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Activated flux TIG welding of non- ferrous metals

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TIG welding process has high levels of stability and permits more refined control than the majority of other arc welding processes. The principal disadvantages of TIG lie in the limited thickness of material which can be welded in a single pass. Activated Flux Tungsten Inert Gas (A-TIG) welding can increase the joint penetration and weld depth/width ratio, thereby reducing angular distortion of the weldment. In this review paper, A-TIG welding properties of nonferrous metals are examined. How the flux increases the penetration depth is explained and then the effects of the chemical composition and thickness of the flux are described in detail.

Keywords: TIG welding, A-TIG welding, Non-ferrous metals welding

Tungsten inert gas (TIG) welding process is known for its versatility and high joint quality. It can be used with a wide variety of materials. However, these advantages of TIG welding are offset by the limited thickness of material that can be welded in a single pass and by the poor productivity of the process. Maximum 2-3 mm thick plates can be welded with TIG process. The poor productivity results from a combination of relatively low energy input, low welding speeds and the high number of passes required to fill the weld joints in thicker material[1].

A new TIG process variant, known as activated flux welding (A-TIG), uses an activating flux to overcome these limitations by increasing the penetration significantly that can be achieved at a given current[2-4]. The A-TIG welding process in which a very thin coating of the flux is deposited on the joint are a prior welding. The flux consistsmainly of oxides, fluorides and chlorides in the form of thin powder dispersed in an organic solvent, usually acetone. During welding, the presence of flux favors the formation of an arrower and deeper weld bead.

This process was invented by researchers at the Paton Welding Institute (PWI) in the Ukraine in the 1960s[5,6].

In A-TIG welding the penetration depth of the weld increases and the weld width decreases. Figure 1 shows the cross-sections of the weld beads obtained in AZ31B magnesium alloys under the same TIG welding conditions[7]. The fluxes TiO_2, Cr_2O_3 and SiO_2 caused an increase in penetration when compared with the conventional TIG welding. This higher penetration was associated directly with the presence of the flux. Figure 2

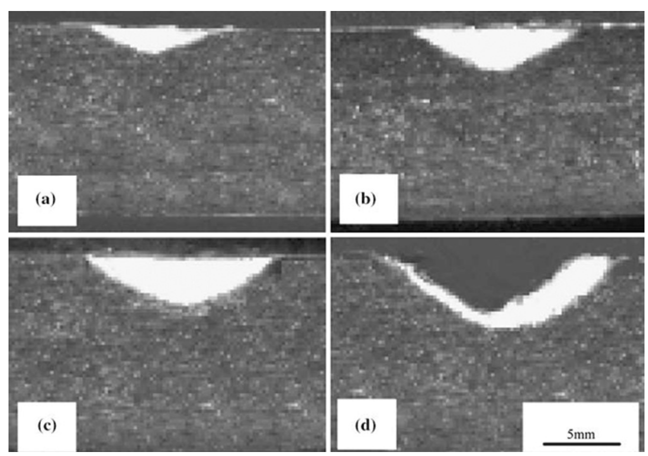

Fig. 1 — Weld pool shapes obtained in AZ31B magnesium alloys TIG welding (a) without flux, and with fluxes of (b) TiO2, (c) Cr2O3 and (d) SiO2[7].

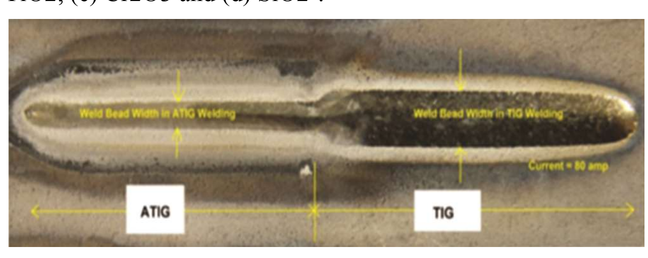

Fig. 2 — Top view of TIG and A-TIG weld bead obtained on a titanium plate[8].

which clearly shows the change in weld bead width reduction while moving from conventional TIG to A-TIG welding in a titanium alloy[8]. On the left side of the platethere was a thin layer of flux and there was no flux on the right side. The welding parameters were kept constant during the welding. The flux narrowed the A-TIG weld.

