Magnetic Arc Control

This control uses magnetic fields to deflect the arc in advantageous directions. It is useful for high speed automatic welding to even out the weld pool, prevent undercut, and promote uniform penetration. The oscillation and positioning effects of these magnetic fields on the arc improve weld appearance and weld bead profiles. See Figure 3.36.

Cold Wire Feed System

GTAW is generally considered a low-deposition process. However, by automating it and adding the filler wire in an automatic fashion its deposition rate can be increased. Increased weld deposition means higher travel speeds and more parts out the door at the end of the day. Figure 3.37 represents a Cold Wire Feed System. Improved penetration and weld profiles can be had by feeding the filler wire into the back edge of the weld pool versus the front half of the weld pool, which is typically done with manual welding. Some systems can be set up where the filler wire is preheated electrically. These systems are referred to as Hot Wire TIG.

Seam Tracking

In order to keep the welding arc on track when following a constantly varying weld seam, systems like Figure 3.38 have been developed. This type control allows the equipment to constantly monitor the weld joint location both horizontally and vertically over the joint. In order to have consistency at high travel speeds, devices like this can control the position of the welding arc within plus and minus 0.005 inch or 0.13 mm.

IV. Electrodes and Consumables

Tungsten Electrodes for GTAW

Electrodes made of tungsten and tungsten alloys are secured within a GTAW torch to carry current to the welding arc. Tungsten is preferred for this process because it has the highest melting point of all metals.

The tungsten electrode establishes and maintains the arc. It is said to be a “nonconsumable” in that the electrode is not melted and included in the weld pool. In fact, great care must be taken so that the tungsten does not contact the weld pool in any way, thereby causing a contaminated, faulty weld. This is generally referred to as a “tungsten inclusion”.

Tungsten electrodes for GTAW come in a variety of sizes and lengths. They may be composed of pure tungsten, or a combination of tungsten and other elements and oxides. Electrodes are manufactured to specifications and standards developed by the American Welding Society and the American Society For Testing And Materials. Electrodes come in standard diameters from .010" through 1/4", as seen in Figure 4.1. The diameter of tungsten electrode needed is often determined by the thickness of base metal being welded and the required amperage to make the weld.

Lengths of tungstens needed are often determined by the type of torch used for a particular application. Standard lengths are shown in Figure 4.2. Of these, the 7" length is the most commonly used. For special applications some suppliers provide them in cut lengths to your specifications. For example, .200" – .500", .501" – 3.000" and 3.001" – 7.000".

Standard Tungsten Sizes

U.S. Customary		SI Units	
Diameter in	Tolerance ± in. [b, c]	Diameter in	Tolerance ± mm [b, c]
0.010[a]	0.001	0.300	0.025
0.020	0.002	0.50	0.05
0.040	0.002	1.00	0.05
0.060	0.002	1.60	0.05
0.093	0.003	2.00	0.05
0.125 (1/8)	0.003	2.40	0.08
0.156 (5/32)	0.003	2.50	0.08
0.187 (3/16)	0.003	3.00	0.08
0.250 (1/4)	0.003	3.20	0.08
		4.00	0.08
		4.80	0.08
		5.00	0.08
		6.40	0.08
		8.00	0.08

Notes:
a. 0.010 in. (0.30 mm) electrodes are also available in coils.
b. Tolerances, other than those listed, may be supplied as agreed upon between supplier and user.
c. Tolerances shall apply to electrodes in both the clean finish and ground finish conditions.

Figure 4.1 Diameters of standard tungsten electrodes (Courtesy AWS).

3" (76 mm)	12" (305 mm)
6" (152 mm)	18" (457 mm)
7" 178 mm)	24" (610 mm)

Figure 4.2 Standard tungsten lengths.

Chemical Composition Requirements for Electrodes[a]							
		Weight Percent					
AWS Classification	UNS Number[b]	W Min. (difference)[c]	CeO_2	La_2O_3	ThO_2	ZrO_2	Other Oxides or Elements Total
EWP	R07900	99.5	—	—	—	—	0.5
EWCe-2	R07932	97.3	1.8 – 2.2	—	—	—	0.5
EWLa-1	R07941	98.3	—	0.8 – 1.2	—	—	0.5
EWLa-1.5	R97942	97.8	—	1.3 – 1.7	—	—	0.5
EWLa-2	R07943	97.3	—	1.8 – 2.2	—	—	0.5
EWTh-1	R07911	98.3	—	—	0.8 – 1.2	—	0.5
EWTh-2	R07912	97.3	—	—	1.7 – 2.2	—	0.5
EWZr-1	R07920	99.1	—	—	—	0.15 – 0.40	0.5
EWG[d]	—	94.5	NOT SPECIFIED				0.5

Notes:

a. The electrode shall be analyzed for the specific oxides for which values are shown in this table. If the presence of other elements or oxides is indicated, in the course of the work, the amount of those elements or oxides shall be determined to ensure that their total does not exceed the limit specified for "Other Oxides or Elements, Total" in the last column of the table.

b. **SAE/ASTM** Unified Numbering System for Metals and Alloys.

c. Tungsten content shall be determined by subtracting the total of all specified oxides and other oxides and elements from 100%.

d. Classification EWG must contain some compound or element additive and the manufacturer must identify the type and minimal content of the additive on the packaging.

Figure 4.3 Tungsten electrode requirements (Courtesy AWS).

Types of tungsten and tungsten alloy electrodes for GTAW are classified according to the chemical makeup of the particular electrode types. Figure 4.3 shows the nine types of electrodes classified by the American Welding Society.

In the first column of Figure 4.3, the AWS identifies the nine classifications as they would for filler metal specifications. The letter "E" is the designation for electrode. The "W" is the designation for the chemical element tungsten.

The next one or two letters designates the alloying element used in the particular electrode. The "P" designates a pure tungsten electrode with no intentionally added alloying elements. The "Ce", "La", "Th", and "Zr" designate tungsten electrodes alloyed with cerium, lanthanum, thorium, or zirconium, respectively.

The number "1", "1.5" or "2" behind this alloy element indicates the approximate percentage of the alloy addition.

The last electrode designation, "EWG", indicates a "general" classification for those tungsten electrodes that do not fit within the other categories. Obviously, two electrodes bearing the same "G" classification could be quite different, so the AWS requires that a manufacturer identify on the label the type and content of any alloy additions.

Electrodes are color coded for ease of identification. Care should be exercised when working with these electrodes so that the color-coding can be kept intact.

Types of Electrodes

EWP (100% Tungsten, Green)

These electrodes are unalloyed, "pure" tungsten with a 99.5% tungsten minimum. They provide good arc stability when using AC current, with either balanced wave or unbalanced wave and continuous high-frequency stabilization. Pure tungsten electrodes are preferred for AC sine wave welding of aluminum and magnesium because they provide good arc stability with both argon and helium shielding gas. Because of their inability to carry much heat, the pure tungsten electrode forms a balled end.

