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Effect of activated TIG flux on performance of dissimilar welds between mild steel and stainless steel

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Abstract. The purpose of the present work was to investigate the effect of oxide fluxes on surface appearance, weld morphology, angular distortion, and weld defect obtained with activated tungsten inert gas (TIG) process applied to the welding of 6 mm thick dissimilar metal plates between JIS G3131mild steel and SUS 316L stainless steel. The CaO, Fe_2O_3, Cr_2O_3, and SiO_2 fluxes used were packed in powdered form. The results indicated that the surface appearance of TIG welds produced with oxide flux formed residual slag. TIG welding with SiO_2 powder can increase joint penetration and weld depth-to-width ratio, and therefore the angular distortion of the dissimilar weldment can be reduced. Furthermore, the defects susceptibility of the as-welded can also be reduced.

Introduction

Dissimilar metal welding is frequently used to join stainless steels to other metal alloys. This approach is most often used where a transition in mechanical properties and/or performance in service are required. For example, austenitic stainless steel piping is often used to contain high-temperature steam in power generation plants. Below a certain temperature and pressure, however, low-carbon and low-alloy steels perform adequately, and a transition from stainless steel to other steels is often used for economic purposes [1]. Most stainless steels can be successfully welded to low-carbon and low-alloy steels. Consideration must be given to the effects of dilution of the weld metal with the two base metals and the different coefficients of thermal expansion in stainless steel and low-carbon or low-alloy steels [2].

An arc welding commonly used to join metal and its alloys. There are several choices amongst the arc welding processes, such as shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), and gas metal arc welding (GMAW) [3]. GTAW process, also known as TIG welding, is most commonly used to join thin sections of stainless steel and non-ferrous metals such as aluminum and magnesium alloys. The process grants the operator greater control over the weld than competing procedures such as SMAW and GMAW, allowing for higher quality welds in a wide variety of metal and its alloys. However, the potential problems of TIG welding lie in the limited thickness of workpiece which can be welded in a single-pass operation [4-6]. Improvements in joint penetration have long been sought in TIG welding process. One of the most notable techniques is the use of activated flux in TIG process which is called activated TIG welding. This technique makes it possible to intensify the conventional TIG practices for joining the thickness of 6 to 10 mm by single-pass welds, with no edge preparation, instead of multi-pass procedures [7,8].

Since not much study has been carried out on the performance of the welded joint for hot-roll mild steel, and considering the intent to use this steel in more structural applications, dissimilar welding was taken into account for this study. In this work, four kinds of oxide powders were used to investigate the effect of activated TIG process on the performance of dissimilar welds between hot-roll mild steel and austenitic stainless steel.

Experimental Procedures

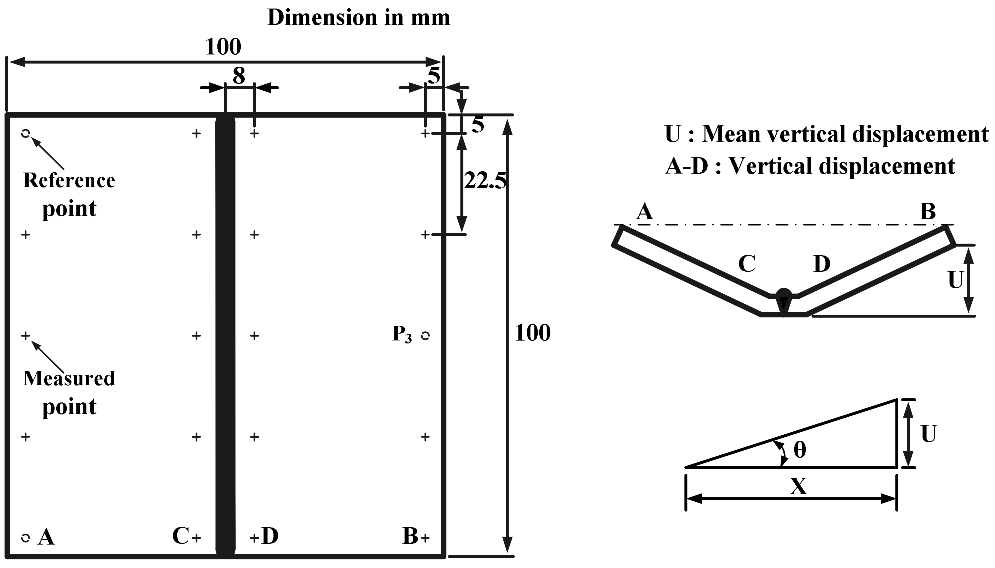
Austenitic stainless steel (SUS 316L) and hot-roll mild steel (JIS G3131) were selected as the base metals. Plates measuring 6 mm thick were cut into 100 × 50 mm strips, roughly polished with 400 grit silicon carbide paper to remove surface contamination, and then cleaned with acetone. Activated flux was prepared using four kinds of single-component oxides (CaO, Fe_2O_3, Cr_2O_3, and SiO_2) packed in powdered form. These powders were mixed with acetone to produce a paint-like consistency. Before welding, a thin layer of the flux was brushed onto the surface of the joint to be welded. The coating density of flux powder was 5 to 6 mg/cm^2.

