



DIAMOND GROUND PRODUCTS, INC.

TUNGSTEN GUIDEBOOK

**GUIDEBOOK FOR THE PROPER SELECTION AND
PREPARATION OF TUNGSTEN ELECTRODES FOR
ARC WELDING**

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This *Guidebook for the Proper Selection and Preparation of Tungsten Electrodes for Arc Welding* is an effort to provide information for use by welders in various industries.

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1 Introduction

This specification is intended to assist welders in selecting and preparing one of the most important and frequently overlooked welding process variables: the electrode. Welders can spend thousands of dollars on welding equipment, but if they do not select and prepare their electrodes with this less expensive process component properly, then their welding results can be poor, inconsistent, or problematic. This guide will help eliminate this variable as a concern in your welding and make it an asset.

This information applies only to the selection and preparation of electrodes for Gas Tungsten Arc Welding (GTAW), also known as Tungsten Inert Gas (TIG) welding and Plasma Arc Welding (PAW). The different types of GTAW and PAW welding that this applies to includes but is not limited to Orbital Tube and Pipe Welding, Automatic/Mechanized TIG Welding, "Micro-TIG," Automatic/Mechanized Plasma Welding, "Micro-Plasma," and Manual Arc Welding. The section of this booklet that describes the proper electrode grinding techniques is dedicated almost entirely to direct current welding, since electrodes for alternating current welding are usually balled and not ground.

GTAW is used in many industries, including Aerospace, Semiconductor, Biotechnology/Pharmaceutical, Tube Producers, Contractors, Automotive, Fitting and Valve Manufacturers, Industrial, Nuclear, and Specialty Gases.

Table 1: Applications for Correctly Ground, Cut and Prepared Tungsten Welding Electrodes For TIG Welding Applications

Orbital TIG/ Tube Welding	To produce the high quality orbital fusion welds required of today's high tech industries, tungsten electrode shape is an important variable that must be kept consistent. Most orbital manufacturers require a precise tungsten length.
Orbital TIG/ Pipe Welding	Orbital pipe welding application using TIG is primarily limited to the nuclear, pharmaceutical, and chemical processing industries. These industries, along with a few not mentioned, require X-ray perfect orbital pipe welds in the 125 amp - 300 amp current range. A consistently prepared electrode is required for consistent current flow and arc voltage characteristics. Most orbital pipe welders use 3/32 or 1/8 diameter electrodes. They also must be cut-to-length, however, not as precise as the orbital tube welder.

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Mechanized TIG Welding	Mechanized Tig Welding encompasses a wide spectrum of applications such as precision bellows welding using .040 diameter tungsten electrode at 1.0 ampere up to high speed tube mills welding with a .250 diameter tungsten electrode using current as high as 600 amperes. A precise yet consistent electrode will have a dramatic effect in weld results and tungsten electrode life. Cutting the tungsten electrode is usually required if the electrode is grossly contaminated.
Manual TIG Welding	Arc starting and arc stability from a consistently prepared tungsten electrode will be beneficial to the manual welder. Most hand welding 'FIG torches require a 7.0" long electrode be cut in half to fit the manual welding torch. This can be accomplished best with the diamond cutting mechanism described in this booklet.
Manual & Mechanized Plasma Arc Welding	The plasma arc welding process requires a very precisely shaped, tungsten electrode. The tip of the tungsten must be kept concentric to the diameter to place it in the correct position centered in the plasma torch. This is a critical parameter adjustment in plasma arc welding. Most plasma welding torches also require a cut-to-length tungsten electrode.

The technical details of TIG and PLASMA arc welding are that an electric arc is transferred from a tungsten electrode to a work piece. Typically, to initiate the arc, high voltage is used to break down and ionize the shielding gas between the electrode and the work piece. Current is then transferred from the electrode to the work to create an electric arc. The tungsten electrode serves as the terminal for the electric arc and fuses together either with or without filler material. Although there are different methods of arc initiation, high voltage arc starting is the standard used in this guidebook.

There are several variables to consider in a welding procedure. Tungsten electrode geometry affects the arc shape (thereby affecting the weld bead size and shape), the weld penetration, and point longevity of the electrode. Proper electrode grinding procedures and equipment should be used in order to ensure that electrodes are dimensionally correct. Finally, different tungsten materials possess different characteristics in arc start ability, electrode life, and contamination resistance. This makes the selection of the proper material for your application an important variable in welding performance. The proper preparation of electrodes in each of these areas will provide the benefits of consistent welding with optimum performance.

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2 Choosing the Proper Tungsten

The proper tungsten material to use for an application depends on many variables, including the type of weld, the composition of the material being welded, the amperage level, among other factors. The following section discusses available options and highlights the accepted standards. The recommendations provided are based on information from industry end users and tungsten manufacturers. However, because of the many variables present in the welding process, it is difficult to generalize. The best way to determine which tungsten material is best suited for a particular application is through testing.

2.1 The Basics

Diameters and Lengths: Tungsten Electrodes are available in a variety of standard diameters and lengths. The most commonly used diameters are shown in Table 2.

Table 2: Common Tungsten Electrodes (U.S. and Metric Measurements)

U.S. Customary Measurements	Metric Measurements
.040"	1.0 mm
1/16" (.062" and .060")	1.6 mm
3/32" (.093")	2.4 mm
1/8" (.125")	3.2 mm
5/32" (.156")	4.0 mm
3/16" (.187")	4.8 mm

In addition to these sizes, some manufacturers also offer .020" (0.5mm) and ¼" (6.4 mm) tungsten. The most common length is 7.00" (175 mm). Tungsten is normally sold in boxes of 10 pieces.

