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Study of Silica-Titania Mixed Flux Assisted TIG Welding Process

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Abstract. An activated flux assisted tungsten inert gas (TIG) welding of type 316L stainless steel was investigated. SiO_2-TiO_2 mixed powder was selected as the activated flux. Mixed fluxes effect on the surface appearance, weld morphology, and ferrite structure were investigated. The results showed that TIG welds surface produced with flux contributed to the formation of residues. The 80% SiO_2+ 20%TiO_2 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.

Introduction

Development of cost-effective welding technique is a key competitive challenge to the future of the manufacturing industry. Arc welding is undoubtedly one of the most common and important joining techniques used today. TIG welding technique is the most popular arc welding process. TIG welding, with a stable arc and high-quality welds but a low productivity, can improve its future potential if the productivity can be significantly increased [1,2]. A novel variant of TIG welding called activated flux assisted TIG welding involves applying a thin layer of flux on the joint surface to be welded. The advanced TIG process can produce a dramatic increase in penetration and productivity [3-7].

Researchers at the E.O. Paton Electric Welding Institute of National Academy of Sciences of Ukraine (Kiev) introduced the concept of using an activated flux assisted TIG welding to increase joint penetration in the 1960s outlined by Gurevich et al. [8]. Most common commercial flux contains oxide, chloride, and fluoride [5,9]. Although previous researchers have enabled us to identify which single-component flux has the greatest influence on TIG joint penetration [10-15]. To improve the performance of activated flux assisted TIG welding process, the understanding of the function of multi-component flux is needed to select a suitable flux and to develop new fluxes for improved the penetration and productivity. 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.

Experimental procedures

Austenitic 316L stainless steel machined into rectangular plates (120 ×120 × 6 mm) was used, with the chemical composition of 0.019 pct C, 0.47 pct Si, 1.77 pct Mn, 0.031 pct P, 0.002 pct S, 17.10 pct Cr, 10.11 pct Ni, 2.05 pct Mo, 0.048 pct N, and the rest remainder Fe. Before welding, the plate surface was ground using 400 grit (silicon carbide) flexible abrasive paper to remove impurities, and then cleaned with acetone. SiO_2-TiO_2 mixed powder was selected as the activated flux. Weight percentage of SiO_2 in the flux was 20%, 40%, 60%, and 80% respectively. Before welding, the flux powders were mixed with acetone to make a paint-like consistency. A brush was used to apply the mixture on the joint surface to be welded. The mean coating density of flux powder was 4.3 mg/cm^2.

Autogenous TIG bead-on-plate welds were performed using a direct current electrode negative power supply with a mechanized operation system in which the torch was moved at a constant speed of 150 mm/min. The weld current was 180A. A standard 2% thoriated tungsten electrode rod of 3.2

mm diameter was used. The electrode tip configuration was a blunt point with a 45° included angle, and electrode gap was 3 mm. Argon was used as shielding gas at a constant flow rate of 12 liter/min. The tip angle of electrode was ground and the electrode gap was measured for each weld before welding to ensure that the weld deposit was made under the same conditions.

Fisher make ferritoscope was used to measure the ferrite content within an austenitic weld metal. This device detects phases such as ferrite by their magnetic susceptibility, which differs from that of the paramagnetic austenite. To minimize the errors due to weld metal inhomogeneity, the mean value of seven measurements for different locations along the as-welded surface was calculated.

Weld cross-sections were taken at several locations along the length of the welds, and samples for metallographic examination were prepared using standard procedures including mounting, grinding, polishing, and etching. Cross-sectional macrographs of the weld were observed, and the dimensions of the penetration depth and bead width were also measured.

