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Study of SiO_2 TiO_2 Mixed Flux Assisted TIG Welding Process

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Abstract

The aim of this study is to evaluate the potential of using tungsten inert gas (TIG) welding assisted by SiO_2/TiO_2 mixtures to improve joint penetration, weld quality in joining geometric shape metallurgical properties and V-notch Charpy impact test of 5-mm thick 17Cr/10Ni/2Mo alloys. The arc constriction and the reversed Marangoni convection are considered to be the two main factors for increasing penetration of A-TIG weld pool. The results indicated that the surface appearance of TIG welds produced with oxide flux formed residual slag. Small addition of oxygen content to weld metal can significantly change the weld shape from a wide shallow type to a narrow deep one, and the weld depth/width ratio can be doubled due to the change in the Marangoni convection from an outward to an inward direction Under the same welding parameters, the penetration capability of TIG welding with TiO2 and SiO2 fluxes was approximately 240% and 292%, respectively. The 50% SiO2+50%TiO2 mixture can produce the greatest improvement function in TIG penetration. Silica-titania mixed flux assisted TIG welding can increase the ferrite content of stainless steel weld metal. This study demonstrates that the application of activated powder assisted TIG welding can improve the weldment performances.

Keywords: Ferrous metals and alloys, Welding, Metallography

1. Introduction

Arc welding is undoubtedly one of the most common and important joining techniques used today. Tungsten inert gas (TIG) welding is one of the most popular welding in various manufacturing industries due to the obtained good weld bead surface and a very high quality welds in a wide variety of metals that are sensitive to the deleterious effects of welding in an oxidizing environment. However TIG welding has some disadvantages, including the limited thickness of the work piece to be welded in a single-pass procedure, low deposition rate, low joint rate and slow travel speed. Generally, the single pass TIG welding with argon as shielding gas is limited to a 3mm depth for the butt-joint of stainless steels. If the weld current increases or the travel speed decreases, the weld bead becomes excessively wide with relatively little gain in the penetration capability [1, 2]. Developing cost-effective TIG welding techniques will be a key competitive challenge for manufacturers in the future recently, a novel modification of the TIG process, namely, active flux TIG (A-TIG), which was first proposed by the E.O. Paton Institute of Electric Welding in the 1960s[3-6]. To improve the penetration of TIG welding, Much investigation has been made on A-TIG welding (active flux TIG welding). Because the weld shape is sensitive to microelements, such as sulfur, oxygen and selenium, a satisfactory weld joint with deep penetration can be obtained with smearing or pre-placing active flux within these microelements on the surface of the weldment in A-TIG welding. To make an activating flux, powder ingredients such oxides, chlorides, and fluorides, are typically added to a solvent of acetone or ethanol. An activated flux is a mixture of powder compounds suspended in carrier solvent. Composition of the flux compounds plays a critical role in increasing the penetration of the TIG-flux welds [7, 8]. Although the mechanism of increasing penetration in A-TIG welding is still under consideration, the effects of the oxide flux quantity on the weld penetration showed that the arc constriction and the reversed Marangoni convection on the top surface of the weld pool were the main mechanism for changing the weld shape according to the experimental and simulated investigation [9]. However, some researchers believe that the main mechanism in the weld pool is the Marangoni flow effect. Fluid flow dominates the transfer of heat in a molten weld pool, and thus, determines the geometric dimensions of the welds [10]. In TIG Welding with the DC electrode negative, the fluid flow in a molten weld pool is driven mainly by surface tension, the Lorentz force, buoyancy, and aerodynamic drag. The surface tension of pure liquid metals normally decreases as temperature increases [11-13]. In other words, pure liquid metals have a negative surface tension gradient ($d\gamma/dT<0$). For TIG welding without flux, the surface tension decreases as the temperature increases.In this condition, the surface tension is highest at the edge of the pool and lowest at the center of the pool. This surface tension gradient dr/dT produces an outward surface fluid flow, as Figure 5a indicates, and generates a wide and shallow weld geometry. The activating flux produces a positive surface tension temperature coefficient that changes the direction of the flow in the weld pool from outward to inward, thereby producing a relatively deep and narrow weld. A positive surface tension gradient ($d\gamma/dT>0$) Figure 1-b can improve penetration [14]. Current theory on the influence of activated flux on TIG welds states that the surface-active trace elements in a molten weld pool convert the surface tension gradient from a negative to positive value. Thus, fluid flow is directed inward along the surface of the weld pool and downward toward the bottom, which tends to increase penetration of the welds. To improve the joint penetration of activated TIG weldment, an understanding of the function of multiple compounds is needed to select suitable components and to develop a multifunctional flux. Although there is substantial published information on TIG welding assisted by mixed oxides, data on SiO_2/TiO_2 mixtures remain limited. Only few data are available in the open literature about the formula for activated flux. Further investigations are needed to confirm the relationship between flux components and weld performance.