The use of fluxes in A-TIG can give much higher production rates while not compromising the high quality of conventional TIG welding[2]. The penetration depth is important in that thicker sections can be welded in a single pass thus reducing cost. A costing analysis of conventional TIG welding compared with A-TIG welding for 6.0mm thickness stainless steel tubes showed that the A-TIG process caused a 50% cost saving[9]. In many A-TIG applications savings were achieved in welding time and weldcosts[10].

Small distortion formation during A-TIG welding is another advantage of this process to the conventional TIG welding. The working stresses which developed during the solidification in the conventional TIG and A-TIG welded joint are shown in Fig. 3[11]. The TIG weld bead was formed with 5 passes but the A-TIG weld bead consisted only 1 pass. Therefore, TIG weld contains a bigger volume of molten metal and a wide weld bead, therefore a bigger contraction occurred during the solidification and a bigger angular distortion formed[11]. Figure 3 indicates that smaller contraction forces formed in A-TIG welding due to the smaller weld metal volume.

The A-TIG welding process was successfully applied to mild steels[12], ferritic stainless steels[13], austenitic stainless steels[14], aluminum alloys[15], magnesium alloys[7], titanium alloys[8] and nickel alloys[16]. There are only few published review papers on A-TIG welding process application to non-ferrous metals[17-19]. These review papers are quite short. This review paper is intended to explain the details of nonferrous metals A-TIG welding process and the effects of the flux chemical composition on weld properties.

Effect of A-TIG welding flux on the weld geometry

Many investigations have been made to explain the effective mechanism of the A-TIG process. Although, there are several mechanisms were proposed by the researchers, there is not a general agreement about the mechanism of the A-TIG welding process. Among the proposed theories the arc constriction[20] and the reversal of the Marangoni convection[21] were found very important. These two proposed theories are explained below. Figure 4 schematically illustrates the important mechanisms underlying the increased penetration capability of TIG weld produced with an activated flux[22]. Figure 4 illustrates the arc column and the anode root of TIG and A-TIG welds. The flux of the A-TIG process constricts the arc column and the anode root diameter compared to the conventional TIG arc at the same current level. Constriction of the plasma column increases the weld penetration as shown in Figure4. In the A-TIG process, it is proposed that arc constriction is produced by the effect of the vaporized molecules capturing electrons in the outer regions of the arc which results in a constricted plasma as shown in Fig. 5[23]. In the central regions of the arc, the temperature is very high than the dissociation temperature of the molecules. The flux atoms are ionized to generate electrons and positive ions. The reactions occurring primarily in the arc column lead to a reduction in the diameter of the plasma column and, hence, the area of the anode

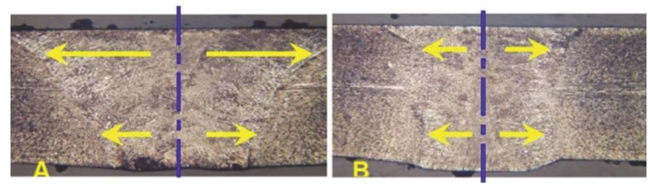

Fig. 3 — The working stresses which developed during the solidification in (A) TIG and (B) A-TIG welded joint. (Arrows represent the contracting forces)[11].