Results and discussion

Effect of silica-titania mixed fluxes on surface appearance

Fig. 1 shows the surface appearance of stainless steel TIG 316L welds produced without flux and with different fluxes. Fig. 1a shows the results of TIG welding without activated flux, which appears clean, smooth, and faultless surface. For TIG welds produced with different fluxes, some residue will remain on the surface and appear to be rough (Fig 1b-f). The residues decreased with the increasing SiO_2 percentage in the silica-titania mixed flux. It should be mentioned that the rough surface tends to increase the risk of both corrosion and product contamination. In addition, the activated flux assisted TIG welding process also produces fumes. Whether these fumes will affect human health is still not certain and requires further investigation.

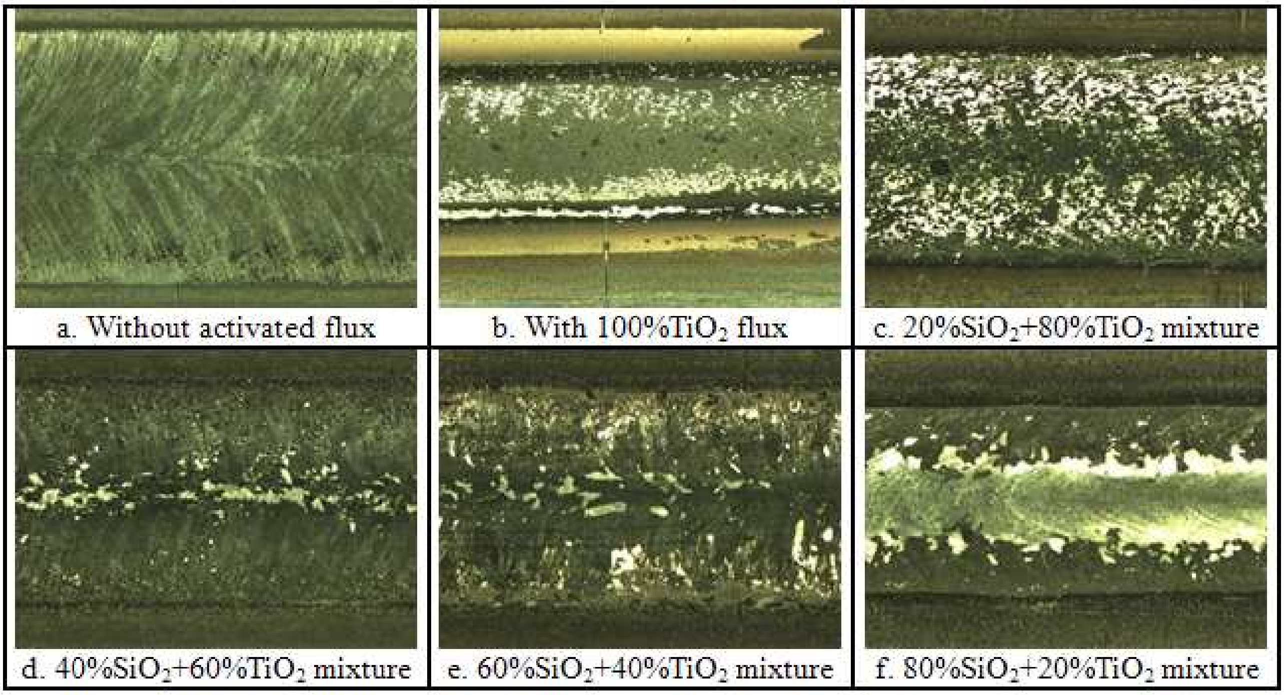
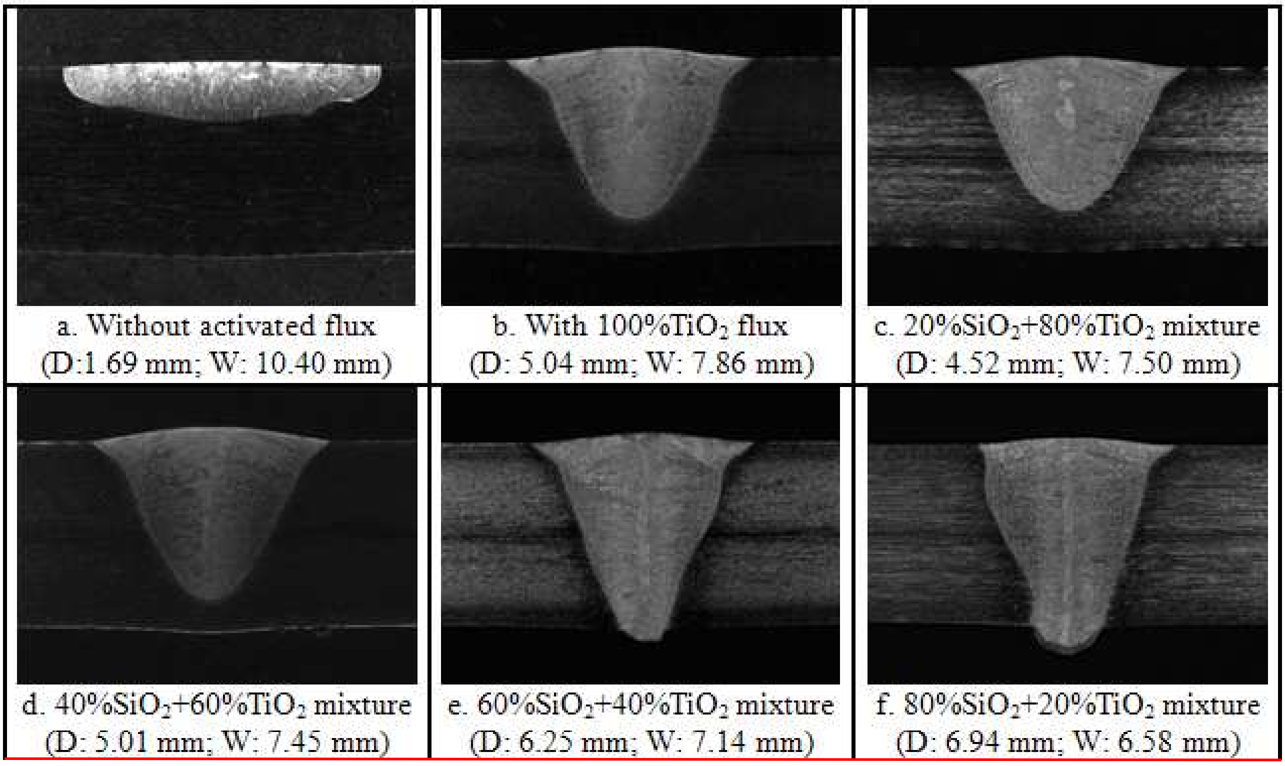