In the present work, the SiO_2-TiO_2 mixed powder was used to investigate the effect of oxide flux components on the surface appearance, weld morphology, and ferrite structure in 6 mm thick stainless steel 316L plates.

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2. Experimental procedures

The base metal used in this experiment is commercial Fe-17%Cr-10%Ni-2%Mo alloy (austenitic 316 L stainless steel). The test plates measured 90×40×5 mm. Before welding, all specimens were roughly ground with 80 grit silicon carbide abrasive paper to remove surface impurities and then cleaned with acetone. Figure.2 shows a schematic diagram of the Preparation process for the activated flux. Powdered SiO_2 and TiO_2 were used. The dry sieving process for estimating the particle size distribution of a powder is used when at least 80% of The particles have sizes less than 74 µm. In the present study, 1500 mg of SiO_2 was mixed with TiO_2 the percentage composition (by weight) in the mixture that was 30%, 50%, and 80% and Prior to welding, the powders was mixed with solvent (1.5 ml Ethanol) to produce a paint-like consistency and was subsequently manually applied with a paintbrush as sufficiently layer thick

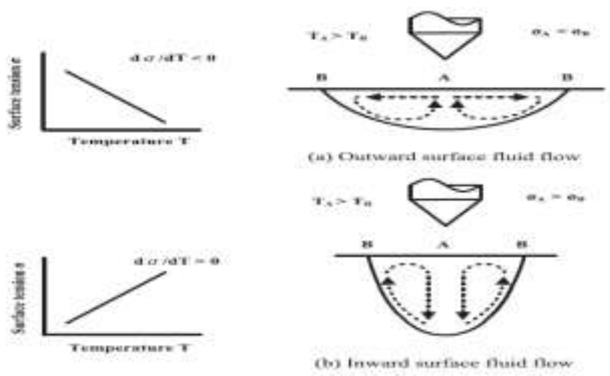

Figure1. Schematic diagram of surface fluid flow pattern

to prevent visual observation of the base metal beneath. The uniformity of the applied powder flux coating is very important. The mixture was manually applied with a paintbrush to leave a layer thick enough to prevent visual observation of the specimen beneath it. Upon evaporation of methanol, a dry powder remained attached to the surface of the specimen to be welded the amount of flux coated per unit area was approximately 3 mg/cm^2. A direct current electrode negative mode was used with a mechanized operation (showed Figure 3) system to allow the welding torch to travel at a constant speed. Table 1 lists the standard welding conditions used in this study. Single-pass, autogenous TIG welding was performed along the centerline of test specimen to produce a bead-on-plate weld. A torch with a standard 2% thoriated tungsten electrode was used during the experiments. The electrode rod was 3.2 mm in diameter, with a 60_ tip angle and an arc gap of 3 mm. Argon of 99.99% purity, was

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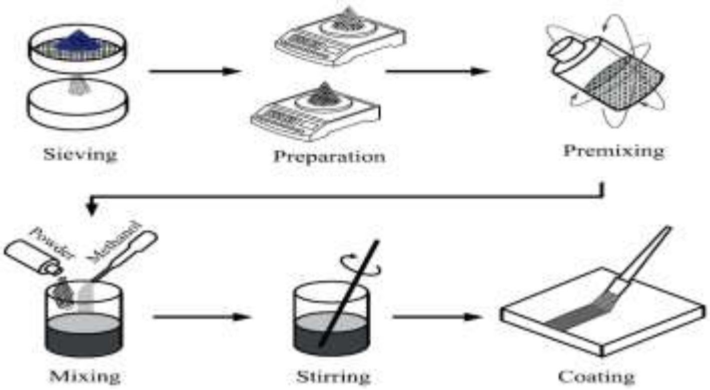


Figure.2. Preparation process for activated flux.