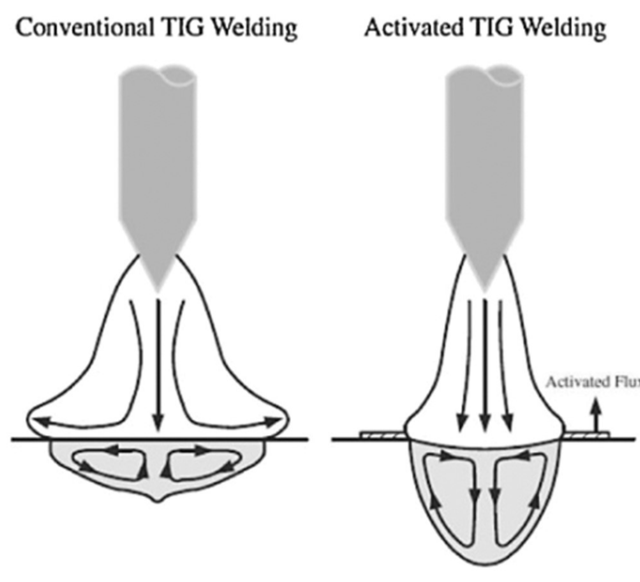

Fig. 4 — Mechanism for increased penetration capability of activated TIG weld[22].

root as shown in Fig. 4. The degree of constriction will be determined by the effectiveness of the flux vapor to combine with the electrons[20].

The weld pool is a very active part of the TIG welding process, with significant energy and momentum transport taking place within it[1]. The weld pool is subjected to variations in surface tension, buoyancy, electromagnetic and aerodynamic plasma drag forces[1]. These forces are the causes of the flow of the liquid metal. The geometry of the weld pool is directly affected with the liquid metal movement[1]. It is well established that surface tension(Marangoni force) is usually the dominant driving force in TIG welding. The Marangoni convection refers to the convection movements due to the surface tension gradient on the weld pool surface, as shown in Fig. 6[24]. While using TIG welding processes, the surfacetension gradient is generally negative, and the convection movements are centrifugal[24]. It is very well known that the change in the magnitude and direction of surface tension gradients on the weld pool surface caused by surface active elements, such as oxygen and sulfur, should change the direction of fluid flow(Marangoni convection) in the weld pool[25]. The addition of an activating flux involves an inversion of the convection currents due to the presence of oxygen at the melting zone surface[26]. It originates from dissociation of the oxides in the activating flux[27] and increases the active surface tension[28]. In this case, the surface tension gradient becomes positive, and the resulting convection movements are vertical. Thus, the A-TIG process leads to an increase in penetration depth and a decrease in weld pool width.

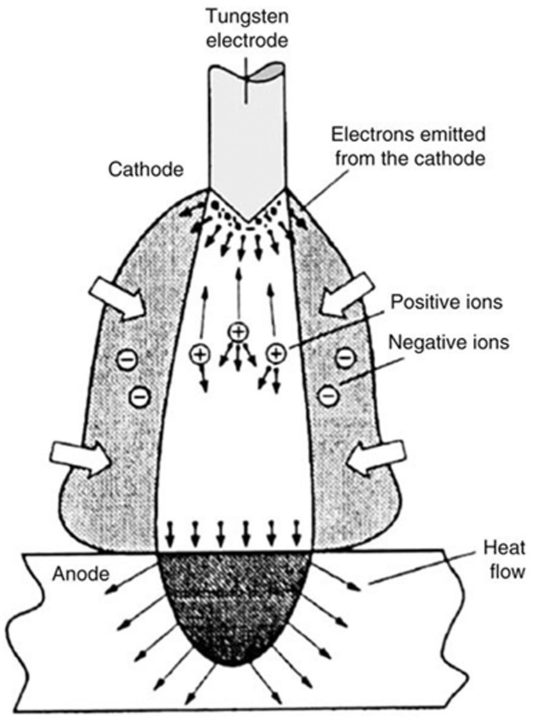

Fig. 5 — Schematic illustration of model of arc constriction by the activating flux[23].