Current Ranges: Refer to Table A.2 of AWS A5.12M/A5.12:2009 *Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting*. The American Welding Society document provides a table that shows the general current ranges for tungsten using Direct Current (DC) and Alternating Current (AC). All values listed are based on using argon as the shielding gas. Different electrode materials will vary slightly from these guidelines. Use of other gases will also change the recommended currents. As such, this chart should be used as a general guide. Also keep in mind that for a given amount of amperage, larger diameter electrodes will last longer, but will be harder to arc start. Excessive current will cause the electrode to melt and drop off. Insufficient current will lead to unstable arc.

International Color Coding Chart: Each stick of tungsten has a color code applied to one end which identifies the material type of the tungsten. Refer to Table 1 of AWS A5.12M/A5.12:2009 *Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting*. The American Welding Society document provides a table that identifies the color coding used in United States, Europe, and Japan, which represent the bulk of the market share of sold tungsten.

Standards: The United States, Europe, and Japan each have a published standard for tungsten as shown in Table 3. These standards dictate the dimensions, packaging, and manufacturing requirements that tungsten must meet. However, meeting these standards does not guarantee that a particular tungsten was manufactured by a high-quality manufacturer.

Table 3: Tungsten Standards

Market Area	Standard Name
United States	ANSI/AWS A5.12
Canada	ASME/SFA
Europe	ISO 6848
Japan	JIS

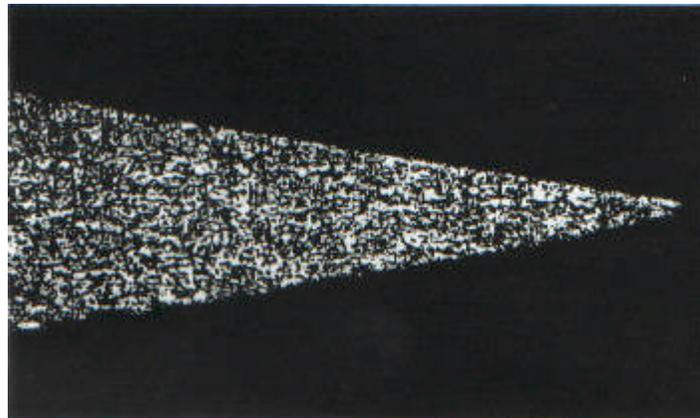
2.2 Determinants of Tungsten Performance

In most applications, welders use tungsten that contains an emission-enhancing oxide such as Thorium, Cerium, or Lanthanum. These oxides naturally migrate from inside the tungsten to the heat at the point of the electrode, where they give off their oxide element in the arc, and leave a film of the metal alloy on the tip. This causes the electrode to have a different temperature at the tip based on the work function of that element. The oxides that are emitted at the tip serve to improve arc starting and stability. They also cause the electrode to provide the same level emission as pure tungsten at much lower temperatures. Lower temperatures improve the longevity of the tungsten and keep the grains within the tungsten smaller for improved arc stability. Thus, oxides are a very important part of tungsten. Each oxide has unique physical characteristics that affect tungsten performance. In addition, the technique used in manufacturing the tungsten will also affect its performance.

2.2.1 Manufacturing Variables

Grain Size and Structure: Figure 1 shows the molecular structure of the inside of a point of tungsten and how it is divided into smaller groups called grains. Oxides migrate to the tip of the tungsten primarily along the boundaries or borders of these grains. It is much easier for the oxides to migrate from inside the tungsten to the tip on the grain boundaries than it is for them to migrate within the crystallized grains. In manufacturing the tungsten, smaller sized grains are better, because they produce more paths and therefore the oxides can more easily migrate to the tip. However, it is a difficult manufacturing process to minimize the size of the grains while maximizing the consistency of the oxide distribution and maintaining the proper quantity of oxides. This difficulty in the manufacturing process is the primary reason for the differences in tungsten performance quality that is produced by the different manufacturers.

Figure 1: Molecular Structure of the Inside Point of Tungsten



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During the extreme temperatures of welding, the grains have a tendency to combine with larger neighboring grains to form one large grain in a process called “grain growth.” However, if a continuous flow of oxides at the grain boundaries is maintained, this serves to surround the grains and keep them from combining. Thus, oxides are grain growth inhibitors. When tungsten runs out of oxides in any area, the grains combine readily, and the tungsten performs poorly because the oxides lack avenues to move to the surface. In Figure 1 the 2% Lanthanated electrode still has a very small grain structure even after one hour of welding time at 180 amps on a 1/16” electrode. This condition is the result of quality manufacturing and the oxide properties of 2% Lanthanated tungsten.

Oxide Distribution and Size: Oxide distribution is a key indicator of quality. Oxides should be distributed homogenously throughout the tungsten. Uneven distribution results in poor performance: areas with little or no oxides will tend to suffer from grain growth, whereas areas with too much oxide will tend to “bottleneck” and prevent the oxides from getting to the point. Higher quality oxides are smaller in size, which allows them to migrate to the tip easier.

2.2.2 Physical Characteristics of Different Oxides

Electron Work Function (eV): Work function is the energy needed to remove an electron from an atom, and it is measured in electron volts (eV). The lower the work function of an electrode, the lower the voltage necessary to strike an arc, thus the easier the arc starts. The oxides added to a tungsten serve to promote the electron emission by lowering the work function of the tungsten. Table 4 lists different oxides and metals and their respective work functions. The lower the eV for the oxide, the easier it will start. The metal work function is important, because upon emitting an oxide, the metal is left as a film on the tip. The lower the eV of the metal at the tip, the lower the temperature will be at the tip which will decrease grain growth and provide a constant flow of oxides and longer service life.