EWCe-2 (2% Cerium, Orange)

Alloyed with about 2% ceria, a non-radioactive material and the most abundant of the rare earth elements, the addition of this small percentage of cerium oxide increases the electron emission qualities of the electrode which gives them a better starting characteristic and a higher current carrying capacity than pure tungsten. These are all-purpose electrodes that will operate successfully with AC or DC electrode negative. Compared with pure tungsten, the ceriated tungsten electrodes provide for greater arc stability. They have excellent arc starting properties at low current for use on orbital tube, pipe, thin sheet and small delicate part applications. If used on higher current applications the cerium oxide may be concentrated to the excessively hot tip of the electrode. This condition and oxide change will remove the benefits of the cerium. The nonradioactive cerium oxide has slightly different electrical properties as compared to the thoriated tungsten electrodes. For automated (orbital tube, etc.) welding these slight changes may require welding parameters and procedures to be adjusted. The cerium electrodes work well with the Advanced Squarewave power sources and should be ground to a modified point.

EWLa-1 (1% Lanthanum, Black), EWLa-1.5 (1.5% Lanthanum, Gold) and EWLa-2 (2% Lanthanum, Blue)

Alloyed with nonradioactive lanthanum oxide, often referred to as lanthana, another of the rare earth elements. These electrodes have excellent arc starting, low-burn-off rate, arc stability, and excellent re-ignition characteristics. The addition of 1 – 2% lanthana increases the maximum current carrying capacity by approximately 50% for a given size electrode using alternating current compared to pure tungsten. The higher the percentage of lanthana, the more expensive the electrode. Since lanthana electrodes can operate at slightly different arc voltages than thoriated or ceriated tungsten electrodes these slight changes may require welding parameters and procedures to be adjusted. The 1.5% content appears to most closely match the conductivity properties of 2% thoriated tungsten. Compared to cerium and thorium the lanthana electrodes had less tip wear at given current levels. Lanthanum electrodes generally have longer life and provide greater resistance to tungsten contamination of the weld. The lanthana is dispersed evenly throughout the entire length of the electrode and it maintains a sharpened point well, which is an advantage for welding steel and stainless steel on DC or the AC from Advanced Squarewave power sources. Thus the lanthana electrodes work well on AC or DC electrode negative with a pointed end or they can be balled for use with AC sine wave power sources.

EWTh-2 (2% Thorium, Red) and EWTh-1 (1% Thorium, Yellow)

Commonly referred to as 1 or 2% thoriated tungstens, these are very commonly used electrodes since they were the first to show better arc performance over pure tungsten for DC welding. However, thoria is a low-level radioactive material, thus vapors, grinding dust and disposal of thorium raises health, safety and environmental concerns. The relatively small amount present has not been found to represent a health hazard. But if welding will be done in confined spaces for prolonged periods of time, or if electrode grinding dust might be ingested, special precautions should be taken concerning proper ventilation. The welder should consult informed safety personnel and take the appropriate steps to avoid the thoria.

The thoriated electrode does not ball as does the pure tungsten, cerium or lanthana electrodes. Instead, it forms several small projections across the face of the electrode when used on alternating current. When used on AC sine wave machines, the arc wanders between the multiple projections and is often undesirable for proper welding. Should it be absolutely necessary to weld with these type machines, the higher content lanthana or thoria electrodes should be used. The thoriated electrodes work well with the Advanced Squarewave power sources and should be ground to a modified point. These electrodes are usually preferred for direct current applications. In many DC applications, the electrode is ground to a taper or pointed. The thorium electrode will retain the desired shape in those applications where the pure tungsten would melt back and form the ball end. The thoria content in the electrode is responsible for increasing the life of this type over the pure tungsten, EWP.

EWZr-1 (1% Zirconium, Brown)

A zirconium oxide (zirconia) alloyed tungsten electrode is preferred for AC welding when the highest quality work is necessary and where even the smallest amounts of weld pool contamination cannot be tolerated. This is accomplished because the zirconium alloyed tungsten produces an extremely stable arc which resists tungsten spitting in the arc. The current carrying capability is equal to or slightly greater than an equal sized cerium, lanthana or thorium alloyed electrode. Zirconium electrodes are typically used only for AC welding with a balled end.

EWG (unspecified alloy, Gray)

This classification covers tungsten electrodes containing unspecified additions of rare earth oxides or combinations of oxides. As specified by the manufacturer, the purpose of the additions is to affect the nature or characteristics of the arc. The manufacturer must identify the specific addition or additions and the quantity or quantities added.

Some “rare earth” electrodes are in this category and they contain various percentages of the 17 rare earth metals. One mixture is 98% tungsten, 1.5% lanthanum oxide, and a .5% special mixture of other rare earth oxides. Some of these electrodes work on AC and DC, last longer than thoriated tungsten, can use a smaller size diameter tungsten for the same job, can use a higher current than similar sized thoriated tungstens, reduce tungsten spitting, and are not radioactive.

Tungsten electrodes for GTAW can easily be recognized by their color code. See Figure 4.4.

Electrode Identification Requirements[a,b]

AWS Classification	Color
EWP	Green
EWCe-2	Orange
EWLa-1	Black
EWLa-1.5	Gold
EWLa-2	Blue
EWTh-1	Yellow
EWTh-2	Red
EWZr-1	Brown
EWG	Gray

Notes:

a. The actual color may be applied in the form of bands, dots, etc., at any point on the surface of the electrode.

b. The method of color coding used shall not change the diameter of the electrode beyond the tolerances permitted.

Figure 4.4 Color codes for tungsten electrodes (Courtesy AWS).

Use of Tungsten Electrodes

Electrodes used for GTAW welding differ greatly in many respects from electrodes used in consumable metal arc welding. The tungsten electrode is not melted or used as filler metal as is the case with SMAW or GMAW electrodes. At least it is not intended to be melted and become part of the weld deposit. However, in cases where the wrong electrode type, the wrong size of electrode, the wrong current, the wrong polarity or technique is used, tungsten particles can be transferred across the arc. The power source used may affect the amount of tungsten which may be transferred across the arc. A machine designed specifically for GTAW welding will usually have characteristics advantageous for the process. Excessive current surges or “spikes” will cause “spitting” of tungsten. Excessive arc rectification on aluminum or magnesium will cause a half-wave effect, and cause particles of tungsten to be transferred across the arc. An understanding of the electrode materials and types of electrodes and their recommended uses will enable the user to make the proper electrode selection.

Tungsten is a very hard steel gray metal. It is a highly refractory metal and does not melt or vaporize in the heat of the arc. It has a melting point of 6170˚ F (3410˚ C), and a boiling point of 10,220˚ F (5600˚ C). Tungsten retains its hardness even when red hot.