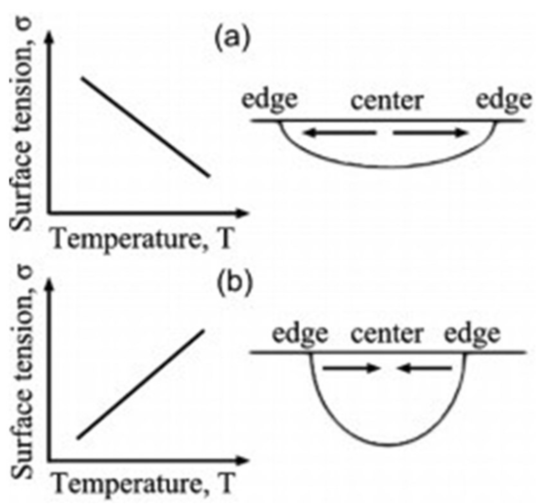

Fig. 6 — Marangoni convection mode in the weld pool (24): (a) $\partial\sigma/\partial T < 0$; (b) $\partial\sigma/\partial T > 0$.

Effects of monofluxes

The A-TIG flux must be suitable for increasing the depth of penetration of welds produced with either argon or argon–helium shielding gases. The nature and exact composition of the flux depends on the material to be welded. Table 1 illustrates the mono fluxes which were successfully applied in A-TIG welding process of nonferrous metals. Each flux powder has its own characteristic effect in the magnesium A-TIG welding process as shown in

Table 1 — Activating fluxes which gave successful results in A-TIG welding of nonferrous metals.

Material	Flux
Aluminum alloys	SiO_2[29,30,31,32,33,51], AlF_3[29], CaF_2[29], TiO_2[29], MgF_2[29], $MgCl_2$[29]
Magnesium alloys	TiO_2[7,29,35,39,40,42], Fe_2O_3[34], LiCl[29,41], $CaCl_2$[29,36,37], $CdCl_2$[29,41,43,44], SiO_2[7,34], MgO[35], Cr_2O_3[7,35], CaO[35], MnO_2[35], $MnCl_2$[38,56], $PbCl_2$[41], AlF_3[43]
Nickel alloys	SiO_2[29,45,46,47], TiO_2[29,47], Cr_2O_3[29], MoO_3[45,46], NiO[46]
Titanium alloys	CaF_2[29,48], MgF_2[29,48,49], AlF_3[29,] NaF[29], $CaCl_2$[29,50], NaCl[29], AlF_3[48], Na_3AlF_6[49]
Cobalt alloys	SiO_2[29], TiO_2[29], Cr_2O_3[29], WO_3[29], Mn_2O_3[29]
Copper alloys	SiO_2[29], B_2O_3[29], MgO[29], MgF_2[29], AlF_3[29], CaO[29]

Fig. 7[35]. The TIG welding with no flux produces fluid flow outward from the center of the weld pool surface, as indicated in Fig. 7(a), resulting in a relatively wide and shallow weld bead. The addition of suitable surface active elements to molten metals can drastically change the surface tension. For A-TIG welding, the surface tension is highest near the center region of the weld pool. Fluid flow will be in ward along the surface of the weld.pool toward the center and then down, and tend to increase the weld penetration and decrease the weld width. Figures 7(b) through(f) showed that the weld penetration increased when the oxide fluxes were used.

However, the weld width did not decrease. These photographs indicated that the fluxes used in the A-TIG welding operation did not cause arc constriction. This result is in contrary with the titanium A-TIG weld thickness shown in Fig. 2.

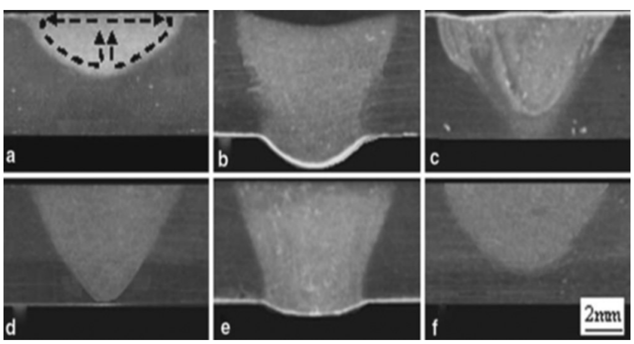

Fig. 7 — Effect of activating fluxes on weld morphology of magnesium: (a) without flux, (b) MgO flux, (c)CaO flux, (d) TiO_2 flux, (e) MnO_2 flux, and (f) Cr_2O_3 flux[35].