Fig. 1 Effect of SiO_2-TiO_2 mixed fluxes on surface appearance

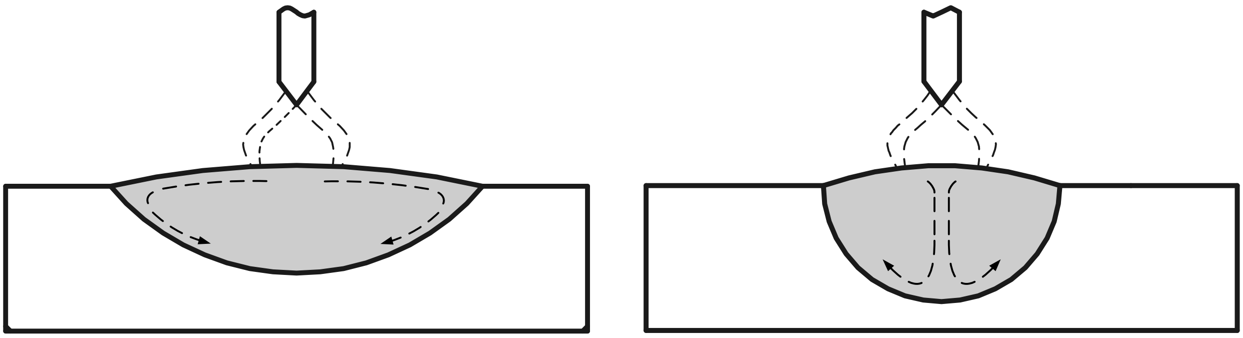
Effect of silica-titania mixed fluxes on weld morphology