Table 4: Physical Properties of Oxides

Material	Oxide eV	Metal eV
Lanthanum	2.5	3.3
Thorium	2.6	3.35
Cerium	3.2	2.84
Pure Tungsten	No oxide present	4.5

The more of an oxide added to tungsten, the lower the work function that tungsten will have, and thus the better it will arc start. A 2% Lanthanated tungsten will arc start more easily than a 1% Lanthanated tungsten (assuming they were made using the same manufacturing process).

Note: It is difficult to compare different types of electrodes without testing because of the different properties of the oxides.

Density: Each oxide has a different density. Thus a 2% by weight thorium, cerium, or lanthanum electrode will all have different amounts of oxides by volume. Table 5 describes the difference between density and weight for different materials.

Table 5: Density versus Weight of an Oxide in a Material

Material	Density (g/cm ³)	Volume % of 2% by weight electrode
Lanthanum	6.15	5.7
Thorium	11.72	3.8
Cerium	6.65	5.2

Although each material has 2% by weight of the oxides, a 2% Lanthanated tungsten has a significantly higher volume of oxides than 2% Thoriated tungsten to feed to the tip.

Note: Even if electrodes are the same type, electrodes of different manufacturers cannot be compared using only the work function and volume of oxides, because this comparison would not take into account the important manufacturing variables such as grain size and structure of the oxide size and distribution. Therefore, the work function and oxide density numbers should only be used as a general guide. Testing is always the best way to determine which tungsten will be best for you.

Migration and Evaporation Rates: The migration rate, or diffusion rate as it is often called, is the rate at which each of the different oxides naturally travels from inside the tungsten to the heat at the tip of the electrode. The evaporation rate is the rate at which the oxides separate from their metal component and are emitted at the tip of the electrode. The optimum-performing electrode is one that has a balance of good migration and evaporation rates. If the migration rate is slower than the evaporation rate, then there will be an inadequate amount of oxides arriving at the tip to maintain a consistent arc and the tungsten may be reduced to the performance level of pure tungsten. If the evaporation rate is slower than the migration rate, the oxides will be crowded at the point. If both of the rates are very high, welding properties at the beginning of welding will be great, but all of the oxides may be used up quickly.

2.3 Oxide Types

The following provides a description of the general characteristics of common oxide types. Keep in mind that testing is the only way to determine which tungsten is optimal for a particular application.

2.3.1 Thoriated (EWTh-1 Yellow Stripe Electrode Classifications: Yellow Stripe; and EWTh-2 Electrode Classifications: Red Stripe)

Thoriated tungsten contains thorium oxide (THO₂ or thoria), and it is the most commonly used tungsten in America. It has become the standard for comparison. However, because it is a low-level radioactive hazard, many users have switched to other alternatives. 2% Thoriated tungsten is a good general use tungsten. It has one of the lowest work functions, and it performs well when overloaded with extra amperage. However, it does not hold its point as well as some other non-radioactive tungstens that have been introduced.

Two types of Thoriated tungsten electrodes are available. The EWTh-1 and EWTh-2 electrodes contain 1 percent and 2 percent, respectively, evenly dispersed through their entire lengths. Thoriated tungsten electrodes are superior to pure tungsten electrodes in several respects. The thoria provides about 20 percent higher current-carrying capacity, generally longer life, and greater resistance to contamination of the weld. With these electrodes, arc starting is easier, and the arc is more stable than with pure tungsten or Zirconiated tungsten electrodes. The EWTh-1 and EWTh-2 electrodes were designed for DCEN applications. They maintain a sharpened tip configuration during welding, which is desirable for welding steel. They are not often used with AC because it is difficult to maintain the balled end, which is necessary with AC welding, without splitting the electrode.

Note: Regarding the radioactivity, thorium is an alpha emitter, but when it is enclosed in a tungsten matrix the risks from radioactivity are negligible. Thus holding a stick of Thoriated tungsten in your hand should not pose a great threat unless a welder has open cuts on their skin. Thoriated tungsten should not get in contact with open cuts or wounds. The more significant danger to welders can occur if thorium oxide gets into the lungs. This can happen from the exposure to vapors during welding or from ingestion of material/dust in the manufacture and grinding of the tungsten. Therefore, precautions should be taken when welding. The use of an exhaust system should be implemented to remove the grinding dust from the work area. Proper disposal in an environmentally-friendly way is also a responsibility. Europe has discussed eliminating the use of thorium altogether because of these problems. Welders should obtain current information on the subject for a complete understanding.

2.3.2 Ceriated (EWCe-2 Electrode Classification: Grey/ Formerly Orange Stripe)

Ceriated tungsten was introduced into the United States in the early 1980s as the first non-radioactive alternative to Thoriated tungsten. It is most commonly offered as 2% Ceriated tungsten, and it is readily available. The EWCe-2 electrodes are tungsten electrodes containing 2 percent cerium oxide (CeO₂), referred to as ceria. It is known to be especially good for DC welding with low amperage because it starts very easily at low amps and usually requires about 10% less amps than Thoriated material to operate. Thus it is the most popular material used for orbital tube and pipe welding, and it is also commonly used for welding very small parts. Compared with pure tungsten, the Ceriated electrodes exhibit a reduced rate of vaporization or burn-off. These advantages of ceria improve with increased ceria content. Cerium also has the highest migration rate so it gives it good welding properties at the beginning, but it has a significantly reduced migration rate over time due to grain growth. However, at lower amperages it should last longer than Thoriated tungsten. Because of these properties, it is generally good for short welding cycles or when a specific number of welds are called for and then the electrode is to be replaced. Higher amperage applications are best left to Thoriated or Lanthanated material. EWCe-2 electrodes will operate successfully with AC or DC, however, it is used primarily for DC welding as it may split if used for AC welding.

