Gas tungsten arc welding

Gas tungsten arc welding (GTAW) , also known as tungsten inert gas (TIG) welding , is an arc welding process that uses a non @-@ consumable tungsten electrode to produce the weld . The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium) , and a filler metal is normally used , though some welds , known as autogenous welds , do not require it . A constant @-@ current welding power supply produces electrical energy , which is conducted across the arc through a column of highly ionized gas and metal vapors known as a plasma .

GTAW is most commonly used to weld thin sections of stainless steel and non @-@ ferrous metals such as aluminum , magnesium , and copper alloys . The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding , allowing for stronger , higher quality welds . However , GTAW is comparatively more complex and difficult to master , and furthermore , it is significantly slower than most other welding techniques . A related process , plasma arc welding , uses a slightly different welding torch to create a more focused welding arc and as a result is often automated .

Development

After the discovery of the short pulsed electric arc in 1800 by Humphry Davy and of the continuous electric arc in 1802 by Vasily Petrov , arc welding developed slowly . C. L. Coffin had the idea of welding in an inert gas atmosphere in 1890 , but even in the early 20th century , welding non @-@ ferrous materials such as aluminum and magnesium remained difficult because these metals react rapidly with the air and result in porous , dross @-@ filled welds . Processes using flux @-@ covered electrodes did not satisfactorily protect the weld area from contamination . To solve the problem , bottled inert gases were used in the beginning of the 1930s . A few years later , a direct current , gas @-@ shielded welding process emerged in the aircraft industry for welding magnesium .

Russell Meredith of Northrop Aircraft perfected the process in 1941 . Meredith named the process Heliarc because it used a tungsten electrode arc and helium as a shielding gas , but it is often referred to as tungsten inert gas welding (TIG) . The American Welding Society 's official term is gas tungsten arc welding (GTAW) . Linde Air Products developed a wide range of air @-@ cooled and water @-@ cooled torches , gas lenses to improve shielding , and other accessories that increased the use of the process . Initially , the electrode overheated quickly and , despite tungsten 's high melting temperature , particles of tungsten were transferred to the weld . To address this problem , the polarity of the electrode was changed from positive to negative , but the change made it unsuitable for welding many non @-@ ferrous materials . Finally , the development of alternating current units made it possible to stabilize the arc and produce high quality aluminum and magnesium welds .

Developments continued during the following decades . Linde developed water @-@ cooled torches that helped prevent overheating when welding with high currents . During the 1950s , as the process continued to gain popularity , some users turned to carbon dioxide as an alternative to the more expensive welding atmospheres consisting of argon and helium , but this proved unacceptable for welding aluminum and magnesium because it reduced weld quality , so it is rarely used with GTAW today . The use of any shielding gas containing an oxygen compound , such as carbon dioxide , quickly contaminates the tungsten electrode , making it unsuitable for the TIG process . In 1953 , a new process based on GTAW was developed , called plasma arc welding . It affords greater control and improves weld quality by using a nozzle to focus the electric arc , but is largely limited to automated systems , whereas GTAW remains primarily a manual , hand @-@ held method . Development within the GTAW process has continued as well , and today a number of variations exist . Among the most popular are the pulsed @-@ current , manual programmed , hot @-@ wire , dabber , and increased penetration GTAW methods .

= = Operation = =

Manual gas tungsten arc welding is a relatively difficult welding method , due to the coordination required by the welder . Similar to torch welding , GTAW normally requires two hands , since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch in the other . Maintaining a short arc length , while preventing contact between the electrode and the workpiece , is also important .

To strike the welding arc , a high frequency generator (similar to a Tesla coil) provides an electric spark . This spark is a conductive path for the welding current through the shielding gas and allows the arc to be initiated while the electrode and the workpiece are separated , typically about 1 @.@ 5 ? 3 mm (0 @.@ 06 ? 0 @.@ 12 in) apart .

Once the arc is struck , the welder moves the torch in a small circle to create a welding pool , the size of which depends on the size of the electrode and the amount of current . While maintaining a constant separation between the electrode and the workpiece , the operator then moves the torch back slightly and tilts it backward about 10 ? 15 degrees from vertical . Filler metal is added manually to the front end of the weld pool as it is needed .