Used as the shielding gas. The tip angle of the electrode was grounded, and the arc gap was measured for each new weld prior to welding to ensure that the welding was performed under the same operating conditions. All test specimens were constraint-free during welding to avoid the influence of reaction stresses. After welding the transverse sections were made at various locations along the welds, whereas samples for metallographic examination were prepared


Figure 3. Experimental setup of TIG welding with flux powder.

Table 1 Welding parameters for autogenous TIG welding experiments

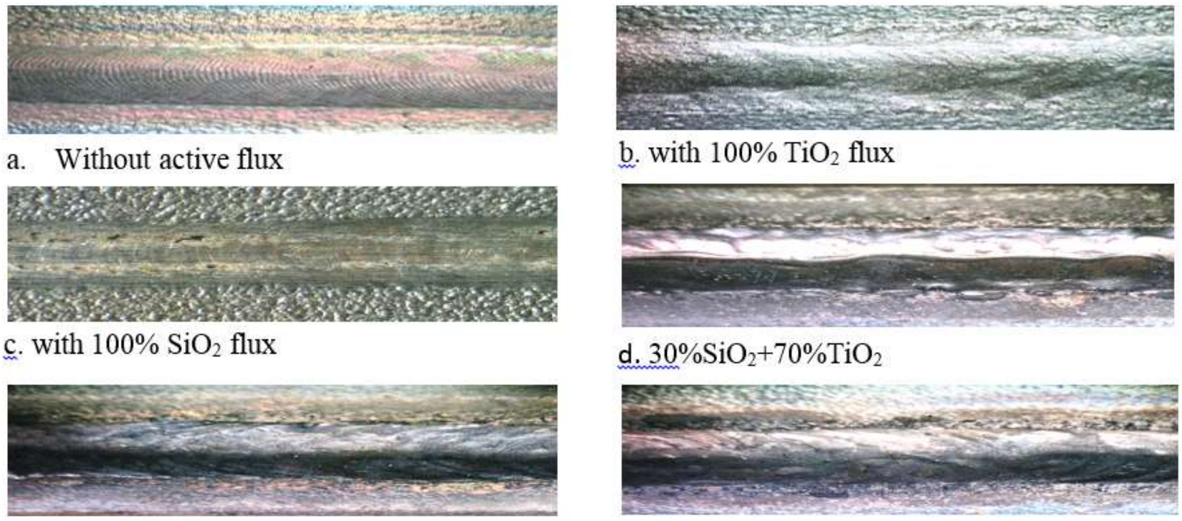
Weld current	100A
Travel speed	3mm/s
Electrode gap	3 mm
Shielding gas	Ar 99.99%
Gas flow ratio	10 lit/min

using standard procedures, including sectioning, mounting, grinding, and polishing to a 0.05 µm finish, followed by electrolytic etching in an electrolyte solution consisting of 10 % acid nitric 65% and 100 ml H_2O. Each sample was examined with a toolmaker's microscope to measure the depth, width, and cross-sectional area of the welds. Some test plates (80mm×60mm×5 mm) were welded with I design butt joints by a one pass layer from both the face and the back side using the active flux. The mechanical properties of the welded joints were evaluated using a V-notched Charpy impact test. Vickers hardness test was used to examine the changes in the structure of the welds. The hardness metal (WM) and base metal (BM) were measured under a load of 10 N for 10s.

3. Results and discussion

1.3 Surface appearance of activated TIG weld

The results shown in Table 2 clearly indicate that 100%SiO_2 produced TIG weld with a high-quality surface, whereas 100%TiO_2 led to the formation of slag, spatter, and undercutting Figure 4 shows the surface appearance of TIG welds made with and without active flux. Figure 4a shows the TIG weld prepared without an active flux. It appeared clean and smooth, and had a colored surface. Figure 4b shows that 100%TiO_2 produced excessive slag, a few spatters, and an irregular surface. Figure 4c indicates that no slag, spatter, or undercutting on the welded surface was produced by using 100%SiO_2 As presented in Figure 4d, a large amount of slag, a few spatters, were produced by using 30%SiO_2/70%TiO_2. A small amount of slag, few spatters, and no undercutting was evident after using 50%SiO_2/50%TiO_2 (Figure 4e). Figure 4f shows that the 70%SiO_2/30%TiO_2 produced a small amount of slag, and no spatter and undercutting. The results shown in Table 2 clearly indicate that 100%SiO_2 produced TIG weld with a high-quality surface, whereas 100%TiO_2 led to the formation of slag and spatter. Because SiO_2 has melting and boiling points substantially lower than those of TiO_2, SiO_2 easily melted under the heat Mixtures. In TIG welding assisted by SiO_2/TiO_2 mixtures, the use of 50%SiO_2/50%TiO_2 produced a welded surface with satisfactory appearance.generated in the TIG welding arc. Moreover, the surface discontinuities in the activated TIG weld metal could be decreased by increasing the concentration of TiO_2 in the SiO_2/TiO_2.