With the choice of several alloy types and a variety of sizes, many factors must be considered when selecting the electrode. One of the main considerations is welding current. The welding current will be determined by several factors including base metal type and thickness, joint design, fit-up, position, shielding gas, type of torch, and other job quality specifications.

An electrode of a given diameter will have its greatest current carrying capacity with direct current electrode negative (DCEN), less with alternating current and the least with direct current electrode positive (DCEP). Figure 4.5 lists some typical current values for electrodes with argon shielding.

Tungsten has a high resistance to current flow and therefore, heats up during welding. In some applications the extreme tip forms a molten hemisphere. The "ball" tip is characteristic of pure tungsten and is most desirable for AC welding with sine wave power sources. The extreme tip is the only part of the electrode which should be this hot. The remainder of the electrode should be kept cool. Excessive electrode stickout beyond the collet will cause heat build-up in the electrode. In a water-cooled torch, the heat is more rapidly dissipated from the collet assembly and helps cool the electrode. Excessive current on a given size electrode will cause the tip to become excessively hot.

		Typical Current Range (Amps)				
		Direct Current, DC	**Alternating Current, AC**			
		DCEN	**70% Penetration**		**(50/50) Balanced Wave A**	
Tungsten Diameter	**Gas Cup Inside Diameter**	**Ceriated Thoriated Lanthanated**	**Pure**	**Ceriated Thoriated Lanthanated**	**Pure**	**Ceriated Thoriated Lanthanated**
.040	#5 (3/8 in)	15 – 80	20 – 60	15 – 80	10 – 30	20 – 60
.060 (1/16 in)	#5 (3/8 in)	70 – 150	50 – 100	70 – 150	30 – 80	60 – 120
.093 (3/32 in)	#8 (1/2 in)	150 – 250	100 – 160	140 – 235	0 – 130	100 – 180
.125 (1/8 in)	#8 (1/2 in)	250 – 400	150 – 200	225 – 325	100 – 180	160 – 250

All values are based on the use of Argon as a shielding gas. Other current values may be employed depending on the shielding gas, type of equipment, and application.
DCEN = Direct Current Electrode Negative (Straight Polarity)

Figure 4.5 Typical current ranges for electrodes with argon shielding.

After the proper size and type of electrode has been selected, how the electrode is used and maintained will determine its performance and life. There are many misconceptions about tungsten electrodes and their correct use. The following information is intended to serve as a guideline to common sense decisions about tungsten electrodes.

Electrode Preparation

For AC Sine Wave and Conventional Squarewave

These electrodes should have a hemispheric or balled end formed. The diameter of the end should not exceed the diameter of the electrode by more than 1.5 times. As an example, a 1/8" electrode should only form a 3/16" diameter end. If it becomes larger than this because of excessive current, there is the possibility of it dropping off to contaminate the weld. If the end is excessively large, and the current is decreased before the molten tip drops off, the arc tends to wander around on the large surface of the electrode tip. The arc becomes very hard to control as it wanders from side to side. If welding conditions are correct, a visual observation of the electrode should reveal a ball end of uniform shape and proper size.

For improved arc focus set the balance control to maximum penetration and try a ceriated, lanthanated or thoriated tungsten with a modified point.

For Advanced Squarewave Use (Pointed)

With the expanded balance control of up to 90% electrode negative, the electrode shape is very nearly the same as for DC electrode negative welding. This improves the ability to focus the arc along with an even greater localization of the heat into the work. Do not use with pure tungsten.

For DC Electrode Negative Use (Pointed)

Since all of the weld energy is provided by electrode negative, there is very little heating affect on the tungsten and a sharp pointed tungsten is generally preferred. Figure 4.6 shows the preferred shapes for balled and the various types of points used with the DC and AC wave shaped power sources.

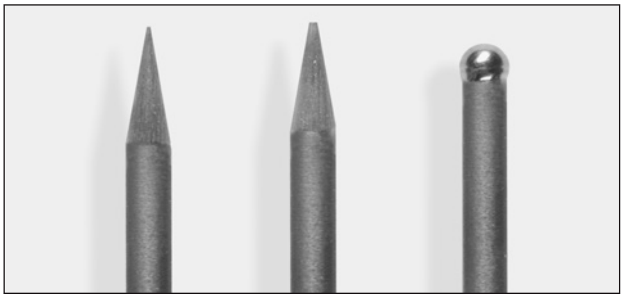
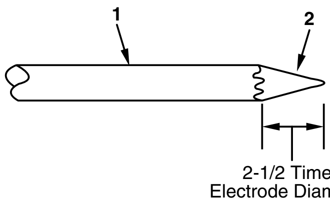


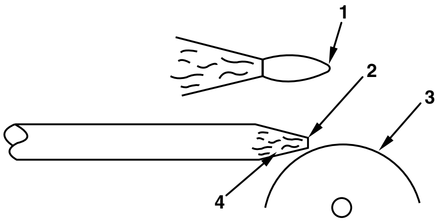
Figure 4.6 The ball diameter should never exceed 1.5 times the electrode diameter. Pointed tungstens are as noted.

Pointing of electrodes is a subject which has received much discussion. There are many theories and opinions on the degree of the point. Again, the application has a bearing on the configuration of the point. Along with application experience, the following should serve as a guide to pointing of electrodes.

A common practice in pointing electrodes is to grind the taper for a distance of 2 to 2-1/2 electrode diameters in length for use on DC and usually to a sharp needle point (see top of Figure 4.7). Using this rule for a 1/8" electrode, the ground surface would be 1/4 to 5/16" long.

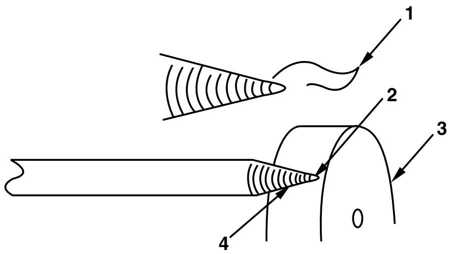


1. Tungsten Electrode
2. Tapered End
Grind end of tungsten on fine grit, hard abrasive wheel before welding. Do not use wheel for other jobs or tungsten can become contaminated causing lower weld quality.



Ideal Tungsten Preparation – Stable Arc

1. Stable Arc
2. Flat
3. Grinding Wheel
4. Straight Ground



Wrong Tungsten Preparation – Wandering Arc

1. Arc Wander
2. Point
3. Grinding Wheel
4. Radial Ground

Figure 4.7 Preparing tungsten for DC electrode negative welding and AC with wave shaping power sources.