2.3.3 Lanthanated (EWLa Electrode Classification)

The most common Lanthanated tungsten contains 2 percent lanthanum oxide (La₂O₃), referred to as lanthana. In Europe and Japan, Lanthanated tungsten has been the most popular alternative to 2% Thoriated tungsten for most applications. It is available as 2%, 1.5%, and 1% Lanthanated tungsten. Lanthanum Trioxide has the lowest work function of any of the materials thus it usually starts easiest and has the lowest temperature at the tip, which resists grain growth and promotes longer service life. Testing of 2% Lanthanated material has shown that it offers a much longer life than Thoriated if not overloaded and better arc starting in most applications. It is also especially good at (a) resisting the "Thermal shock" of pulsing, (b) working in welding in situations where there are numerous re-ignitions with a short weld cycle, and (c) resisting contamination. Welders with tube mill applications have been especially satisfied with this material because its longer life reduces down time. Also, as a general rule it will probably require about 15% less amps to start and sustain low current arcs. The Lanthanum in this tungsten is a "rare earth" material and is not radioactive. It has not been as heavily marketed and used in the United States as in Europe or Japan, however Diamond Ground Products, Inc. has been offering this material since 1993. This tungsten is primarily used for DC welding, but will also show good results for AC welding. The EWLa-1 electrodes were developed around the same time as the Ceriated electrodes and for the same reason, that lanthanum is not radioactive. These electrodes contain 2 percent lanthanum oxide (La₂O₃).

2.3.4 Zirconiated Tungsten (EWZr01 Electrode Classification: Brown Stripe; and EWZr-8 Classification: White Stripe)

Zirconiated tungsten electrodes (EWZr) contain a small amount of zirconium oxide (ZrO₂). Zirconiated tungsten electrodes have welding characteristics that generally fall between those of pure and Thoriated tungsten. Zirconiated tungsten is most commonly used for AC welding because it balls up well in AC welding and has a more stable arc than pure tungsten. It also resists contamination well in AC welding. However, while it has better current carrying and arc starting characteristics than pure tungsten, on the whole it is the worst non-radioactive tungsten from a performance standpoint.

2.3.5 Pure Tungsten (EWP Electrode Classification: Green Stripe)

Pure tungsten electrodes (EWP) contain a minimum of 99.5 percent tungsten, with no intentional alloying elements. Pure tungsten has a very high work function, and thus it is more difficult to start and produce a stable arc than other materials. Also, because of the high work function, the temperature at the tip is higher and grain growth occurs. This leads to an unstable arc, starting difficulty, and a shorter service life. Pure tungsten is only used for AC welding; however, better alternatives are available.

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2.3.6 Other Options

In addition to the materials listed above, there are other less common materials, such as 1% Thoriated, 4% Thoriated, 2% Yttriated, and also mixes of different oxides in the same tungsten. Diamond Ground Products, Inc. introduced tungsten called TRI MIX™, which combines three non-radioactive materials into one tungsten. The goal was to make the best possible tungsten by balancing the migration and evaporation rates, while keeping the work function down. It starts and re-ignites very well, and it offers a particularly excellent service life in welding situations where welding cycles of at least 15 minutes are used. Technical studies in Japan have shown that mixed tungsten is very successful in optimizing welding, and thus it is expected that more of this type of product will become available in the U.S. market. The Japanese and European markets are already recognizing the benefits of combining three non-radioactive oxides into one electrode. Cryo-T tungsten is a Thoriated tungsten that has been treated with a multi-step cryogenic process. This process produces a more dense structure of the Thoriated tungsten blend. User testing has shown that Cryo-T tungsten has resulted in:

- Easier starting compared to 2% Thoriated tungsten.
- A much longer tip life compared to non-treated 2% Thoriated tungsten electrodes.
- More consistent welds as a result of crisp starts.
- Longer overall electrode life when compared to a 2% Thoriated tungsten.
- Higher amperage tolerance as compared to a 2% Thoriated tungsten.

Cryo-T is recommended for all current users of 2% Thoriated tungsten.

2.3.7 Electrode Sizes and Current Capacities

Selecting the correct electrode for specific applications must take into account the different current levels and power supplies. Current levels that are in excess of those recommended for a given electrode size and tip configuration will cause the tungsten to erode or melt. Tungsten particles may fall into the weld pool and become defects in the weld joint. Current levels that are too low for a specific electrode diameter can cause arc instability. Direct current with the electrode positive requires a much larger diameter to support a given level of current, because the tip is not cooled by the evaporation of electrons but heated by their impact. In general, a given electrode diameter on DCEP would be expected to handle only 10 percent of the current possible with the electrode negative. With alternating current, the tip is cooled during the electrode negative cycle and heated when positive. Therefore, the current carrying capacity of an electrode on AC is between that of DCEN and DCEP. In general, it is about 50 percent less than that of DCEN.

2.4 Determining Which Tungsten to Use

Testing is the best way to determine which tungsten material is best for a particular application and/or which manufacturer produces a high quality tungsten. Document the following properties of the different tungsten when testing in order to compare products.