a. Without active flux

b. with 100% TiO_2 flux

c. with 100% SiO_2 flux

d. 30%SiO_2+70%TiO_2

e. 50%SiO_2+50%TiO_2

f. 70%SiO_2+30%TiO_2

Figure 4 Effect of oxide compounds on surface appearance of TIG weld metal.

2.3 Effect of SiO_2-TiO_2 mixed fluxes on weld morphology

Various oxide compounds have different effects on heat transfer and fluid flow during the activated TIG welding process. These effects can be observed from the weld shape. Figure 5 shows the transverse cross sections of TIG welds made with and without oxide compounds. Figure 5a shows that the TIG welds made without active flux. When using TIG welding without flux, the temperature coefficient of surface tension on the molten pool generally exhibited a negative value. If the surface tension in the pool center is lower than the temperature at the pool edge, then the surface tension gradient $d\gamma/dT$ generates centrifugal Marangoni convection in the molten pool Figure 5b-c show that a deep weld shape was produced by using 100%SiO_2 and 100%TiO_2. Figure 5e, f suggests that all of the shapes resulting from TIG welds made with SiO_2/TiO_2 mixtures were also narrow and deep. However, 70%SiO_2/30%TiO_2 produced a relatively wide, shallow weld shape compared with those produced by using 50%SiO_2/50%TiO_2 and 30%SiO_2/70%TiO_2. When TIG welding with Active fluxes is used, the temperature coefficient of surface tension on the molten pool changed from a negative to a positive value. Therefore, the surface tension at the pool center was higher than at the pool edge. This indicated that the surface tension gradient introduces centripetal Marangoni convection in the molten pool Geometric characteristics of the TIG welds can be characterized by the weld depth, bead width, and weld D/W ratio. Figure.6 shows the geometric

Table 2. Summary of surface appearance of TIG welds made with various compounds.

Type flux	Slag	Spatter	Undercut
SiO_2	No	No	No
TiO_2	Yes	Yes	Yes
30%SiO_2+70%TiO_2	Yes	No	No
50%SiO_2+50%SiO_2	Yes	No	No
70%SiO_2+30%TiO_2	Yes	No	No

characteristics of TIG welds made with and without oxide compounds. There were significant variations in the weld depth and bead width of the TIG weld metal Compared with the geometric

Characteristics of TIG weld prepared with the active flux, there are clear increments in weld depth and a decrease in bead width resulting from the use of SiO_2/TiO_2 mixtures. However, the

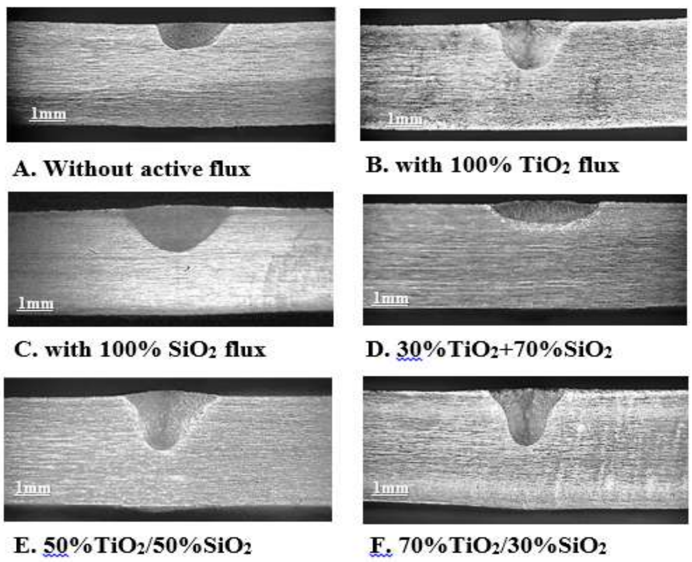


Figure 5 Effect of oxide compounds on geometric shape of TG weld metal.

