GAZ TUNGSTEN ARC WELDING: Electrical current and polarity

The TIG process (GTAW) provides a better protection of the molten pool against air contamination.

The success of a welding operation requires to have a joint free of any traces of oxide or contaminant in order to ensure a good metallurgical continuity through the welded joint.Those eventual contaminants will affect the wetting of the filler metal and the quality of the fusion with the base material, also it will generate some inclusions in the weld. The presence of those inclusion will degrade the performance of the joint, like the ductility in the case of steels or the electrical and thermical conductivity in the case of the aluminum and copper alloys.

Among the common welding processes, the TIG process (GTAW) provides a better protection of the molten pool against air contamination. Besides, it remains the most recommended welding process in the following different situations :

- Assembling of cryogenic installations (low temperatures) where according to the codes and standards in effect, high toughness levels are required in the welded joints.
- Welding of refractory metals (niobium, tantalum, molybdenum, etc.) that are highly sensitive for oxidation at high temperatures.
- Welding of highly reactive metals with air : magnesium, aluminum, titanium, zirconium.

The other main advantage of the TIG process consists in the fact that the filler metal is introduced directly and separately in the molten pool without crossing the arc, which prevents the loss of alloy elements by oxidation during welding.

As the solid rods don't include any flux to dissolve oxides or clean the impurities on the base metal surface, a good mechanical cleaning is required before welding in order to take out the layer of dust, reduce the oxide skin and expose the base material. This step has much importance on obtaining a good quality joints especially on highly reactive metals to oxygen such as magnesium or aluminum where the oxide tends quickly to get thicker.

Metals and types of oxides

In the TIG welding, the type of welding current AC or DC and also the polarity, straight "normal" (DC-, DCEN) or reverse (DC+, DCEP); depend to a large extent on the base metal, thus on the nature of its oxide. For that, it would be suggested to distinguish two principal classes of metals. Metals and / or alloys were the oxide is tenacious and stable: magnesium, aluminum, titanium, aluminum-bronze, zinc, copper-beryllium, stainless steel and nickel alloys containing chromium, aluminum or titanium.

Metals and alloys whose oxide are unstable and / or crumbly such as mild steels, low alloy steels, cast iron, copper and its alloys (bronze, brass, copper-nickel), nickel and the alloys without Cr, Al, Ti, etc.

This distinction allows first to determine some approach relating to the selection of the type of current and also the polarity to be used in the TIG welding.

Also, it is also question to mention here the fact that the metals whose oxide is unstable are roughly insensible to the type of current contrary to the metals that are very easily oxidable at room temperature.

Effect of electric current and polarity

The inert gases employed in the TIG welding are ionized under the effect of electric arc. The ionization and the expansion of these gases have a double effect: the stabilization of the electric arc and the protection of the weld pool, the base metal and the end of the filler metal against air contamination. Furthermore, the positive charges resulting from the gas ionization are accelerated and directed by the electric field toward the negative pole (cathode). Thus, depending on the electric current type and polarity in direct current, the different mechanisms in TIG welding are occuring:

Direct current straight polarity (DC-, DCEN): This polarity doesn't provide a good cleaning of the surface oxide. But it allows to have a good penetration since most of the heat is concentrated on the part (positive electrode) following the impact of the electron. This polarity can be used in the following situations: Massive or thick parts and where the oxide is unstable; high thermal conductivity metals like copper where the thermal lost can be compensated while keeping a stable and hot arc. However, since there is no cleaning effect with this polarity, it will however be necessary to proceed to a good mechanical cleaning of the surface before welding.

Direct current reverse polarity (DC+, DCEP): Most of the heat is concentrated on the electrode (positive electrode) and not on the part. This polarity is used for the welding of the thin sections where the penetration is not really an important factor versus to the importance to avoid the deformation and the burning of the plate. So in that case it is recommended to maintain a short arc to reduce the welding energy and in the same way the distortion tendency.

For this type of polarity, the positive ions of the ionized gas are accelerated to the base metal (negative electrode) where the impact will exercise a stripper effect in fragmenting the surface oxide layer. This scouring effect happens piece by piece and is simultaneously assisted by the electrons issued from the sub-surface, which is just under of the oxide film. The effect from the latter is to evacuate and disperse this oxide once fragmented by the gas ions. This polarity is effective for his cleaning effect and foremost in the case of metals and alloys with a very stable oxide layer and / or a good cleaning action is necessary. This is the case, for example, of aluminum, magnesium, bronze-aluminum, etc. Because of the low penetration produce by this polarity, it is better to use it for the thin plates cases.

Nevertheless, it is important to know that this type of polarity could cause an overheat at the level of the tungsten electrode which could cause the fusion of the tip. This situation would required that we select the proper size of tungsten electrode in order to have more resistance to the overheat effect.

Alternative current AC: Using alternative current ensures the two actions per cycle: penetration and cleaning. Penetration action during the negative alternation of the electrode then cleaning and cathode scouring during the positive alternation. This allows to combine the advantages of the two polarities DCEN (DC-) et DCEP (DC+).