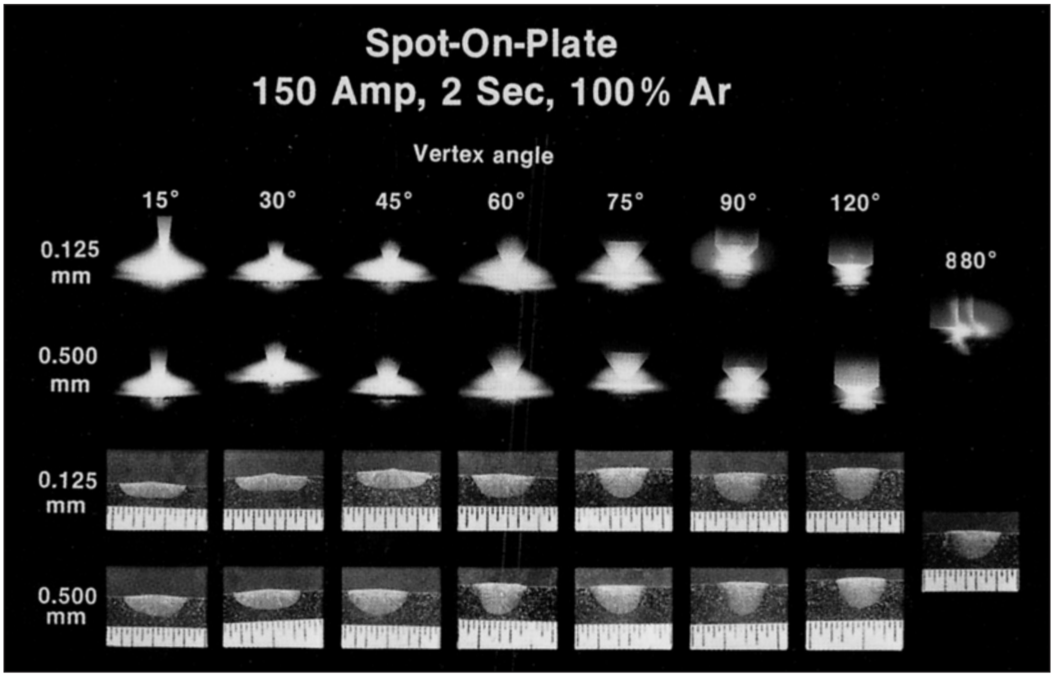


Figure 4.8 Arc shape and weld profile as a function of electrode tip angle. Image courtesy of *American Welding Society (AWS) Welding Handbook, 8th ed., Volume 2*, "Welding Processes." Miami: American Welding Society.

Needle-pointed electrodes are usually preferred on very thin metals in the range of .005" to .040". In other applications, a slightly blunted end is preferred because the extreme point may be melted off and end up in the deposit. In many applications, pointing is done where actually a smaller electrode should be used. Figure 4.8 shows examples of various arcs and weld profiles produced by changing the electrode tip angle.

Tungsten is harder than most grinding wheels, therefore it is chipped away rather than cut away. The grinding surface should be made of some extremely hard material like diamond or borazon. The grinding marks should run lengthwise with the point (see middle and bottom of Figure 4.7). If the grinding is done on a coarse stone and the grinding marks are concentric with the electrode, there are a series of ridges on the surface of the ground area. There is a possibility of the small ridges melting off and floating across the arc. If the stone used for grinding is not clean, contaminating particles can be lodged in the grinding crevices and dislodge during welding, ending up in the deposit. The grinding wheel used on tungsten electrodes should be used for no other material.

The surface of the tungsten after use should be shiny and bright. If it appears dull, an excess of current is indicated. If it appears blue to purple or blackened, there is insufficient postflow of the shielding gas. This means the surrounding atmosphere oxidized the electrode while still hot, and it is now contaminated. Continuing to weld with this condition can only result in the oxide flaking off and ending up in the weld deposit. A general rule for postflow is one second for each ten amperes of welding current. This is normally adequate to protect the tungsten and weld pool until they both cool below their oxidizing temperature.

Contamination of the electrode can occur in several ways in addition to the lack of postflow shielding gas. The most common form of contamination is contact between electrode and weld pool or electrode and filler rod. Loss of shielding gas or contamination of the shielding gas due to leaking connections or damaged hoses causes electrode contamination. Excessive gas flow rates and nozzles that are dirty, chipped or broken cause turbulence of the shielding gas. This aspirates atmospheric air into the arc area causing contamination.

The electrode that has been contaminated by contact with the pool or filler rod will have a deposit of the metal on the electrode. If this is not too serious, maintaining an arc on a scrap piece of material for a period of time may vaporize the deposit off the electrode. If the contamination cannot be removed in this manner, the preferred method is to grind the electrode to remove the contamination. Use good grinding techniques, as improper techniques can cause problems or injury. Breaking the contaminated tungsten off is generally not recommended as it may cause a jagged end, split or bend the electrode. This may result in excessive electrode heating and a poorly shaped arc. Proper tungsten shaping and removal of contamination is a key to maintaining consistent welds. A properly prepared tungsten will reduce or eliminate arc wandering, splitting, spitting and weld quality inconsistencies. Figure 4.9 shows a specially designed grinder for tungsten preparation.

Figure 4.9 Bench model tungsten grinder.

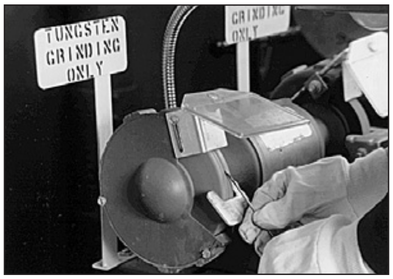


Figure 4.10 Tungsten electrode preparation.

Use good techniques when grinding the electrode to remove contamination. Grinding should be done on a fine grit hard abrasive wheel. Figure 4.11 shows several 1/8" tungsten electrodes. Notice the different tip configurations.

Figure 4.12 A typical air separation facility operated by the Canadian Liquid Air company at Varennes, Quebec, Canada.

Shielding Gas

All arc welding processes utilize some method of protecting the molten weld pool from the atmosphere. Without this protection, the molten metal reacts with gases in the atmosphere and produces porosity (bubbles) in the weld bead greatly reducing weld strength.

The importance of atmospheric shielding is reflected in the fact that all arc welding processes take their names from the method used to provide the shielding; Gas Tungsten Arc, Gas Metal Arc, Submerged Arc, Shielded Metal Arc, Flux Cored, etc.