TIG weld prepared with 30%TiO_2+70%SiO_2 had no significant effect on the weld D/W ratio. The D/W ratio of TIG welds made with SiO_2/TiO_2 mixtures increased with increasing concentration of TiO_2. In TIG welding assisted by SiO_2/TiO_2 mixtures, the use of 50%SiO_2/50%TiO_2 enabled maximum penetration of the welded joint. But According to investigations teseng and wang [16] The 80%SiO_2+20%TiO_2 mixture can produce the greatest improvement in penetration capability, up to 410%, compared with the conventional TIG welding of stainless steel 316L plates Although many investigations into the mechanisms of the increased joint penetration of activated TIG weldment have been carried out, there is still no common agreement

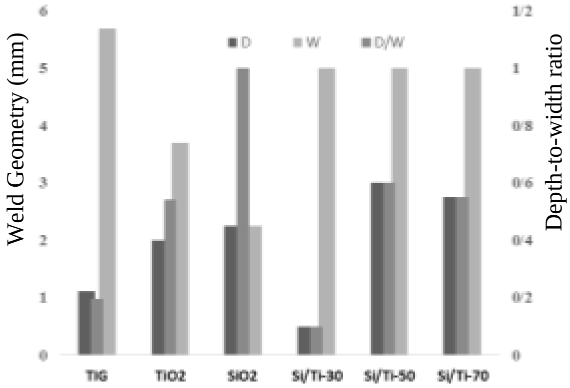


Figure 6 Geometric characteristic of TIG welds produced with and without flux

on the mechanism. On the basis of the present results, it is considered that the surface tension gradient and plasma arc column play a role in increasing the penetration of activated TIG joint [10-15]. Due to the presence of oxygen in the oxide flux, the temperature coefficient of surface tension on the molten pool changed from the negative to the positive, which caused centripetal Marangoni convection mode. Corresponding heat transfer from the weld surface to the root caused the metal plasma to be localized at the Center of the molten pool. As a result, a constricted anode root was formed, and higher current density and energy concentration in the arc column further promoted the centripetal Marangoni convection in the molten pool driven by Lorentz force (Chern et al., 2011) [17], which in turn brought about a greater arc forces acting on the molten pool. Therefore, the multiplied effect of the centripetal Marangoni convection and Constricted arc plasma will not only produce a narrower bead width but also increase the weld depth. Although further Investigation must clarify the physical mechanisms involved in this phenomenon, this study demonstrated the effect of specific flux on the activated TIG welds.

3.3 Metallurgical Characterizations of TIG-Flux Welds

The microstructure of an austenitic stainless steel matrix consists mainly of full austenite under the slow cooling of equilibrium solidification. However, during the non-equilibrium solidification process, fast cooling usually resulted in the incomplete transformation of ferrite phase to austenite phase. This may occur because the transformation from ferrite phase to austenite phase is a diffusion controlled process; the fast cooling in the welding process does not offer sufficient time to complete the phase transformation after solidification and cooling to room temperature. This study used an austenitic 316L stainless steel (ferrite content of 0.5 FN) as a weld metal without flux; its microstructure is shown in Figure 7(a). Figures 7(b,c,d,e,f) show the microstructures of the austenitic 316 L stainless steel TIG weld metals with fluxes. The microstructures of the weld metal produced with active flux exhibited a mixed morphology of lacy and skeletal ferrites too. The experimental weld metals did not exhibit a considerable difference in solidification structures between TIG welds produced with active flux and those mixed fluxes. This is because the UNS S31603 stainless steel weld metal solidified in the ferritic-austenitic (FA) mode, which has delta ferrite as the primary phase. During welding, the cooling rate of the weld metal is so rapid, that phase transformation of the delta ferrite to the austenite is not complete, resulting in more delta ferrite being retained in the stainless steel weld metal after solidification. In TiO_2- or SiO_2 -flux assisted TIG welding, the higher ferrite retained in the austenitic 316 L stainless steel weld metals may be attributed to the fast cooling of the welds instead of the composition of the flux compound, because flux additions act indirectly, and the heat input is the crucial factor affecting the ferrite content retained in the weld metals after solidification.