An autogenous TIG process was performed on the test specimen using an automatic welding machine to produce a butt-joint weld. Travel speed and weld current were 150 mm/min and 200 A, respectively. 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. The arc length was 3 mm. Argon gas was used as shielding gas at a constant flow rate of 12 L/min.

After welding, experiments were also carried out to measure the angular distortion in a butt welded joint. Fig. 1 is a schematic diagram of the weld distortion measurement. A hole was drilled at the back of points P_1, P_2, and P_3, and a pillar was inserted in each hole. Three pillars (one fixed, two adjustable) were used to adjust the horizontal level, and the distance from each point to the horizontal surface was then recorded. Measurements were taken before and after welding. During the measurement, the stage was moved along X-axis direction, and the mean vertical displacement U was obtained. The angular distortion θ can be derived from the equation:

$$\theta = \tan^{-1}\frac{U}{X} \tag{1}$$

Finally, the five positions on either side of the welds were averaged, then added together to give the mean angular distortion value.



(a) Measuring position (b) Measuring theory

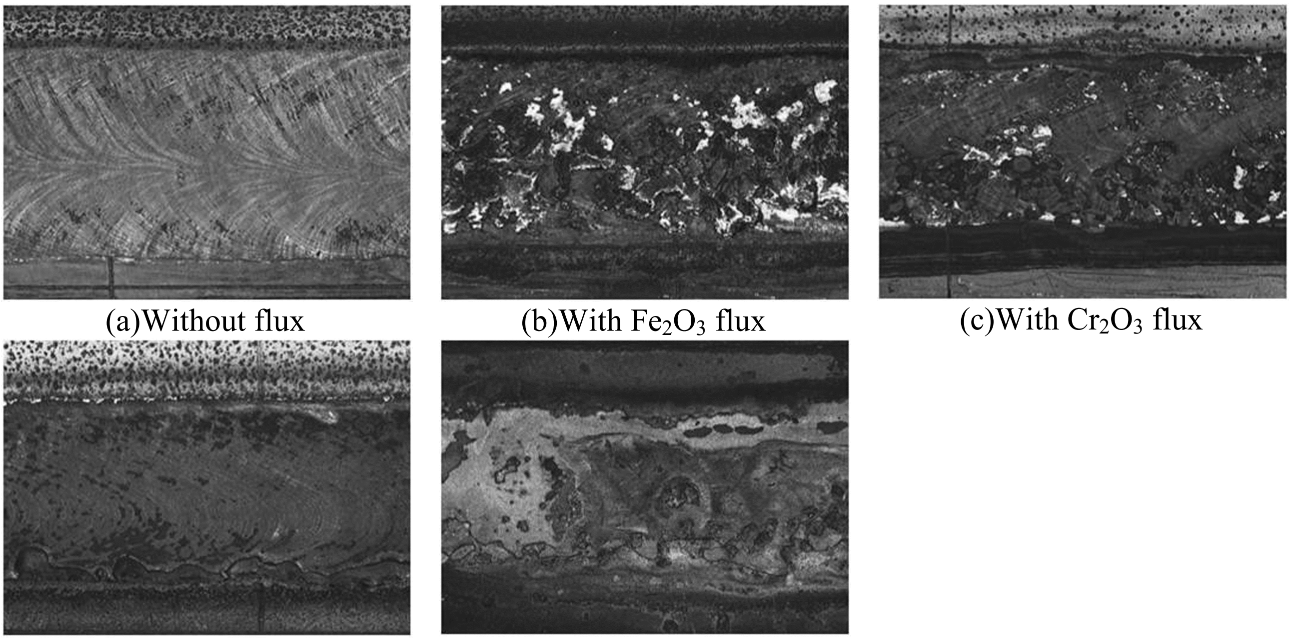
Fig. 1 Schematic diagram of weld distortion measurement

An optical microscope was used to measure the dimensions of weld depth and bead width. All metallographic samples were prepared using standard procedures, including mounting, grinding, and polishing, followed by etching in a solution of 10g $CuSO_4$-50ml HCl-50ml H_2O or 5% Nital.

Results and Discussion

Effect of Oxide Flux on Surface Appearance. Fig. 2 shows the surface appearance of activated TIG welds produced with and without flux. Fig. 2a shows the results of TIG welding without flux, which produced a smooth and clean surface. Fig. 2b, 2c, and 2e show that the use of Fe_2O_3, Cr_2O_3, and CaO fluxes produced excessive slag. Fig. 2d shows the few slag of TIG welds obtained with use of the SiO_2 flux. These results clearly indicated that TIG welds produced with oxide fluxes contributed to the formation of the residual slag.