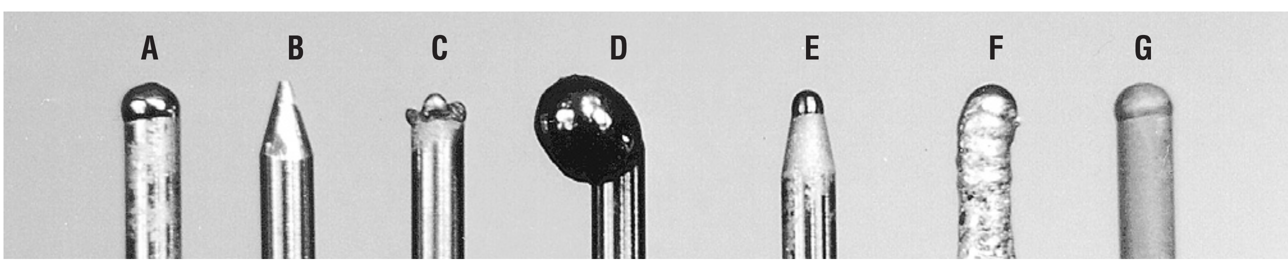


Figure 4.11 1/8" Tungstens.

ELECTRODE "A" has the "ball" end. This pure tungsten was used with alternating current with a sine wave power source on aluminum. Notice the end is uniform in shape and possesses a "shiny bright" appearance.

ELECTRODE "B" is a 2% thoriated tungsten ground to a taper and was used with direct current electrode negative, or a similar shape for Advanced Squarewave applications.

ELECTRODE "C" is a 2% thoriated tungsten used with an alternating current sine wave power source on aluminum. Note that this electrode has several small ball shaped projections rather than a round complete "ball end" like the pure tungsten.

ELECTRODE "D" is a pure tungsten used with alternating current sine wave power source or balance control set to excessive cleaning action on an AC wave controlled power source on aluminum. This electrode was subjected to a current above the rated capacity. Notice the "ball" started to droop to one side. It became very molten during operation and continuing to operate would have caused the molten end to drop into the weld pool.

ELECTRODE "E" is a pure tungsten that was tapered to a point and used on direct current electrode negative. Notice the "ball" tip characteristic of the pure tungsten. Pointing of pure tungsten is not recommended as the extreme point will always melt when the arc is established, and often times the molten tip will drop into the molten weld pool.

ELECTRODE "F" was severely contaminated by touching the filler rod to the tungsten. In this case, the contaminated area must be broken off and the electrode reshaped as desired.

ELECTRODE "G" did not have sufficient gas postflow. Notice the black surface which is oxidized because the atmosphere contacted the electrode before it cooled sufficiently. If this electrode were used, the oxidized surface will flake off and drop into the weld pool. Postflow time should be increased so the appearance is like electrode "A" after welding.

Primarily two inert gases are used for shielding purposes for TIG. They are argon and helium. Shielding gases must be of high purity for welding applications. The purity required is at a level of 99.995%.

Although the primary function of the gas is to protect the weld pool from the atmosphere, the type of gas used has an influence on the characteristics and behavior of the arc and the resultant weld bead. The chief factor influencing the effectiveness of a shielding gas is the gas density. Argon, with an atomic weight of 40, is about one and a half times heavier than air and ten times heavier than helium which has an atomic weight of 4. Argon after leaving the torch nozzle tends to form a blanket over the weld, whereas helium tends to rise rapidly from the arc area. In order to obtain equivalent shielding, flow rates for helium are usually two to three times that of argon.

An examination of the characteristics and a comparison of these gases will serve as a guide to shielding gas selection.

Argon

Argon is obtained as a byproduct in the manufacturing of oxygen. Breaking down the contents of the atmosphere would approximately yield the following:

.9% Argon
78.0% Nitrogen
21.0% Oxygen
.1% Other rare gases

Looking at these percentages, it's evident that many cubic feet of air must be processed in order to obtain a cylinder of argon. The price of argon may vary widely depending on locality and volume purchased.

Argon may be obtained in the gaseous state in cylinders or as a liquid in specially constructed cylinders or in bulk tanks. As a liquid, argon will be at a temperature of slightly below -300˚ F (-184˚ C). The most commonly used size of cylinder contains 330 cubic feet (935 Liters) at 2640 p.s.i. (18,203 kPa) at 70˚ F (21˚ C). When large volumes are required a bulk liquid supply is most desirable and economical. Each gallon (3.785 liters) of liquid will produce approximately 112 cubic feet (317 L) of gaseous argon. Liquid argon may be obtained in cylinders containing up to 4,000 cubic feet (11.328 kL) of gaseous argon. If larger quantities are desired, a bulk liquid tank may be installed.

When choosing a shielding gas, a fact that must be considered is the ionization potential of the gas. Ionization potential is measured in volts and is the point where the welding arc will be established between the electrode and the workpiece through the shielding gas. In other words, it is the voltage necessary to electrically charge the gas so that it will conduct electricity. The ionization potential of argon is 15.7 volts. So this is the minimum voltage that must be maintained in the welding circuit to establish the arc or to weld with argon. The ionization potential is different for every gas and has a major effect on the arc and weld bead. The ionization potential for helium is 24.5 volts. Comparing two welding circuits, each being equal except for shielding gas, the arc voltage produced with argon would be lower than that produced by helium.

Argon has low thermal conductivity which means it is not a good conductor of heat. This results in a more compact, higher density arc. Arc density refers to the concentration of energy in the arc. With argon this energy is confined to a narrow or more "pinpointed" area.

Argon provides excellent arc stability and cleaning action even at low amperages.

Helium

Unlike argon, helium has high thermal conductivity. Due to this higher thermal conductivity, the arc column expands, reducing current density in the arc. The arc column will become wider and more flared out than the arc column with argon shielding gas. Figure 4.13 illustrates the two arc columns. The more flared out the arc column, the more work surface area is being heated. The heat at the center of the arc can move more readily downward toward the colder metal at the bottom of the workpiece. This results in a deeper penetrating arc. Figure 4.13 also illustrates the resultant weld beads and the difference in penetration produced by argon and helium.

It was mentioned previously that with an equivalent arc length, helium will produce a higher arc voltage than will argon. Since the total power is a product of voltage and amperage, it is apparent that more heat energy is available with helium. Helium or argon-helium mixtures are desirable on thick material and where high travel speeds are desired. The use of a 2:1 helium to argon gas mixture has also been shown to yield lower porosity welds in production situations by allowing wider variation in welding parameters. With helium shielding any slight variation of arc length can have quite an affect on arc voltage and consequently total arc power. For this reason, helium is not as desirable as argon for manual welding applications.

Because of its higher ionization potential, it is more difficult to start an arc with helium shielding gas, especially at lower amperages. Argon is used almost exclusively when welding at 150 amps and lower.

Because helium is a light gas, flow rates are usually two or three times higher than argon for equivalent shielding. The cost of helium is considerably more than argon, and with the increased flow rate, total cost of shielding goes up sharply. The cost must be weighed against increased penetration on thick material and the increased travel speed attainable.