4.3 Evaluation of the quality of welded joints

The Charpy impact toughness test data for the weld joint produced by with and without flux welding process in the as weld condition at room temperature is shown in Table3. For two samples with and without flux Charpy test was conducted at ambient temperature. The weld joint without flux exhibited good toughness value of 188 J in room temperature was performed. For full penetration welding on thick. Plates 6 mm when use of welding flux welding operations (Back weld) were performed with flux. Then hit three samples were taken from both with and without flux. Based on these results, it was found that relatively good result can be achieved when using flux. In the without flux weld metal samples has 75/2 J the average amount of energy is absorbed. But welding with flux TiO250% + SiO250% of the average amount of energy 57/3 J has attracted. According to the report by researchers welding flux in the presence of TiO2 the possibility of a bubble and its bursting exists within the weld metal [32]. After the defeat of sample surveys welding with flux 50% TiO_2+ 50% SiO_2 as shown in Figure 8a, it was determined that there are small pores in the direction of welding. The cause of the creation of bubbles in the weld metal is likely due to the presence of TiO2 oxide Compound respectively. It was also found that a slight drop due to the strength of the weld metal in the weld Metal is the gas chambers.

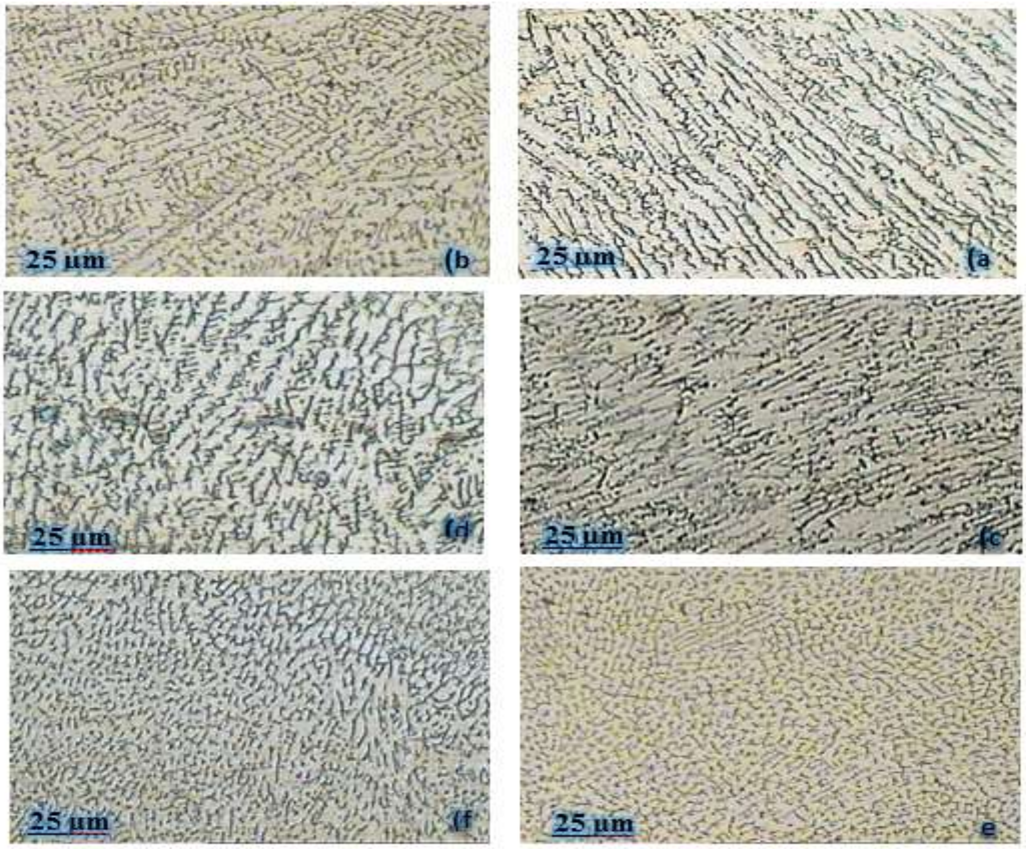


Figure 7 Microstructure of base metal and TIG welds produced with and without flux. a. Without active flux, b. with 100% TiO_2 flux, c. with 100% SiO_2 flux, d. 30%SiO_2+70%TiO_2, e. 50%SiO_2/50%TiO_2, f. 70%SiO_2/30%TiO_2

5.3 Fructugraphy

The surface as observed in the SEM for impact tested sample of weld joint produced with and without flux at room temperature is shown in Figure. 8a and b respectively. Figure. 8a shows a dimple structure implying that failure is by ductile mode while at sub zero the failure mode was brittle as shown in Figure. 8b.