Ease of Ignition (arc starting)	Ease of first arc start
	Ease of re-ignition of same tip after previous use(s)
Service Life	Maximum number of ignitions
	Retention of tip geometry during use
Quality of Welds	Arc shape
	Arc stability
	Quality of welding joint
	Depth of weld pool
Power Consumption	Compare amount of power used

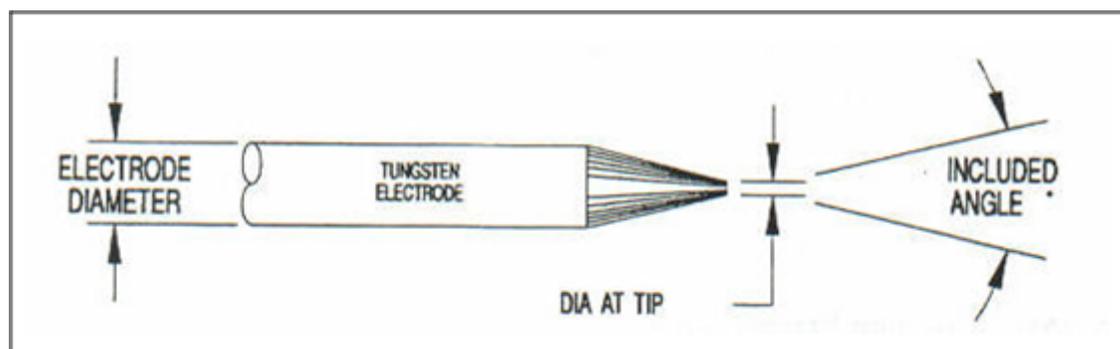
Utilizing materials that last longer and improve arc starting can lower costs and improve the welding process. In addition, reduced down time in replacing and preparing new electrodes is a substantial savings to consider.

3 Proper Preparation

3.1 Electrode Geometry

Tungsten electrodes may be used with a variety of tip geometries. In AC welding, pure or Zirconiated tungsten electrodes are usually used and are melted to form a balled end. This section of the guidebook is dedicated to grinding electrodes for DC welding. The complete geometry for DC welding is comprised of the electrode diameter, the included angle (a.k.a. taper) and the tip (flat) diameter. In addition, the surface finish of the grind is also important.

Figure 2: Electrode Geometry



Choosing the best electrode geometry requires compromise among various attributes such as: shorter to longer electrode life, easier to more difficult arc starting, deeper to shallower weld penetration, and wider to narrower arc shape (and thus bead shape and size as well). Whichever geometry is selected, it should be used consistently as part of a successful welding procedure.

For best results, electrode configuration should be tested while welding procedures are being developed; it should be noted as a critical process variable for the weld procedure; and close tolerances should be held for all subsequent welds.

Electrode Diameter: The welding equipment manufacturer's recommendations are almost always the best way to choose which diameter electrode to use. There are also guidelines published by the American Welding Society, which are duplicated in Table 2 of this guidebook. Note that larger diameters can accommodate higher amperages; and larger diameter electrodes will last longer than smaller ones, but smaller ones will be easier to arc start. Use of higher current levels than those that are recommended for a given electrode size will cause the tungsten to deteriorate or breakdown more rapidly. As the tip erodes, the probability of tungsten particles falling into the weld pool and defecting the weld is much greater. If the current used is too low for a specific electrode diameter, arc instability can occur.

For a given level of current, direct current with the electrode positive requires a much larger diameter, because the tip is not cooled by the evaporation of electrons but heated by their impact; and thus it will become hot and subject to erosion. In fact, an electrode used with DCEP can handle approximately only 10% of the current that it could with the electrode negative. With AC welding, the tip is cooled during the electrode negative cycle and heated when positive. Thus, an electrode on AC can handle the current somewhere between the capacity of an electrode on DCEN and DCEP and about 50% less than that of DCEN.

Electrode Tip/Flat: The shape of the tungsten electrode tip is an important process variable in precision arc welding. A good selection of tip/flat size will balance the need for several advantages. The bigger the flat, the more likely arc wander will occur and the more difficult it will be to arc start. However, increasing the flat to the maximum level that still allows arc start and eliminates arc wander will improve the weld penetration and increase the electrode life. Some welders still grind electrodes to a sharp point, which makes arc starting easier. However, they risk decreased welding performance from melting at the tip and the possibility of the point falling off in the weld pool. In situations where very low amperage is used or short weld cycles are used (i.e., one second or less), a pointed electrode is desirable; however, for other situations it would be beneficial to prepare a flat at the end of the electrode.

Guidelines for testing can be found in Table 6; also refer to the welding equipment manufacturer's recommendations. During the welding operation, the accurately ground tip of a tungsten electrode is at a temperature in excess of 3000° C (5500° F). Incorrect or inconsistent diameter flat at the tip of the tungsten electrode can lead to the following problems:

- Pointed electrode tip drops into weld pool creating weld defect
- Reduction in electrode life
- Arc instability
- Change in arc voltage from one electrode to another due to inconsistent tip shape

In AC welding, pure or Zirconiated tungsten electrodes melt to form a hemispherical balled end. For DC welding, Thoriated, Ceriated, or Lanthanated tungsten electrodes are usually used. For the latter, the end is typically ground to a specific included angle, often with a truncated end. Various electrode tip geometries affect the weld bead shape and size. In general, as the included angle increases, the weld penetration increases and the width of the weld bead decreases. Although small diameter electrodes may be used with a square end preparation for DCEN (Direct Current Electrode Negative) welding, conical tips provide improved welding performance.