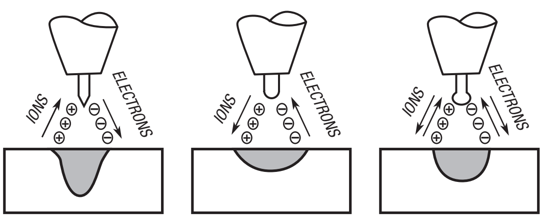
The produced alternative current gives less deep penetration than the direct polarity DCEP and reduce the arc blowing problem. Initially, the inconvenience of the alternative current was linked to the fact that the arc turns off and reboot at each half cycle when the current passes by the zero level. The high frequency alternative current development is advantageous to remedy to this problem in allowing the arc to reinitiate with a minimum of delay.

The increase in the frequency will allow to have a tighter cone arc which contributes also to reduce the form of the weld bead. This feature constitute an advantage for the realization of angle joints and the penetration passes. However, the reduction in the frequency will stretch the bead profile and will give a large scouring zone.

The AC current is mainly recommended for the welding of aluminum, magnesium and their alloys, beryllium-copper, etc.

In brief, the electric current type effect and the polarity in direct current (DC-) on the features of the bead that the welding is schematized on the below figure :

Effect of the balance control in AC mode on the bead features

CURRENT TYPE	DCEN	DCEP	AC(BALANCED)
ELECTRODE POLARITY	NEGATIVE	POSITIVE	
ELECTRODE AND ION FLOW / PENETRATION CHARACTERISTICS			
OXIDE CLEANING ACTION	NO	YES	YES – ONCE EVERY HALF CYCLE
HEAT BALANCE IN THE ARC (APPROX)	70% AT WORK END 30% AT ELECTRODE END	30% AT WORK END 70% AT ELECTRODE END	50% AT WORK END 50% AT ELECTRODE END
PENETRATION	DEEP; NARROW	SHALLOW; WIDE	MEDIUM
ELECTRODE CAPACITY	EXCELLENT e.g., 3.2 mm (1/8 in) 400A	POOR e.g., 6.4 mm (1/4 in) 120 A	GOOD e.g., 3.2 mm (1/8 in) 225 A

In AC welding, the positive / negative alternation ratio could be controlled in order to adjust the joint penetration ratio versus the surface action cleaning and vice versa. As shown on the below diagram, we establish the following figures :

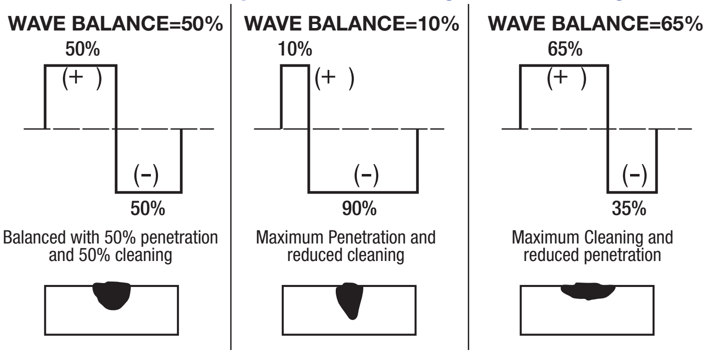
50% (+) / 50% (-): the electrode and the part will alter at each half cycle, the cleaning effect and the penetration are distributed equally;

10% (+) / 90% (-): the part is used as an anode (positive pole) during only 10% of the cycle and the tungsten electrode as a cathode (negative pole) during 90% of the cycle. The result is that the penetration is at maximum and that the cleaning effect is less;

65% (+) / 35% (-): The part is used as an anode (positive pole) during 65% of the cycle and the electrode as a cathode (negative pole) during only 35% of the cycle. This will give maximum cleaning and less penetration.

The following table summarizes some TIG process polarity data for some metals and alloys.

Variation of the penetration-cleaning rate for welding



Some data on the polarity of the TIG process for some metals and alloys

Metal / Alloy	Current and polarity	Type of oxide and remarks
Copper	DC- (DCEN)	Unstable and very crumbly oxide. Very localized heating by TIG welding is beneficial for very high thermal conductivity metal. DCEN (DC-) polarity compensate thermal loss.
Beryllium-copper	AC	Stable beryllium oxide layer
Aluminum-bronze	AC	Stable aluminum oxide layer
Aluminum Magnesium	AC DC+ (DCEP) on thin sections DC- (DCEN) for automatic welding on sections thicker than 1/4" (6.35 mm). The base metal must be cleaned immediately prior to welding.	Very Stable oxide
Stainless steel	DC- (DCEN) AC with a short arc in automatic welding especially on thin plates. A long arc increases the heat input and causes warping.	Stable chromium oxide
Nickel	DC- (DCEN) AC to reduce deformations	Unstable and crumbly nickel oxide. Stable oxide on alloys with Cr, Al or Ti
Refractory metals: W, Mo, Ta, Nb	DC- (DCEN)	High temperature metals that are very oxidable
Mild and low alloy steels, cast iron	DC- (DCEN)	Unstable and crumbly oxide

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