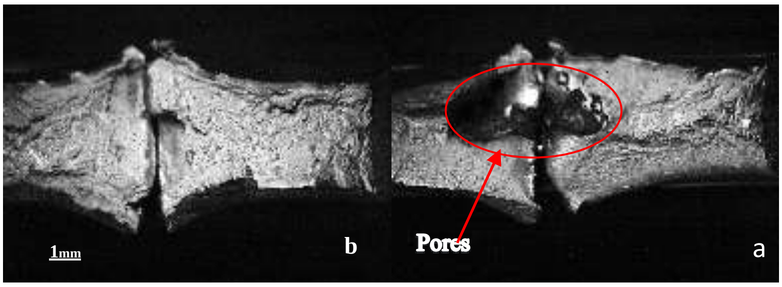


Figure 8 Scanning electron micrograph of fracture surface.

Figure 9 shows the hardness of austenitic 316 L stainless steel TIG weldments produced with and without flux. In a conventional TIG weldment, the average value of the TIG weld metal is estimated as 215 VHN. In a TiO2-flux assisted TIG weldment, the average values of the weld metal is approximately 217 Hv. In a SiO2-flux assisted TIG weldment, the average values of the weld metal is approximately 184 Hv. The increase in hardness of the weld metal can be attributed to the presence of the ferrite phase. However in effect combine SiO_2 with TiO_2 particle hardness weld metal significantly reduce compared to without and with flux. Also increases TiO_2 particles in mixed flux SiO_2/TiO_2, increase hardness weld metal. Moreover, the hardness in the activated TIG weld metal could be decreased by increasing the concentration of TiO_2 in the SiO_2/TiO_2 mixture.

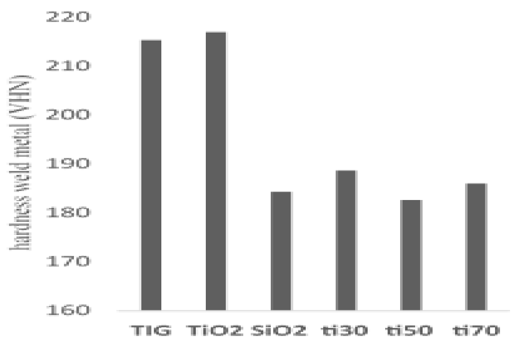


Figure 9 Hardness of TIG weldment produced with and without flux

Table 3. Impact test result of butt joint welded with and without flux.

Type weld	Design joint	Position of V-notch	Number pass weld	Absorbed impact energy (J)	Lateral expansion (mm)
Without flux	V- joint	Weld	5 pass	75.2	1.37
With flux 50% SiO_2+ 50% TiO_2	Butt joint	Weld	2 pass	57.3	1.90

4. CONCLUSIONS

In the present work, SiO_2-TiO_2 mixed powders were selected as the activated flux. Autogenous TIG welding was conducted on stainless steel 316L plates to produce a bead-on-plate weld. The effects of mixed fluxes on the surface appearance, weld morphology, and microstructural characterization were investigated. These results can be summarized as follows
:

1. For TIG welds produced with SiO_2 flux, the welds surface appears to be rough, with some residue. The activated flux assisted TIG welding process also produces fumes.
2. The 50%SiO_2+50%TiO_2 mixture can produce the greatest improvement in penetration capability, up to 300% compared with the conventional TIG welding of stainless steel 316L plates.
3. In the present work, surface tension gradient is considered as a possible mechanism for increased the activated flux assisted TIG penetration of stainless steel joint.
4. The oxide flux assisted TIG welding with a faster cooling rate, and ferrite structure presents within an austenitic matrix of stainless steel 316L weld metal can therefore be increased.

5. Acknowledgments

The authors gratefully acknowledge the financial support provided to this study by the Fanavaran Uniqtig Pars CO. and the Electrode Etemad CO. Yazd.

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