Table 6: Tip Recommendations by Electrode Diameter Size

Electrode Diameter	General Tip Recommendations
.020" (0.5mm)	0 - .005"
.040" (1.0mm)	0 - .020"
1/16" (1.6mm)	0 - .030"
3/32" (2.4mm)	.005" - .030"
1/8" (3.2mm)	.010" - .040"
5/32" (4.0mm)	.010" - .050"
3/16" (4.8mm)	.010" - .060"
1/4" (6.4mm)	.010" - .070"

Electrode Included Angle/Taper: Electrodes for DC welding should be ground longitudinally and concentrically with diamond wheels to a specific included angle in conjunction with the tip/flat preparation. Different angles produce different arc shapes and offer different weld penetration capabilities. In general, blunter electrodes that have a larger included angle provide the following benefits:

- Last Longer
- Have better weld penetration
- Have a narrower arc shape
- Can handle more amperage without eroding.

Sharper electrodes with smaller included angle provide:

- Offer less arc weld
- Have a wider arc
- Have a more consistent arc

Larger tungsten diameters and higher currents are normally paired with larger tapers in the 25° to 45° included angle range in order to increase electrode service life and provide a more stable arc. More pointed tips in the 10° to 25° included angle range are used for lower current.

Electrode Angle Surface Finish: The smoothness of the finish on the prepared tip of the electrode will determine some of the characteristics of the welding process. In general, points should be ground as fine as possible to improve welding properties and increase the service life of the electrode. Electrodes that are ground too coarse result in unstable arcs.

Surface finish is typically expressed as a Root Mean Square (RMS) or as a Roughness Average (Ra). RMS is a comparative number as related to surface finishes measured with a profilometer. A fine finish is in the range of 20-40 RMS, a machined finish often is in the range of 80-120RMS, and gritblasted surfaces will be in the range of 400-500 RMS. The Ra value is defined as the average value of the departures from its centerline through a prescribed sampling length. Measured values expressed as RMS will read approximately eleven percent higher than values expressed in Ra. (Microinches x 1.11 = RMS).

A standard finish of around 20 RMS, which would still show the longitudinally ground lines to the naked eye, is an all-purpose, quality finish for any application. A high-polished, or mirror-like finish of approximately 6-8 RMS, where few or no lines can be seen, is better for the longevity of the electrode because without any grit to the electrode surface, it is much less likely for contamination to “stick” to the electrode point and thus less erosion takes place. However, for welding power supplies that do not have strong arc starting characteristics, a finish of approximately 20 RMS is better because the longitudinally ground lines will help steadily lead the electrons to the extreme point of the electrode which assists in arc starting. Some manufacturers of pre-ground welding electrodes provide coarser finishes in the 30 to 40 RMS ranges; however, these do not last long, they provide unstable arcs, and they tend to be too gritty for extended, effective arc starting.

Typical Manufacturers’ Recommended Geometries: Many manufacturers provide information on recommended electrode geometries, because they have already preformed testing to determine which electrode geometry is the most beneficial for their equipment in various applications. However, when this information is not available, Diamond Ground Products, Inc. or other industry experts are the best source for this information.

Tolerances Required for Different Applications: Many welding applications are deemed highly critical and require strict tolerances on the length, taper, and flat, in addition to a high-polished finish. These applications include orbital tube welding for high purity, pharmaceutical, aerospace applications, fitting manufacturing, and many others. Basic guidelines for tolerances in these applications are $\pm .002$ " for the length, $\pm 1/2^\circ$ for the taper, and $\pm .002$ " for the tip/flat. Where applications require electrodes to be manufactured to these extreme tolerances, it is necessary to use equipment such as an optical comparator, microscope, and micrometer in addition to the precision tungsten electrode grinder which is required for almost all applications. Other applications will often call for their own specific tolerances. Where not specified, keep reasonable tolerances for the type of work being performed and remain as consistent as possible.

3.2 The Proper Equipment

In most applications, it is very important that a dedicated, custom tungsten electrode grinder is used. Other grinding equipment that may be available at a typical facility either typically does not offer the means for proper longitudinal diamond grinding nor consistency of preparation from one electrode to the next. As a result, they will take up too much of a welder's costly time to produce an electrode that may not weld or weld for very long. In addition, a non-dedicated machine will be contaminated with foreign material because it is used for grinding parts other than tungsten. This will contaminate the electrode and cause welding problems.

Refer to Table 7 to determine whether a piece of equipment will efficiently produce consistent and repeatable electrodes and welds.

Table 7: Questions to Ask to Determine a Proper Electrode Grinder

Question	Conditions
Does it grind longitudinally?	A necessity
Does it incorporate a diamond-grinding wheel?	A necessity
How many electrodes can a typical diamond grinding wheel make before requiring replacement?	The more the better. This also varies based on operator use.
If a cutting apparatus is needed, does it offer a diamond-cutting wheel with measurement apparatus?	Notching the electrode and hand breaking is not acceptable
How short can the electrode be cut?	Match this condition to your needs.