Welders often develop a technique of rapidly alternating between moving the torch forward (to advance the weld pool) and adding filler metal . The filler rod is withdrawn from the weld pool each time the electrode advances , but it is always kept inside the gas shield to prevent oxidation of its surface and contamination of the weld . Filler rods composed of metals with a low melting temperature , such as aluminum , require that the operator maintain some distance from the arc while staying inside the gas shield . If held too close to the arc , the filler rod can melt before it makes contact with the weld puddle . As the weld nears completion , the arc current is often gradually reduced to allow the weld crater to solidify and prevent the formation of crater cracks at the end of the weld .

= = = Safety = = =

Welders wear protective clothing , including light and thin leather gloves and protective long sleeve shirts with high collars , to avoid exposure to strong ultraviolet light . Due to the absence of smoke in GTAW , the electric arc light is not covered by fumes and particulate matter as in stick welding or shielded metal arc welding , and thus is a great deal brighter , subjecting operators to strong ultraviolet light . The welding arc has a different range and strength of UV light wavelengths from sunlight , but the welder is very close to the source and the light intensity is very strong . Potential arc light damage includes accidental flashes to the eye or arc eye and skin damage similar to strong sunburn . Operators wear opaque helmets with dark eye lenses and full head and neck coverage to prevent this exposure to UV light . Modern helmets often feature a liquid crystal @-@ type face plate that self @-@ darkens upon exposure to the bright light of the struck arc . Transparent welding curtains , made of a polyvinyl chloride plastic film , are often used to shield nearby workers and bystanders from exposure to the UV light from the electric arc .

Welders are also often exposed to dangerous gases and particulate matter . While the process doesn 't produce smoke , the brightness of the arc in GTAW can break down surrounding air to form ozone and nitric oxides . The ozone and nitric oxides react with lung tissue and moisture to create nitric acid and ozone burn . Ozone and nitric oxide levels are moderate , but exposure duration , repeated exposure , and the quality and quantity of fume extraction , and air change in the room must be monitored . Welders who do not work safely can contract emphysema and oedema of the lungs , which can lead to early death . Similarly , the heat from the arc can cause poisonous fumes to form from cleaning and degreasing materials . Cleaning operations using these agents should not be performed near the site of welding , and proper ventilation is necessary to protect the welder .

= = = Applications = = =

While the aerospace industry is one of the primary users of gas tungsten arc welding , the process is used in a number of other areas . Many industries use GTAW for welding thin workpieces , especially nonferrous metals . It is used extensively in the manufacture of space vehicles , and is also frequently employed to weld small @-@ diameter , thin @-@ wall tubing such as those used in the bicycle industry . In addition , GTAW is often used to make root or first @-@ pass welds for piping of various sizes . In maintenance and repair work , the process is commonly used to repair tools and dies , especially components made of aluminum and magnesium . Because the weld metal is not transferred directly across the electric arc like most open arc welding processes , a vast assortment of welding filler metal is available to the welding engineer . In fact , no other welding process permits the welding of so many alloys in so many product configurations . Filler metal alloys , such as elemental aluminum and chromium , can be lost through the electric arc from volatilization . This loss does not occur with the GTAW process . Because the resulting welds have the same chemical integrity as the original base metal or match the base metals more closely , GTAW welds are highly resistant to corrosion and cracking over long time periods , making GTAW the welding procedure of choice for critical operations like sealing spent nuclear fuel canisters before burial .

= = Quality = =

Gas tungsten arc welding , because it affords greater control over the weld area than other welding processes , can produce high @-@ quality welds when performed by skilled operators . Maximum weld quality is assured by maintaining cleanliness ? all equipment and materials used must be free from oil , moisture , dirt and other impurities , as these cause weld porosity and consequently a decrease in weld strength and quality . To remove oil and grease , alcohol or similar commercial solvents may be used , while a stainless steel wire brush or chemical process can remove oxides from the surfaces of metals like aluminum . Rust on steels can be removed by first grit blasting the surface and then using a wire brush to remove any embedded grit . These steps are especially important when negative polarity direct current is used , because such a power supply provides no cleaning during the welding process , unlike positive polarity direct current or alternating current . To maintain a clean weld pool during welding , the shielding gas flow should be sufficient and consistent so that the gas covers the weld and blocks impurities in the atmosphere . GTAW in windy or drafty environments increases the amount of shielding gas necessary to protect the weld , increasing the cost and making the process unpopular outdoors .

The level of heat input also affects weld quality . Low heat input , caused by low welding current or high welding speed , can limit penetration and cause the weld bead to lift away from the surface being welded . If there is too much heat input , however , the weld bead grows in width while the likelihood of excessive penetration and spatter increase . Additionally , if the welding torch is too far from the workpiece the shielding gas becomes ineffective , causing porosity within the weld . This results in a weld with pinholes , which is weaker than a typical weld .