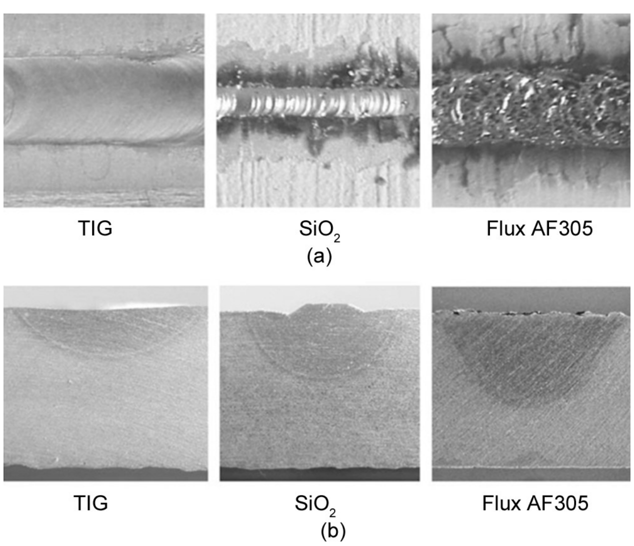

Fig. 8 — Effect of activating fluxes on weld morphology of aluminum welds[33]. (a) Surface appearance and (b) Cross-section appearance

Usually in industrial applications a mixture of powders is used as the flux in A-TIG welding process[52-55]. The ratio of each powder in the mixture is important for penetration[45]. The companies produce their own fluxes, but they don't publish the chemical compositions[53]. They give only a rough chemical composition. The improved flux give a better penetration than a mono flux as shown in Fig. 8[33]. The weld width of SiO_2 flux A-TIG weld is smaller than the TIG weld. But the weld thickness of the Flux 305A-TIG weld is bigger than the TIG weld. TIG weld has a better surface thanA-TIG welds. Surface roughness increased with metal oxide formation on the liquid weld pool of A- TIG weld. If improper flux is used in A-TIG welding, weld defects can occur. For example, the undercut defect was observed on the weld bead surface of Inconel 718 alloy welds using MoS_2flux[46].

For A-TIG process, a paste is obtained by mixing flux powder in a liquid carrier which is very often alcohol or acetone. However, such volatile solvents do not allow to maintain a constant liquid/flux concentration in flux paste. Thus, in order to ensure a constant mass application, distilled water was preferentially used as liquid carrier[51]. Aluminum A-TIG welding was carried out with the activating fluxes dissolved by acetone, distilled water, ethanol and methyl ethyl ketone (MEK) respectively, the influence of solvent on weld penetration is shown in Fig. 9[51]. Among the four kinds of solvents, acetone has the most obvious effect, followed by ethanol.

The flux thickness on the welding piece affects the weld penetration depth in A-TIG welding of

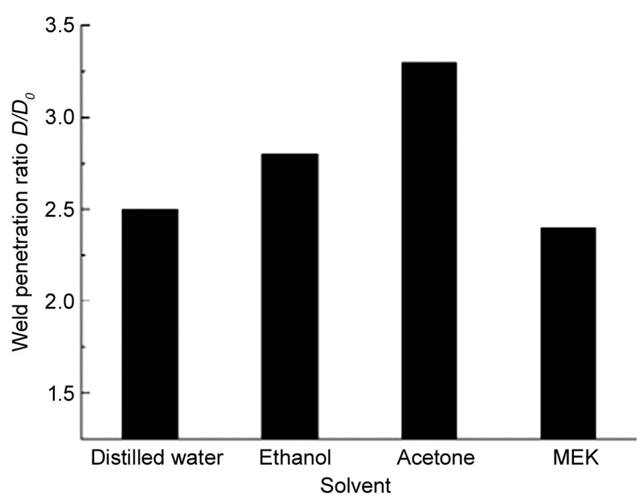

Fig. 9 — Effect of flux solvent on weld penetration in aluminum A-TIG welding[51].