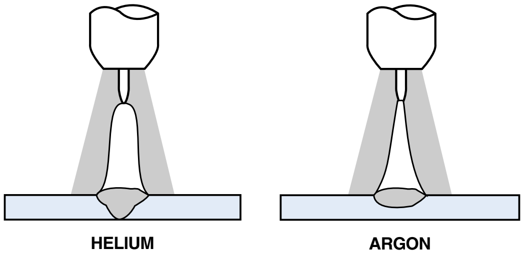


Figure 4.13 A representation of the affects on the arc and bead produced by argon and helium shielding gases. Note the wider arc and deeper penetration produced by the helium shielding gas.

Hydrogen

Just as helium is mixed with argon to take advantage of the best features of both gases, hydrogen is mixed with argon to further constrict the arc and produce a cleaner weld with a greater depth to width ratio (penetration). This mix is used primarily for welding austenitic stainless steel and some nickel alloys. The addition of hydrogen to argon also increases travel speed. It should be noted that an argon hydrogen mix will introduce the risk of hydrogen cracking and metal porosity particularly in multipass welds.

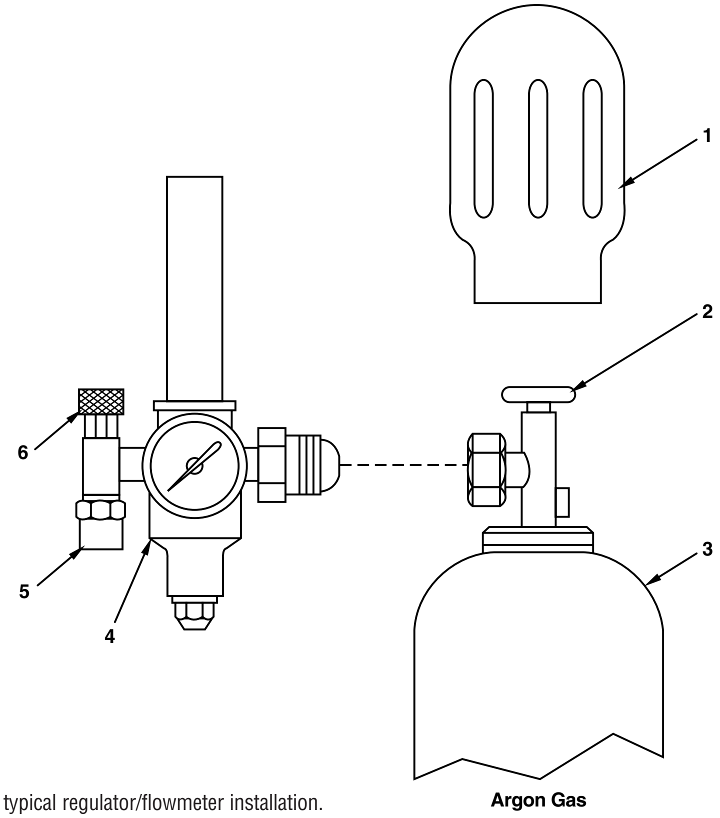
Nitrogen

Nitrogen when mixed with argon provides the capability of producing more energy to the work than with argon alone. This can be particularly beneficial when welding materials of high conductivity such as copper. However, a nitrogen mix cannot be used on ferrous metals such as steel and stainless steel because nitrogen pick up in the weld pool causes a significant reduction in strength and a weaker, more porous bead.

Flow Rate

The correct flow rate is an adequate amount to shield the molten weld pool and protect the tungsten electrode. Any greater amount than this is wasted. The correct flow rate in cubic feet per hour is influenced by many variables that must be considered on each application. Generally speaking, when the welding current, nozzle diameter, or electrode stickout is increased, the flow rate should be increased. When welding in the AC mode the current reversals have a disturbing affect on the shielding gas and flow should be increased by 25%. And of course when welding in a drafty situation, flow rate should be doubled. When welding corner or edge joints, excessive flow rates can cause air entrapment. In this situation, the effectiveness of the shielding gas can be improved by reducing the gas flow by about 25%.

Figure 4.15 The regulator/flowmeter regulates the flow of shielding gas from the cylinder to the welding torch. This meter displays the amount of pressure in the cylinder as well as the rate of flow.



Obtain gas cylinder and chain to running gear, wall, or other stationary support so the cylinder cannot fall and break off valve.

1. Cap

2. Cylinder Valve
Remove cap, stand to side of valve, and open valve slightly. Gas flow blows dust and dirt from valve. Close valve.

3. Cylinder

4. Regulator/Flowmeter
Install so face is vertical.

5. Gas Hose Connection
Fitting has 5/8 – 18 right-hand threads. Obtain and install gas hose.

6. Flow Adjust
Typical flow rate is 15 cfh (cubic feet per hour)
Make sure flow adjust is closed when opening cylinder to avoid damage to the flowmeter.

Figure 4.14 A typical regulator/flowmeter installation.

Preflow and Postflow

The purpose of both preflow and postflow is to prevent contamination of both the weld pool and the tungsten electrode by the surrounding atmosphere.

When the torch is not in use, air will enter the system through the nozzle. Moisture in the air can condense inside the nozzle and gas hose and then cause hydrogen contamination during initial stages of the weld. The shielding gas preflow will clear the air and moisture from the torch and prevent this contamination.

Postflow works a little differently. Immediately after the welding arc is extinguished, the weld bead, filler rod and the tungsten electrode remain hot enough to cause a chemical reaction with oxygen in the atmosphere. The result of this oxidization is quite obvious when it occurs because it causes the weld bead, filler rod and tungsten to turn black. Proper postflow will prevent oxidization from occurring by shielding the hot electrode and weld area, and by speeding up the cooling process. It should be remembered that a tungsten that has discolored because of oxidization must be properly removed.

Backing Dams and Trailing Shields

Just as the surface of the weld bead must be protected from atmospheric contamination, the backside must be protected as well. In the case of pipe welding or other full penetration butt joints, this can be accomplished with a backing dam, as seen in Figure 4.16. Often a backing dam can be something as simple as heavy paper used to close off the ends of the pipe through which a gas hose is passed to fill the pipe with shielding gas to elaborate diaphragms, hoses and valves. A length of angle iron can be clamped to the backside of straight line weldments to hold the gas in place for that type of weld.

In some cases where the weld occurs too fast for the torch supplied shielding gas to protect the pool and tungsten, a trailing shield may be used. Trailing shields are available as separate devices that attach to the torch or torch nozzle. Back or trail shielding is required on reactive metals like titanium, duplex steels, stainless steels, etc. This type shielding keeps the welds bright and shiny without discoloration and oxidation, thus reducing rework due to contamination.

Figure 4.16 A welder prepares to install a backing dam over the end of a pipe to be welded.

GTAW and Use of Filler Metal

The GTAW tungsten electrode is a nonconsumable (does not melt) and thus does not become part of the weld, as do SMAW or GMAW electrodes that melt and become filler metal which adds to the weld volume. This is advantageous on thin materials (usually under 1/16") where the GTAW weld fuses the edges of the base materials together. This is referred to as an "autogenous" weld (no filler), and is common on thin metal butt, lap and flange joints.