In the present work, the weld morphology is characterized by the penetration depth *D* and bead width *W*. Fig. 2 shows the weld morphology of type 316L stainless steel TIG welds produced without flux and with different fluxes. TIG welds without activated flux created a wide and shallow morphology (Fig. 2a), while the TIG welds with different fluxes created a narrow and deep morphology (Fig. 2b-f). It was obvious that the increases in penetration depth and the decrease in bead width are significant with use of the silica-titania mixed fluxes. 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. It should be mentioned that the increase in depth was enough to give a full penetration TIG weld produced with the 60%SiO_2+40%TiO_2 mixture assisted weld current of 180A in 6 mm thick stainless steel 316L plates.



a. Without activated flux (D:1.69 mm; W: 10.40 mm)
b. With 100%TiO_2 flux (D: 5.04 mm; W: 7.86 mm)
c. 20%SiO_2+80%TiO_2 mixture (D: 4.52 mm; W: 7.50 mm)
d. 40%SiO_2+60%TiO_2 mixture (D: 5.01 mm; W: 7.45 mm)
e. 60%SiO_2+40%TiO_2 mixture (D: 6.25 mm; W: 7.14 mm)
f. 80%SiO_2+20%TiO_2 mixture (D: 6.94 mm; W: 6.58 mm)

Fig. 2 Effect of SiO_2-TiO_2 mixed fluxes on weld morphology



a. Outward fluid flow
b. Inward fluid flow

Fig. 3 Schematic of liquid metal flow in weld pool

Fluid flow patterns have a significant influence on the heat transfer distribution in the weld pool, and consequently, determine the weld morphology [16]. During arc welding, the driving forces acting on the fluid flow of weld pool include the buoyancy, electromagnetic force, aerodynamic drag, and surface tension [17]. As a result, the liquid metal convection of weld pool is driven by a combination of various forces. It is generally agreed that the surface tension gradients are the major driving force contributing to liquid metal convection in the weld pool. The surface tension gradient is established by the temperature difference along the pool surface. Arc heating makes the temperature of the pool surface significantly higher at the center than at the edge. For TIG welding without flux, the surface tension will be highest level at the edge of weld pool and lowest level near the centre of weld pool. Surface tension gradient therefore produces liquid metal outwards from the centre of pool surface (Fig. 3a), resulting in a shallow and wide weld as shown in Fig. 2a. When the surface active elements, such sulfur or oxygen, exceed a certain concentration in the weld pool, the temperature coefficient of surface tension dramatically changes from negative to positive [18,19]. This means that the surface tension of liquid metal increases with the increase in temperature. For TIG welding with oxide flux, the surface tension is highest near the centre of weld pool. The liquid metal will be inwards along the pool surface towards the centre and then down to pool root (Fig. 3b). As a result, a deep and narrow weld can be obtained as shown in Fig. 2b-f.

Effect of silica-titania mixed fluxes on ferrite structure

Ferrite number (FN) is an arbitrary standardized value for designating the ferrite content within an austenitic stainless steel weld metal. Fig. 4 shows the measured ferrite content in stainless steel 316L weld metal (as-welded) produced without flux and with different fluxes. For TIG welds produced without flux, the measured ferrite content in stainless steel 316L weld metal with a mean of 4.9 FN. When using the SiO_2-TiO_2 mixed fluxes, the measured ferrite content in activated TIG weld metal is increased to 5.5–6.3 FN. It is well known that the cooling rate determines the amount of ferrite that can transform to austenite. Compared with the conventional TIG welding, the activated flux assisted TIG welding generates a high energy density of heat source [20], and therefore results in a lower heat input and a faster cooling rate. Because fast cooling rates favor retention of the ferrite structure, it is possible to have more metastable delta-ferrite phase remained at room temperature. Also, the optical micrographs did not reveal significant differences in microstructure between welds produced with the pure TiO_2 flux and those produced with the SiO_2-TiO_2 mixed fluxes.