If the amount of current used exceeds the capability of the electrode , tungsten inclusions in the weld may result . Known as tungsten spitting , this can be identified with radiography and can be prevented by changing the type of electrode or increasing the electrode diameter . In addition , if the electrode is not well protected by the gas shield or the operator accidentally allows it to contact the molten metal , it can become dirty or contaminated . This often causes the welding arc to become unstable , requiring that the electrode be ground with a diamond abrasive to remove the impurity .

= = Equipment = =

The equipment required for the gas tungsten arc welding operation includes a welding torch utilizing a non @-@ consumable tungsten electrode , a constant @-@ current welding power supply , and a shielding gas source .

= = = Welding torch = = =

GTAW welding torches are designed for either automatic or manual operation and are equipped with cooling systems using air or water . The automatic and manual torches are similar in construction , but the manual torch has a handle while the automatic torch normally comes with a mounting rack . The angle between the centerline of the handle and the centerline of the tungsten electrode , known as the head angle , can be varied on some manual torches according to the preference of the operator . Air cooling systems are most often used for low @-@ current operations (up to about 200 A) , while water cooling is required for high @-@ current welding (up to about 600 A) . The torches are connected with cables to the power supply and with hoses to the shielding gas source and where used , the water supply .

The internal metal parts of a torch are made of hard alloys of copper or brass so it can transmit current and heat effectively . The tungsten electrode must be held firmly in the center of the torch with an appropriately sized collet , and ports around the electrode provide a constant flow of shielding gas . Collets are sized according to the diameter of the tungsten electrode they hold . The body of the torch is made of heat @-@ resistant , insulating plastics covering the metal components , providing insulation from heat and electricity to protect the welder .

The size of the welding torch nozzle depends on the amount of shielded area desired . The size of the gas nozzle depends upon the diameter of the electrode , the joint configuration , and the availability of access to the joint by the welder . The inside diameter of the nozzle is preferably at least three times the diameter of the electrode , but there are no hard rules . The welder judges the effectiveness of the shielding and increases the nozzle size to increase the area protected by the external gas shield as needed . The nozzle must be heat resistant and thus is normally made of alumina or a ceramic material , but fused quartz , a high purity glass , offers greater visibility . Devices can be inserted into the nozzle for special applications , such as gas lenses or valves to improve the control shielding gas flow to reduce turbulence and introduction of contaminated atmosphere into the shielded area . Hand switches to control welding current can be added to the manual GTAW torches .

= = = Power supply = = =

Gas tungsten arc welding uses a constant current power source , meaning that the current (and thus the heat) remains relatively constant , even if the arc distance and voltage change . This is important because most applications of GTAW are manual or semiautomatic , requiring that an operator hold the torch . Maintaining a suitably steady arc distance is difficult if a constant voltage power source is used instead , since it can cause dramatic heat variations and make welding more difficult .

The preferred polarity of the GTAW system depends largely on the type of metal being welded . Direct current with a negatively charged electrode (DCEN) is often employed when welding steels , nickel , titanium , and other metals . It can also be used in automatic GTAW of aluminum or magnesium when helium is used as a shielding gas . The negatively charged electrode generates heat by emitting electrons , which travel across the arc , causing thermal ionization of the shielding gas and increasing the temperature of the base material . The ionized shielding gas flows toward the electrode , not the base material , and this can allow oxides to build on the surface of the weld . Direct current with a positively charged electrode (DCEP) is less common , and is used primarily for shallow welds since less heat is generated in the base material . Instead of flowing from the electrode to the base material , as in DCEN , electrons go the other direction , causing the electrode to reach very high temperatures . To help it maintain its shape and prevent softening , a larger electrode is often used . As the electrons flow toward the electrode , ionized shielding gas flows back toward the base material , cleaning the weld by removing oxides and other impurities and thereby improving its quality and appearance .

Alternating current , commonly used when welding aluminum and magnesium manually or semi @-@ automatically , combines the two direct currents by making the electrode and base material alternate between positive and negative charge . This causes the electron flow to switch directions constantly , preventing the tungsten electrode from overheating while maintaining the heat in the base material . Surface oxides are still removed during the electrode @-@ positive portion of the cycle and the base metal is heated more deeply during the electrode @-@ negative portion of the cycle . Some power supplies enable operators to use an unbalanced alternating current wave by modifying the exact percentage of time that the current spends in each state of polarity , giving them more control over the amount of heat and cleaning action supplied by the power source . In addition , operators must be wary of rectification , in which the arc fails to reignite as it passes from straight polarity (negative electrode) to reverse polarity (positive electrode) . To remedy the problem , a square wave power supply can be used , as can high @-@ frequency voltage to encourage ignition .