Welds on thicker metals (about 1/16" and up), beveled joints and poor fitup joints may need filler wire added to the weld pool for proper fusion and weld strength. This is usually done by hand feeding the filler wire into the pool. The filler rod diameter should be approximately the same as the electrode diameter. The hot end of the filler rod should be kept in the blanket of shielding gas and/or postflow until it has cooled below its oxidation temperature.

Automated GTAW uses a wire feeder to automatically feed a continuous wire into the weld pool as the weld proceeds along the joint. Figure 3.37 on page 30 shows this type of equipment.

Types of GTAW Filler Metals

Perhaps the most common filler material for GTAW takes the form of 36" straight rods that are fed by one hand while the other hand manipulates the torch. Figure 4.17 shows standard sizes for filler rods, according to the American Welding Society. These rods usually come in 10 or 50 pound boxes or tubes and often have the wire type on a tag or stamped into the side of each piece of filler rod. TIG is preferred for critical work that is generally done to a code and approved welding procedures. To maintain control the filler metal must be identifiable.

Standard Sizes[a]

Standard Package Form	Diameter in.	Diameter mm	Tolerance[b] in.	Tolerance[b] mm
Straight lengths[b,c] and Coils without support	1/16 (0.0625)	1.6	±0.0015	±0.04
	3/32 (0.094)	2.4		
	1/8 (0.125)	3.2		
	5/32 (0.156)	4.0		
	3/16 (0.187)	4.8		
	1/4 (0.250)	6.4		

Notes:

a. Dimensions, tolerances, and package forms (for round filler metal) other than those shown shall be agreed by purchaser and supplier.

b. There is no specified tolerance for cast rod in straight lengths.

c. Length of wrought rods shall be 36 in.,+0. — − 1/2 in. (approximately 900 ± 20 mm). Length of cast rods shall be 18 in. ± 1/2 in. (approximately 450 ± 12 mm)

Figure 4.17 Sizes of GTAW filler rod.

Also used to a lesser degree are flattened rods. These are preferred by some welders who feel it is easier to feed the rods because of their shapes. Figure 4.18 shows sizes of flattened rods.

Another type of filler material is coiled wire for automated GTAW. This would be the same wire used on a given material for the GMAW process.

Typical Sizes of Flattened Rods*

Equivalent Round Diameter		Thickness		Width	
in.	mm	in.	mm	in.	mm
1/16	1.6	0.047	1.2	0.072	1.8
3/32	2.4	0.070	1.8	0.105	2.7
1/8	3.2	0.095	2.4	0.142	3.6
5/32	4.0	0.115	2.9	0.175	4.4
3/16	4.8	0.140	3.6	0.210	5.3
1/4	6.4	0.187	4.8	0.280	7.1

*Standard length shall be 36 in. +0, –1/2 in. (approximately 900 ±20 mm).

Figure 4.18 Flattened rod sizes for GTAW.

Filler Metal Specifications

The American Welding Society (AWS) publishes several booklets of specifications for GTAW filler materials. Often these booklets are used as specifications for GMAW electrode wires as well. Figure 4.19 is a list of AWS filler material, shielding gas and tungsten electrode specification booklets.

A5.7	Copper and Copper Alloy Bare Welding Rods and Electrodes
A5.9	Corrosion Resisting Chromium and Chromium-Nickel Steel Bare and Composite Metal Cored and Stranded Welding Electrodes and Welding Rods
A5.10	Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods
A5.12	Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting
A5.13	Solid Surfacing Welding Rods and Electrodes
A5.14	Nickel and Nickel Alloy Bare Welding Rods and Electrodes
A5.16	Titanium and Titanium Alloy Welding Electrodes and Rods
A5.18	Carbon Steel Filler Metals for Gas Shielded Arc Welding
A5.19	Magnesium Alloy Welding Rods and Bare Electrodes
A5.21	Composite Surfacing Welding Rods and Electrodes
A5.24	Zirconium and Zirconium Alloy Bare Welding Rods and Electrodes
A5.28	Low Alloy Steel Filler Metals for Gas Shielded Arc Welding
A5.30	Consumable Inserts
A5.32	Welding Shielding Gases

Figure 4.19 AWS specifications for GTAW filler materials, shielding gases and tungsten electrodes.

Types and Designations of Filler Metals

Steel

There are seven designations for carbon steel filler rods. A typical designation would be ER70S-6 for TIG. The "ER" means the filler can be used for either GTAW or GMAW. If the designation lacked the "R" it would signify a continuous electrode for use with GMAW only. There is no designation for rod using just the "R", it will always be "ER". The "70" stands for the welded tensile strength, measured in thousands of pounds per square inch. "S" stands for "Solid" electrode as opposed to a tubular or hollow wire such as that used in the flux cored welding process. And the "6" refers to the particular degree of manufactured chemical percentages within the rods composition. In other words, the number at the end of the description refers to which classification of wire is being used.

Stainless Steels

There are many more stainless steel designations than there are steel designations. A typical classification of a stainless rod would be ER308. The "ER", as it is in steel, stands for either continuous electrode, or electrode rod. The "308" designates a specific stainless steel chemical composition. These numbers are often used to match the filler rod to specific compositions of base metals being welded.

Certain types of stainless steel rods may have letters or numbers after the three digits, such as "L" meaning low carbon content, or "Si" meaning high silicon content. Sometimes a manufacturer's brand name may use "ELC" instead of "L" to mean Extra Low Carbon, or "HiSil" instead of "Si" meaning High Silicon Content.

It's important to remember the "ER" designations because the AWS has separate specification books for "ER" filler metals and for "E" filler metals. "E" filler metals, such as E308-16, would refer to covered welding electrodes, such as those used for SMAW (Stick).

Titanium

There are approximately 13 different designations for titanium filler rods. A typical designation would be ERTi-5ELI. The "ER" means the filler can be used for either GTAW or GMAW. The "Ti" indicates titanium, the "5" is specific characteristics such as alloy content, and the "ELI" means extra-low interstitial impurities. If the base metal has extra-low interstitial impurities the filler metal selected should also carry the same classification. The interstitial nature of elements such as carbon, hydrogen, oxygen and nitrogen are kept very low with the ELI classification.

When welding titanium and its alloy, the filler metal should closely match the alloy content of the base metal being welded. The ERTi-1, -2, -3 and -4 are designations for commercially pure titanium (CP) welding. These unalloyed filler metals can tolerate some contamination from the welding atmosphere without significant loss in ductility. Unalloyed filler metals may be used to weld titanium alloys when ductility is more important than joint strength. Less than 100% joint efficiencies can be expected.