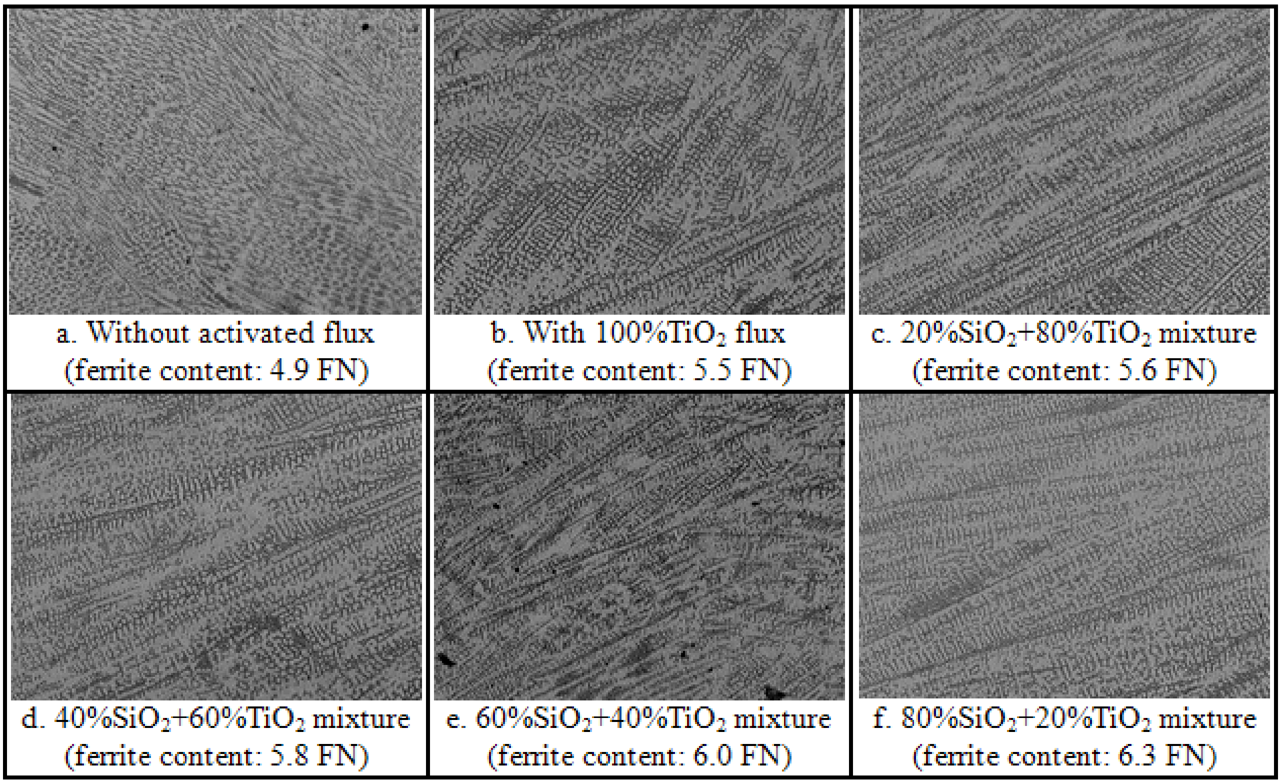


Fig. 4 Effect of SiO_2-TiO_2 mixed fluxes on morphology and content of ferrite structure

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 and/or TiO_2 flux, the welds surface appears to be rough, with some residue. The activated flux assisted TIG welding process also produces fumes.
2. 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.
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.

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