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Question	Conditions
What is the surface finish to the electrode after grinding?	20 RMS is fine for most uses, finer finishes are even better.
How quickly does it take to flat, grind, and cut a typical electrode?	A .040" diameter electrode should not take more than 60 seconds after setup.
What is the process for setup to flat, grind, and cut different electrode diameters, angles, flats, and lengths?	It should sound simple and direct. Otherwise, it will take too long and become cumbersome.
What is the process the equipment operator needs to follow to complete one electrode?	It should be simple enough that all welders can repeat the process and produce the same electrode.
What tolerances can a typical operator expect to produce for the angle, length, and flat?	Match these to your needs.
Are accessories such as vacuum dust collection, on site carrying case, a wide variety of collets, etc. readily available? Is support readily available? What is the warranty?	Match these to your needs.
How expensive is it?	Expect to pay quite a bit more than a standard bench grinder, but a good tungsten grinder will pay for itself over time with saved welding time, saved electrode preparation time, and improved welds.

3.3 Proper Grinding and Cutting Techniques

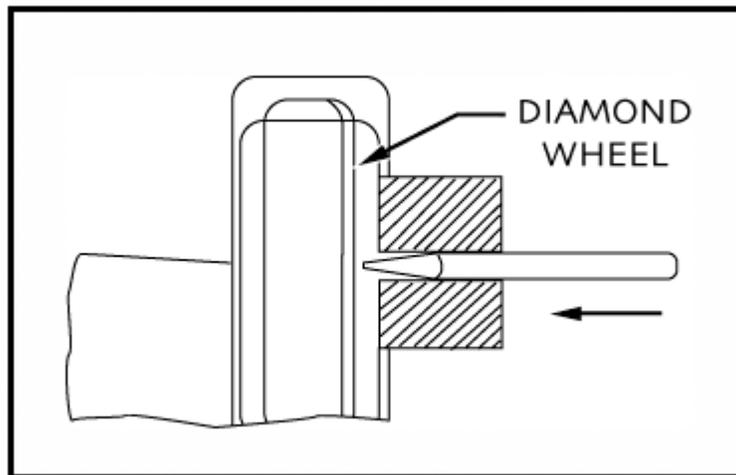
Tungsten electrodes are the crucial electrical carrier in the welding process, and they must be ground and cut properly. Improperly prepared electrodes can lead to arc wander, splitting, shedding, welding inconsistencies, or expensive mistakes. Properly ground and cut electrodes can improve arc starting and stability.

Always use diamond wheels when grinding and cutting. While tungsten is a very hard material, the surface of a diamond wheel is harder, and this makes for smooth grinding. Grinding without diamond wheels, such as aluminum oxide wheels, can lead to jagged edges, imperfections, or poor surface finishes not visible to the eye that will contribute to weld inconsistency and weld defects. Also, welders should avoid contact of the electrode with the weld pool. If this does happen, the contaminated portion of the tip should be cut off, the electrode should be reground from the beginning.

Tip/Flat Preparation: When preparing a flat from a used electrode, if the end to be ground is exceedingly contaminated, the old tip it should be cut off before preparing the flat. Figure 3 illustrates how to recondition an electrode with minimal contamination. This procedure would also work with a new electrode or an electrode with the contamination cut off. Simply push the electrode at exactly a 90° angle to the side of the wheel. There should be an apparatus to hold the tungsten so that the angle is maintained.

Note: New electrodes and cut electrodes already have a flat at the tip of the electrode.

Figure 3: Reconditioning an Electrode



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Table 8: Tungsten Electrode Tip Shapes and Current Ranges

Electrode Diameter	Diameter At Tip	Included Angle	DCEN Constant Current Range, A	DCEN Pulsed Current Range, A
.040" / 1.00mm	.005" / .125mm	12	2 to 15	2 to 25
.040" / 1.00mm	.010" / .25mm	20	5 to 30	5 to 60
.060" / 1.60mm	.020" / .5mm	25	8 to 50	8 to 100
.060" / 1.60mm	.030" / .8mm	30	10 to 70	10 to 140
.093" / 2.40mm	.030" / .8mm	35	12 to 90	12 to 180
.093" / 2.40mm	.045" / 1.1mm	45	15 to 150	15 to 250
.125" / 3.20mm	.045" / 1.1mm	60	20 to 200	20 to 300
.125" / 3.20mm	.060" / 1.5mm	90	25 to 250	25 to 350

Taper Grinding: The most important element of proper taper grinding is that the electrode must be ground longitudinally (lengthwise). Grinding electrode tips crosswise has a negative effect on the stability and formation of the arc at the electrode tip. Tungsten electrodes are manufactured with the molecular structure of the grain running lengthwise and thus grinding crosswise is “grinding against the grain.” More importantly, electrons flow at a greater density on the surface of the electrode. If electrodes are ground or polished crosswise, the electrons have to jump across the grinding marks. The arc begins before the tip, spreads out, and usually wanders. The tungsten electrode becomes overheated and wears out more quickly. By grinding longitudinally with the grain, the electrons are led steadily and with less difficulty to the extreme tip of the tungsten electrode. The arc starts straight and remains narrow, concentrated, and stable. The electrode is subjected to less Thermal shock, and therefore lasts longer. Figure 4 provides an example of correct and incorrect grinding.

Figure 4: Correct and Incorrect Grinding



CORRECT

Lengthwise grind marks do not restrict welding current. Mirror finish preferred.



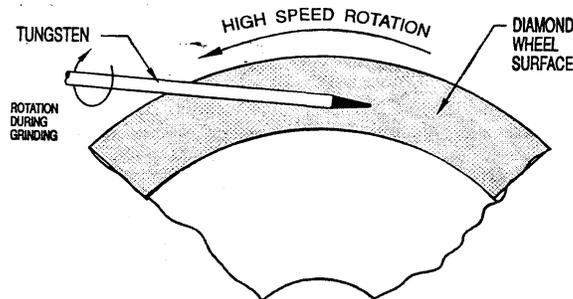
INCORRECT

Crosswise grind marks restrict welding current, cause arc wander, and risk inclusions

For the best possible arc stability, diamond grinding of tungsten electrodes should be done with the length of the electrode at a 90° angle to the axis of the grinding wheel as shown in Figure 5. The diamond-grinding wheel should not be used for grinding anything other than tungsten to ensure that the wheel and thus the tungsten tip will not become contaminated during the grinding operation and then transfer that foreign material to the weld.