Filler metal contamination is very serious when welding titanium. The filler wire should be wiped clean with acetone and a lint-free cloth. Cleaning should continue until the cloth is free from any indications of contamination. The filler wire should also be inspected for any physical defects such as cracks, seams or laps. These defects may trap contaminations making them difficult or impossible to remove. To prevent recontamination of the filler rod, it should be handled after cleaning in a so-called “white glove” procedure (clean lint free gloves).

Aluminum

There are approximately 12 designations for aluminum filler rods. A common all purpose rod is ER4043. The “ER” designates electrode or rod, and the “4043” designates a specific chemical composition. ER4043 is used with many aluminum base metals, but always consult electrode wire manufacturers for the proper filler to use in critical welds. Figure 4.20 contains some typical examples.

Base Metal, (T)Temper	Filler Metal
1100	ER1100
2014-T6	ER4043
2219-T81	ER2319
3003	ER1100
5005	ER5356
5456	ER5556
6061-T4	ER4043
6061T-6	ER5356
7005T-53	ER5356

Figure 4.20 Typical aluminum base metal filler metal recommendations.

Figure 4.21 represents some GTAW filler metals cross referenced between the AWS classification number and a typical manufacturers specification number.

Table 3.6
Guide to the Choice of Filler Metal for Aluminum

Base Metal	319.0,333.0 354.0,355.0 C355.0,380.0	356.0,A356.0 A357.0,359.0 413.0,A444.0 443.0	511.0,512.0 513.0,514.0	7005^{k},7039 710.0,711.0 712.0	6070	6061 6063.6101 6201,6151 6351,6951	5456	5454	5154 5254^{a}	5086	5083	5052 5652^{a}	5005 5050	3004 Alc.3004	2219 2519	2014 2036	1100 3003 Alc.3003	1060 1070,1080 1350
1060,1070, 1080,1350	$4145^{c,i}$	$4043^{i,f}$	$4043^{e,i}$	4043^{i}	4043^{i}	4043^{i}	5356^{c}	4043^{i}	$4043^{e,i}$	5356^{c}	5356^{c}	4043^{i}	1100^{c}	4043	4145	4145	1100^{c}	1188^{j}
1100,3003 Alclad 3003	$4145^{c,i}$	$4043^{i,f}$	$4043^{e,i}$	4043^{i}	4043^{i}	4043^{i}	5356^{c}	$4043^{e,i}$	$4043^{e,i}$	5356^{c}	5356^{c}	$4043^{e,i}$	4043^{e}	4043^{e}	4145	4145	1100^{c}	
2014,2036	4145^{g}	4145			4145	4145									4145^{g}	4145^{g}		
2219,2519	$4145^{g,c,i}$	$4145^{c,i}$	4043^{i}	4043^{i}	$4043^{f,i}$	$4043^{f,i}$	4043	4043^{i}	4043^{i}	4043	4043	4043i	4043	4043	$2319^{c,f,i}$			
3004 Alclad 3004	4043^{i}	4043^{i}	5654^{b}	5356^{e}	4043^{e}	4043^{b}	5356^{e}	5654^{b}	5654^{b}	5356^{e}	5356^{e}	$4043^{e,i}$	4043^{e}	4043^{e}				
5005,5050	4043^{i}	4043^{i}	5654^{b}	5356e	4043^{e}	4043^{b}	5356^{e}	5654^{b}	5654^{b}	5356^{e}	5356^{e}	$4043^{e,i}$	$4043^{d,e}$					
$5052,5652^{a}$	4043^{i}	$4043^{b,i}$	5654^{b}	5356^{e}	$5356^{b,c}$	$5356^{b,c}$	5356^{b}	5654^{b}	5654b	5356^{e}	5356^{e}	$5654^{a,b,c}$						
5083		$5356^{c,e,i}$	5356^{e}	5183^{e}	5356^{e}	5356^{e}	5183^{e}	5356^{e}	5356^{e}	5356^{e}	5183^{e}							
5086		$5356^{c,e,i}$	5356^{e}	5356^{e}	5356^{e}	5356^{e}	5356^{e}	5356^{b}	5356^{b}	5356^{e}								
$5154,5254^{a}$		$4043^{b,i}$	5654^{b}	5356^{b}	$5356^{b,c}$	$5356^{b,c}$	5356^{b}	5654^{b}	$5654^{a,b}$									
5454	4043^{i}	$4043^{b,i}$	5654^{b}	5356^{b}	$5356^{b,c}$	$5356^{b,c}$	5356^{b}	$5554^{c,e}$										
5456		$4043^{b,i}$	5356^{e}	5556^{e}	5356^{e}	5356^{e}	5556^{e}											
6061,6063, 6351,6101 6201,6151, 6951	$4145^{c,i}$	$5356^{c,e,i}$	$5356^{b,c}$	$5356^{b,c,i}$	$4043^{b,i}$	$4043^{b,i}$												
6070	$4145^{c,i}$	$4043^{e,i}$	$5356^{c,e}$	$5356^{c,e,i}$	$4043^{e,i}$													
7005^{k},7039, 710.0,711.0 712.0	4043^{i}	$4043^{b,i}$	5356^{b}	5356^{e}														
511.0,512.0 513.0,514.0		$4043^{b,i}$	$5654^{b,d}$															
356.0,A356.0 A357.0,359.0 413.0 A444.0,443.0	$4145^{c,i}$	$4043^{d,i}$																
319.0,333.0 354.0,355.0, C355.0,380.0	$4145^{d,c,i}$																	

NOTES:

1- Service conditions such as immersion in fresh or salt water, exposure to specific chemicals or a sustained high temperature (over 150 °F) may limit the choice of filler metals. Filler alloys 5356, 5183, 5556, and 5654 are not recommended for sustained elevated temperature service.

2- Recommendations in this table apply to gas shielded arc welding processes. For gas welding, only 1100, 1188, and 4043 filler metals are ordinarily used.

3- All filler metals are listed in AWS specification A5.10.

a Base metal alloys 5652 and 5254 are used for hydrogen peroxide service. 5654 filler metal is used for welding both alloys for low temperature service (150°F and below)

b 5183, 5356, 5554, 5556, and 5654 may be used. In some cases they provide: (1) improved color match after anodizing treatment; (2) highest weld ductility, and (3) higher weld strength. 5554 is suitable for elevated temperature service.

c 4043 may be used for some applications.

d Filler metal with the same analysis as the base metal is sometimes used.

e 5183, 5356, or 5556 may be used.

f 4145 may be used for some applications

g 2319 may be used for some applications

i 4047 may be used for some applications

j 1100 may be used for some applications

k This refers to 7005 extrusions only (X-prefix still applies to sheet and plate).

4- Where no filler metal is listed, the base metal combination is not recommended for welding.

Figure 4.21 Cross reference chart on GTAW filler metals. Courtesy of the Aluminum Association.