
 - c. a precise bevel.
 - d. a and b above
 - e. b and c above
- Q9-29** Which of the following is not an advantage of brazing?
- a. ease of joining thick sections
 - b. ability to join dissimilar metals
 - c. ability to join thin sections
 - d. a and b above
 - e. b and c above
- Q9-30** Of the following metals, which cannot be effectively cut using OFC?
- a. high carbon steel
 - b. low carbon steel
 - c. medium carbon steel
 - d. stainless steel
 - e. none of the above
- Q9-31** Which of the following gases can be used to perform OFC?
- a. MAPP
 - b. propane
 - c. acetylene
 - d. natural
 - e. all of the above

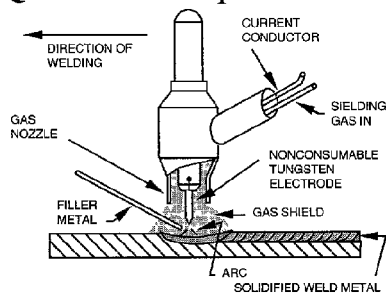
Q9-32 Which of the following cutting processes can be used to cut any metal?

- a. OFC
- b. CAC-A
- c. PAC
- d. a and b above
- e. b and c above

Q9-33 The width of a cut is technically referred to as the:

- a. gap
- b. dross
- c. kerf
- d. drag
- e. none of the above

Q9-34 Which process is illustrated below?



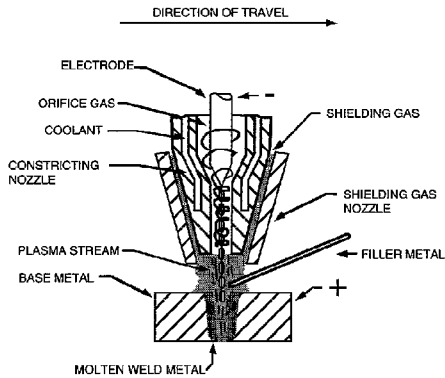
- a. GMAW
- b. PAW
- c. GTAW
- d. BMAW
- e. CAW

Q9-35 ESW designates which process?

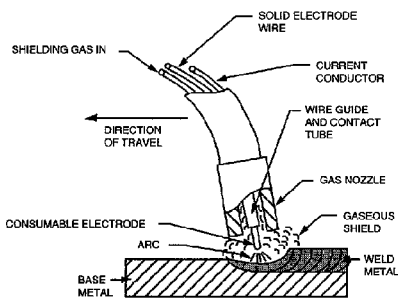
- a. electric slag arc welding
- b. electrosag arc welding
- c. electric slag welding
- d. electrosag welding
- e. electric stud welding

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Q9-36 Which process is illustrated below?



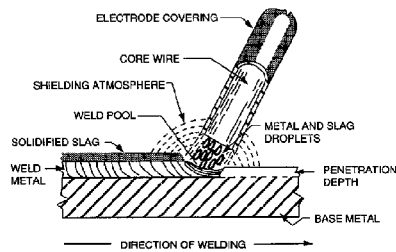
- a. GMAW
- b. PAW
- c. GTAW
- d. TIG
- e. CAW



Q9-37 Which process is illustrated below?

- a. GMAW
- b. PAW
- c. GTAW
- d. TIG
- e. CAW

Q9-38 Which process is illustrated below?



- a. GMAW
- b. SAW
- c. GTAW
- d. SW
- e. SMAW

Q9-39 SMAW designates which process?

- a. stick metal arc welding
- b. shielded metal arc welding
- c. submerged arc welding
- d. seam metal arc welding
- e. short circuiting metal arc welding

Q9-40 SW designates which process?

- a. stud welding
- b. stud arc welding
- c. submerged welding
- d. stick welding
- e. submerged arc welding

Q9-41 SAW designates which process?

- a. stud welding
- b. stud arc welding
- c. submerged welding
- d. stick welding
- e. submerged arc welding

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Q9-42 FCAW designates which process?

- a. flux cored arc welding
- b. flux centered arc welding
- c. furnace controlled arc welding
- d. friction arc welding
- e. flow arc welding

Q9-43 GMAW designates which process?

- a. gas machine arc welding
- b. gas method arc welding
- c. gas material arc welding
- d. gas metal arc welding
- e. general material arc welding

Q9-44 GTAW designates which process?

- a. gas tungsten arc welding
- b. general tungsten arc welding
- c. globular transfer arc welding
- d. gas torch arc welding
- e. none of the above

Q9-45 PAW designates which process?

- a. plasma arc welding
- b. pressure arc welding
- c. plate arc welding
- d. percussion arc welding
- e. none of the above

Q9-46 Which of the following could result in the creation of porosity in the GTAW of 6061-T6 aluminum structural members for an aircraft application?