Note: An exhaust system should be used when grinding Thoriated electrodes to remove the grinding dust from the work area.

Figure 5: Electrode at 90° Angle to Grinding Wheel



Cutting to Length: One of the most overlooked areas of tungsten electrode preparation is the cutting operation or contaminated tip removal. Contaminated tungsten electrode tips are a common problem that confronts TIG welders. A contaminated electrode produces an erratic arc and a dirty, contaminated weld. The best way to ensure that all contamination is removed from the tip is to cut off that part of tungsten. Regrinding a contaminated tip may not remove all of the contamination, and it can deposit the contamination on the grinding wheel, only to be picked up again in future grinding.

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Because tungsten is a very hard material, proper cutting involves using a diamond-cutting wheel for consistent, clean cuts. Many welders cut their tungsten **incorrectly** using one of the following methods:

- For .040" and 1/16" diameter electrodes: using wire cutters or hands to break electrodes.
- For 3/32" or 1/8" diameter electrodes: using two pairs of pliers and a twisting motion or notching the electrode on the grinding wheel and then breaking the electrode by hand or with pliers
- For electrodes larger than 1/8" diameter: using a sharp hammer blow to the electrode on a sharp metal edge or notching the electrode on a grinding wheel and then hitting with a hammer on a sharp metal edge.

All of these methods risk safety and weld problems. The electrode can be splintered or shattered without the welder noticing it. Fractured electrodes can lead to arc instability, parts of the tungsten dropping into the weld pool creating a weld defect, and other problems. Also, if the tungsten shatters there is the risk of eye or hand injury. In any case, it is much easier to cut an electrode quickly and properly with the correct cutting apparatus designed specifically for how hard and brittle tungsten is.

The cutting apparatus should keep the tungsten rigidly secure on either side of the cut for stability and so that the cut is exactly at a 90° angle. Using a diamond cutting wheel will ensure that the cut will be clean and smooth and void of fractures or splintering. A silicon carbide wheel should never be used as it can contaminate the tungsten. The apparatus should be quick and easy to use, have safety covers, and provide a scale to ensure the exact length is measured and cut.

3.4 Safety Suggestions

Tungsten welding electrodes should never be manually ground on an abrasive belt or wheel (particularly silicone carbide). The risk of injury when hand (manually) grinding a very hard brittle material like tungsten is quite high. Always follow standard safety guide lines when operating high speed grinding equipment.

- Use approved safety glasses
- Do not wear loose clothing which may get caught in moving parts
- Wear protective hair covering to contain long hair
- Wear safety shoes with non-slip sole
- Whenever possible, use a vacuum system to remove tungsten and thorium dust generated in the work area.
- Never operate power tools when tired, intoxicated, or when taking medication that causes drowsiness

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Hand and glove protection is strongly recommended, because the most common injuries are to the fingers and eyes. Holding and grinding the tungsten electrode by hand can result in burned fingers, laceration to fingers, and splintered tungsten electrodes in hand or fingers. Eye injury generally occurs from manually grinding tungsten electrodes without a safety shield or safety glasses. Small slivers of tungsten electrode may become stuck in the operator's eye.

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4 DGP Products that Meet Welders' Needs

Diamond Ground Products, Inc. specializes in maximizing the quality and consistency of one of the most frequently overlooked welding process variables: the electrode. DGP offers products that improve and maximize the efficiency of welding process.

4.1 The Proper Tungsten

The DGP factory is a "One-Stop-Shop" for all of your tungsten needs. We stock all the sizes of the most commonly used tungsten: 2% Thoriated, 2% Ceriated, 2% Lanthanated, our trademarked multi-oxide blended tungsten called TRI-MIX™ and our newest offering, Cryo-T tungsten which has been cryogenically treated. In order to service all of your possible tungsten needs, we also offer 1% Lanthanated, 1½% Lanthanated, 1% Zirconated, and Pure tungsten with reasonable delivery times. Free evaluation samples are always available for welders to determine which type of tungsten will maximize their welding performance.

4.2 The Proper Precision Tungsten Electrode Grinders

To develop the first tungsten electrode grinder that actually meets the needs of welders, DGP worked closely with actual end users to learn what they wanted to accomplish and how they wanted to do it. The result was an economical system for quick and easy preparation of tungsten electrodes for TIG and Plasma welding applications. This system makes up the core of all of DGP and Piranha tungsten electrode grinder models

4.3 Properly Pre-Ground and Cut Electrodes

For applications like orbital welding, which require extreme tolerances, DGP offers pre-ground Welding Electrodes that are cut, ground, and finished to the user's specifications. DGP adheres to tolerances of ± .002" on the length, ± ½° on the included angle (taper), and ± .002" on the tip flat. We are the leading manufacturer of this product in the U.S. Please call or write for free evaluation samples in either our standard 20 RMS or our High Polished 6-8 RMS finishes.

4.4 Replacement Tungsten Grinder Wheels

DGP offers a complete line of high-quality, low-cost replacement diamond grinding wheels for your tungsten electrode grinders. DGP grinding wheels are in-stock, and ready to ship immediately.

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