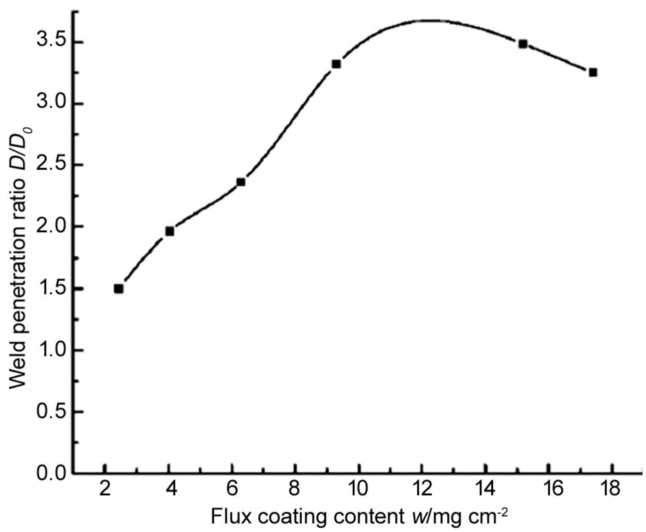

Fig. 10 — Effect of flux coating content on weld penetration in aluminum A-TIG welding[51].

nonferrous metals[33,40,51]. The change in D/D_0 with the content is shown of in Fig. 10[51]. D_0 is the weld depth of the TIG weld and D is the weld depth of the A-TIG weld of an aluminum alloy. In this experiment, D/D_0 first increases and then decreases with the central coat content. When the central coat content is between 10 and 15 mg/cm^2, the weld penetration is increased the most obviously. May be it is just because that an increase in the central coat content can cool and compress the arc. However, if the content is too large, the input heat transferred from arc to weld pool metal will reduce, leading to a decrease in weld penetration depth. A similar result was obtained in A-TIG welding of magnesium alloy with the TiO_2flux[40] and $CdCl_2$[43].

In TIG welding applications filler wires needed in most cases. Magnesium alloy is usually weldedwith TIG welding, however, the weld bead penetration is so shallow in TIG because of the high heat conductivity of magnesium alloy[55]. In a new magnesium A-TIG application, the activated flux was not coated on the work pieces. İnstead, the flux was coated on the surface of the filler wire[55,56]. Then conventional TIG was done with the coated wire. In the arc column the amount of the evaporation of magnesium increased dramatically with the flux wire, the electron temperature of the arc plasma decreased and the electron densities increased. The current density increased and the arc conducting channel constriction with the electron density increased which was induced by the ionization of magnesium and flux elements atoms. Thus, the flux coated wire led to a great improvement in penetration, up to 300%, comparing with the normal wire at the same welding current[56].

The arc constriction theory considers that the electrical arc constriction is generated by the dissociation and ionization of the constituent elements of the fluxes, and the more the flux vapors enter the arc and the greater the extent to which they are dissociated, the more the arc will contract owing to the increase of thermal conductivity of the arc. The constrictive effect will increase the temperature in the arc because of the increase in current density[9]. According to this theory, it can be concluded that the temperature of the arc in the flux coated wire weld process was much higher than that in the normal wire flux pasted weld, since so much flux was taken directly into the arc column by the filler wire in the flux coated wire weld. Therefore, it is believed that the deep penetration in the flux coated wire weld in the present experiments was caused by arc constriction[56].

Conclusion

This paper explains how the welding flux cause an increase in weld penetration depth ox A-TIG welding process of non-ferrous metals. The following results were obtained from the literature review:

1. A-TIG welding achieves significant improvement in penetration depth compared to conventional TIG welding.
2. The weld penetration depth and weld width size of a A-TIG weld depends on the chemical composition of the flux.
3. Acetone is most effective solvent for a A-TIG welding flux.
4. The surface roughness is high in A-TIG welds due to the formed oxides in the weld pool.
5. The optimum thickness of the flux coat on welding work-pieces is about12mg/cm^2.

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