= = = Electrode = = =

The electrode used in GTAW is made of tungsten or a tungsten alloy , because tungsten has the highest melting temperature among pure metals , at 3 @,@ 422 ° C (6 @,@ 192 ° F) . As a result , the electrode is not consumed during welding , though some erosion (called burn @-@ off) can occur . Electrodes can have either a clean finish or a ground finish ? clean finish electrodes have been chemically cleaned , while ground finish electrodes have been ground to a uniform size and have a polished surface , making them optimal for heat conduction . The diameter of the electrode can vary between 0 @.@ 5 and 6 @.@ 4 millimetres (0 @.@ 02 and 0 @.@ 25 in) , and their length can range from 75 to 610 millimetres (3 @.@ 0 to 24 @.@ 0 in) .

A number of tungsten alloys have been standardized by the International Organization for Standardization and the American Welding Society in ISO 6848 and AWS A5.12 , respectively , for use in GTAW electrodes , and are summarized in the adjacent table .

Pure tungsten electrodes (classified as WP or EWP) are general purpose and low cost electrodes . They have poor heat resistance and electron emission . They find limited use in AC welding of e.g. magnesium and aluminum .

Cerium oxide (or ceria) as an alloying element improves arc stability and ease of starting while decreasing burn @-@ off . Cerium addition is not as effective as thorium but works well , and cerium is not radioactive .

An alloy of lanthanum oxide (or lanthana) has a similar effect as cerium , and is also not radioactive .

Thorium oxide (or thoria) alloy electrodes offer excellent arc performance and starting , making them popular general purpose electrodes . However , it is somewhat radioactive , making inhalation of thorium vapors and dust a health risk , and disposal an environmental risk .

Electrodes containing zirconium oxide (or zirconia) increase the current capacity while improving arc stability and starting and increasing electrode life .

Filler metals are also used in nearly all applications of GTAW , the major exception being the welding of thin materials . Filler metals are available with different diameters and are made of a variety of materials . In most cases , the filler metal in the form of a rod is added to the weld pool manually , but some applications call for an automatically fed filler metal , which often is stored on spools or coils .

= = = Shielding gas = = =

As with other welding processes such as gas metal arc welding , shielding gases are necessary in GTAW to protect the welding area from atmospheric gases such as nitrogen and oxygen , which can cause fusion defects , porosity , and weld metal embrittlement if they come in contact with the electrode , the arc , or the welding metal . The gas also transfers heat from the tungsten electrode to the metal , and it helps start and maintain a stable arc .

The selection of a shielding gas depends on several factors , including the type of material being welded , joint design , and desired final weld appearance . Argon is the most commonly used shielding gas for GTAW , since it helps prevent defects due to a varying arc length . When used with alternating current , argon shielding results in high weld quality and good appearance . Another common shielding gas , helium , is most often used to increase the weld penetration in a joint , to

increase the welding speed , and to weld metals with high heat conductivity , such as copper and aluminum . A significant disadvantage is the difficulty of striking an arc with helium gas , and the decreased weld quality associated with a varying arc length .
Argon @-@ helium mixtures are also frequently utilized in GTAW , since they can increase control of the heat input while maintaining the benefits of using argon . Normally , the mixtures are made with primarily helium (often about 75 % or higher) and a balance of argon . These mixtures increase the speed and quality of the AC welding of aluminum , and also make it easier to strike an arc . Another shielding gas mixture , argon @-@ hydrogen , is used in the mechanized welding of light gauge stainless steel , but because hydrogen can cause porosity , its uses are limited . Similarly , nitrogen can sometimes be added to argon to help stabilize the austenite in austenitic stainless steels and increase penetration when welding copper . Due to porosity problems in ferritic steels and limited benefits , however , it is not a popular shielding gas additive .

= = Materials = =

Gas tungsten arc welding is most commonly used to weld stainless steel and nonferrous materials , such as aluminum and magnesium , but it can be applied to nearly all metals , with a notable exception being zinc and its alloys . Its applications involving carbon steels are limited not because of process restrictions , but because of the existence of more economical steel welding techniques , such as gas metal arc welding and shielded metal arc welding . Furthermore , GTAW can be performed in a variety of other @-@ than @-@ flat positions , depending on the skill of the welder and the materials being welded .