- a. insufficient cleaning of the weld joint
- b. contaminated filler metal
- c. leak in the shielding gas hose
- d. presence of drafts during the welding operation
- e. all of the above

- Q9-47** An ER70S-6 electrode can be used with which of the processes?
- a. GTAW
 - b. GMAW
 - c. PAW
 - d. all of the above
 - e. none of the above
- Q9-48** A granular flux is a characteristic of which of the following?
- a. ESW
 - b. SAW
 - c. SMAW
 - d. both a and b
 - e. both b and c
- Q9-49** Which of the classifications listed below produces the strongest weld metal?
- a. ER70S-6
 - b. E70T-5
 - c. E7018
 - d. F7A2-EM12K
 - e. no difference
- Q9-50** Which process is classified as a chemical welding method?
- a. GTAW
 - b. GMAW
 - c. ESW
 - d. PAW
 - e. OAW
- Q9-51** Which cutting methods use electricity?
- a. PAC
 - b. CAC-A
 - c. OAC
 - d. a and b above
 - e. b and c above

9-38

Q9-52 A tubular electrode is a significant characteristic of which process?

- a. SAW
- b. ESW
- c. FCAW
- d. SMAW
- e. GMAW

Q9-53 Which arc welding process is used very effectively for the welding of various types of attachments to surfaces of plates and structural members?

- a. SMAW
- b. GMAW
- c. FCAW
- d. SW
- e. ESW

Q9-54 Molding shoes is a term associated with which process?

- a. SAW
- b. GTAW
- c. ESW
- d. FCAW
- e. GMAW

Q9-55 Short circuiting metal transfer is a mode of operation for

- a. GTAW.
- b. FCAW.
- c. SMAW.
- d. none of the above.
- e. all of the above.

Q9-56 The need for electrode holding ovens for some types of its filler metal is a disadvantage of which process below?

- a. SMAW
- b. FCAW
- c. SAW
- d. all of the above
- e. a and b

Q9-57 Which process uses a carbon electrode?

- a. SMAW
- b. GMAW
- c. GTAW
- d. CAC-A
- e. PAC

Q9-58 EWTh-1 is an electrode designation for which of those processes listed below?

- a. GTAW
- b. PAW
- c. GMAW
- d. a and b above
- e. b and c above

Q9-59 The ability to easily join dissimilar metals is an advantage of

- a. GTAW.
- b. PAW.
- c. FB.
- d. all of the above.
- e. none of the above.

Q9-60 F7P6-EM12 is a filler metal designation for

- a. SMAW.
- b. GMAW.
- c. FCAW.
- d. SAW.
- e. PAW.

Q9-61 The ability to perform keyhole welding is a primary advantage of

- a. GTAW.
- b. PAW
- c. SMAW
- d. FCAW
- e. SAW

9-40

Q9-62 Which gases can be used for OFW?

- a. MAPP
- b. acetylene
- c. natural gas
- d. propane
- e. all of the above

Q9-63 Which gases below can be used for TB?

- a. acetylene
- b. oxygen
- c. natural gas
- d. propane
- e. all of the above

Q9-64 A ferrule is an item used for shielding in which process below?

- a. ESW
- b. PAW
- c. PAC
- d. SW
- e. FB

Q9-65 When GTAW is used, what type of current results in the greatest amount of penetration?

- a. dcen
- b. dcep
- c. ac
- d. hwac
- e. no difference

Q9-66 A constricting nozzle is one of the components for which welding process?

- a. PAW
- b. GTAW
- c. SAW
- d. GMAW
- e. SW

- Q9-67** What gases can be used for GMAW?
- a. carbon dioxide
 - b. argon
 - c. 75% argon-25% carbon dioxide
 - d. 98% argon-2% oxygen
 - e. all of the above
- Q9-68** The process which can be used either with or without an external shielding gas is
- a. GMAW.
 - b. SMAW.
 - c. FCAW.
 - d. GTAW.
 - e. PAW.
- Q9-69** Which of the welding processes below is generally considered to provide the highest deposition rate?
- a. SAW
 - b. ESW
 - c. FCAW
 - d. SMAW
 - e. GMAW
- Q9-70** When welding carbon steel with the OAW process, the torch should be adjusted to provide
- a. an oxidizing flame.
 - b. a carburizing flame.
 - c. a neutral flame.
 - d. a heating flame.
 - e. none of the above.
- Q9-71** What processes can be used to cut austenitic stainless steels?
- a. PAC
 - b. CAC-A
 - c. GTAW
 - d. a and b above
 - e. b and c above

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- Q9-72** The requirement for two separately-supplied gases is a characteristic of which process?
- a. GTAW
 - b. GMAW
 - c. FCAW
 - d. PAW
 - e. none of the above
- Q9-73** Which of the following processes utilize a flux to provide necessary shielding?
- a. SMAW
 - b. SAW
 - c. GMAW
 - d. a and b above
 - e. all of the above