= = = Aluminum and magnesium = = =

Aluminum and magnesium are most often welded using alternating current , but the use of direct current is also possible , depending on the properties desired . Before welding , the work area should be cleaned and may be preheated to 175 to 200 ° C (347 to 392 ° F) for aluminum or to a maximum of 150 ° C (302 ° F) for thick magnesium workpieces to improve penetration and increase travel speed . AC current can provide a self @-@ cleaning effect , removing the thin , refractory aluminum oxide (sapphire) layer that forms on aluminum metal within minutes of exposure to air . This oxide layer must be removed for welding to occur . When alternating current is used , pure tungsten electrodes or zirconiated tungsten electrodes are preferred over thoriated electrodes , as the latter are more likely to " spit " electrode particles across the welding arc into the weld . Blunt electrode tips are preferred , and pure argon shielding gas should be employed for thin workpieces . Introducing helium allows for greater penetration in thicker workpieces , but can make arc starting difficult .
Direct current of either polarity , positive or negative , can be used to weld aluminum and magnesium as well . Direct current with a negatively charged electrode (DCEN) allows for high penetration . Argon is commonly used as a shielding gas for DCEN welding of aluminum . Shielding gases with high helium contents are often used for higher penetration in thicker materials . Thoriated electrodes are suitable for use in DCEN welding of aluminum . Direct current with a positively charged electrode (DCEP) is used primarily for shallow welds , especially those with a joint thickness of less than 1 @.@ 6 mm (0 @.@ 063 in) . A thoriated tungsten electrode is commonly used , along with a pure argon shielding gas .

= = = Steels = = =

For GTAW of carbon and stainless steels , the selection of a filler material is important to prevent excessive porosity . Oxides on the filler material and workpieces must be removed before welding to prevent contamination , and immediately prior to welding , alcohol or acetone should be used to clean the surface . Preheating is generally not necessary for mild steels less than one inch thick , but low alloy steels may require preheating to slow the cooling process and prevent the formation of martensite in the heat @-@ affected zone . Tool steels should also be preheated to prevent cracking in the heat @-@ affected zone . Austenitic stainless steels do not require preheating , but martensitic and ferritic chromium stainless steels do . A DCEN power source is normally used , and thoriated electrodes , tapered to a sharp point , are recommended . Pure argon is used for thin workpieces , but helium can be introduced as thickness increases .

= = = Dissimilar metals = = =

Welding dissimilar metals often introduces new difficulties to GTAW welding , because most materials do not easily fuse to form a strong bond . However , welds of dissimilar materials have numerous applications in manufacturing , repair work , and the prevention of corrosion and oxidation . In some joints , a compatible filler metal is chosen to help form the bond , and this filler metal can be the same as one of the base materials (for example , using a stainless steel filler metal with stainless steel and carbon steel as base materials) , or a different metal (such as the use of a nickel filler metal for joining steel and cast iron) . Very different materials may be coated or " buttered " with a material compatible with a particular filler metal , and then welded . In addition , GTAW can be used in cladding or overlaying dissimilar materials .

When welding dissimilar metals , the joint must have an accurate fit , with proper gap dimensions and bevel angles . Care should be taken to avoid melting excessive base material . Pulsed current is particularly useful for these applications , as it helps limit the heat input . The filler metal should be added quickly , and a large weld pool should be avoided to prevent dilution of the base materials .

= = Process variations = =

= = = Pulsed @-@ current = = =

In the pulsed @-@ current mode , the welding current rapidly alternates between two levels . The higher current state is known as the pulse current , while the lower current level is called the background current . During the period of pulse current , the weld area is heated and fusion occurs . Upon dropping to the background current , the weld area is allowed to cool and solidify . Pulsed @-@ current GTAW has a number of advantages , including lower heat input and consequently a reduction in distortion and warpage in thin workpieces . In addition , it allows for greater control of the weld pool , and can increase weld penetration , welding speed , and quality . A similar method , manual programmed GTAW , allows the operator to program a specific rate and magnitude of current variations , making it useful for specialized applications .

= = = Dabber = = =

The dabber variation is used to precisely place weld metal on thin edges . The automatic process replicates the motions of manual welding by feeding a cold filler wire into the weld area and dabbing (or oscillating) it into the welding arc . It can be used in conjunction with pulsed current , and is used to weld a variety of alloys , including titanium , nickel , and tool steels . Common applications include rebuilding seals in jet engines and building up saw blades , milling cutters , drill bits , and mower blades .