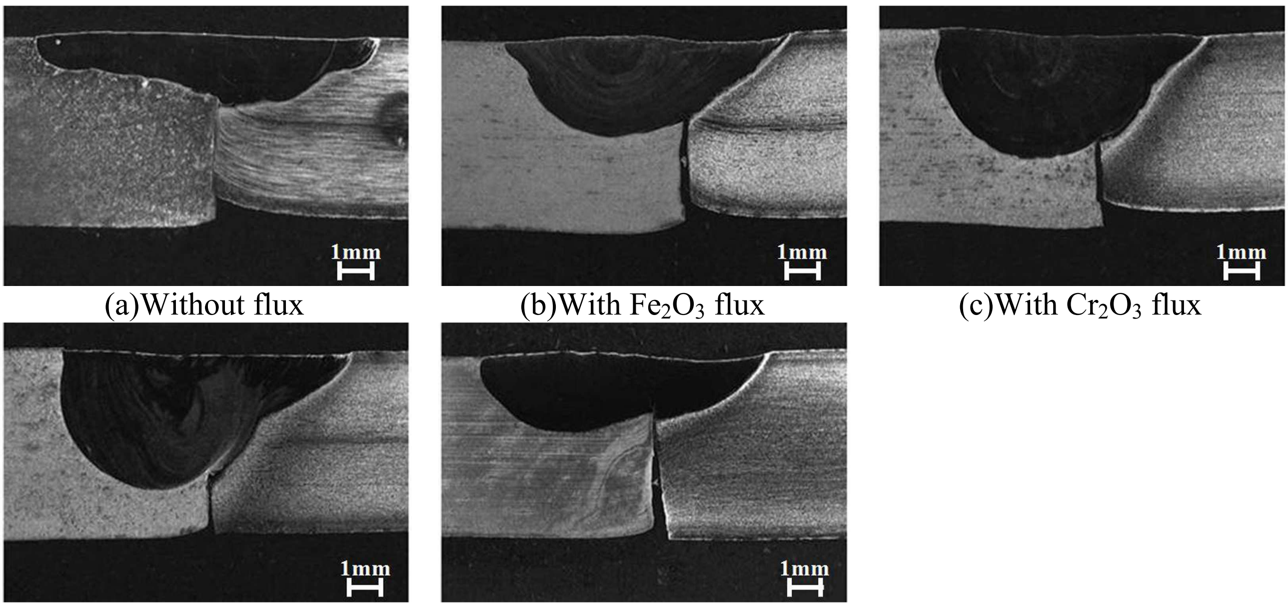
Effect of Oxide Flux on Weld Morphology. Fig. 3 shows the cross-sections of TIG welds produced with and without flux. TIG welds without flux exhibited a wide and shallow morphology (Fig. 3a). TIG welds with flux, which is composed of Fe_2O_3, Cr_2O_3, and SiO_2 powders, exhibited a narrow and deep morphology (Fig. 3b-3d). The CaO flux powder has no significant effect on penetration of TIG welds as shown in Fig. 3e.



(a)Without flux (b)With Fe_2O_3 flux (c)With Cr_2O_3 flux

(d)With SiO_2 flux (e)With CaO flux

Fig. 2 Effect of oxide flux on surface appearance



(a)Without flux (b)With Fe_2O_3 flux (c)With Cr_2O_3 flux

(d)With SiO_2 flux (e)With CaO flux

Fig. 3 Effect of oxide flux on weld morphology

Fig. 4 shows the characteristics of weld geometry produced with and without flux. The increases in weld depth and the decrease in bead width are significant with use of the Fe_2O_3, Cr_2O_3, and SiO_2 fluxes. The results also showed that the certain flux provided a high weld depth-to-width ratio. In the present study, the SiO_2 flux led to the greatest improvement in joint penetration and satisfactory surface appearance of G3131 mild steel to 316L stainless steel dissimilar welds.

According to work by Heiple and Roper [9], the direction of fluid flow in the molten pool can affect the weld geometry. The temperature coefficient of surface tension is a factor in driving the direction of fluid flow in the molten pool. For TIG welding without flux, the surface tension will be greatest at the edge of weld pool and lowest in the hottest part of weld pool near the center under the arc. The surface tension gradient therefore produces fluid flow outwards from the centre of the molten pool surface (Fig. 5a), and resulting in a relatively wide and shallow weld. The addition of the oxygen element to the molten pool can drastically change the temperature dependence of the surface tension. For TIG welding with Fe_2O_3, Cr_2O_3, and SiO_2 flux, the surface tension is highest near the centre region of weld pool. The fluid flow will be inwards along the surface of weld pool towards the centre and then down (Fig. 5b), and tends to produce a narrow and deep weld.

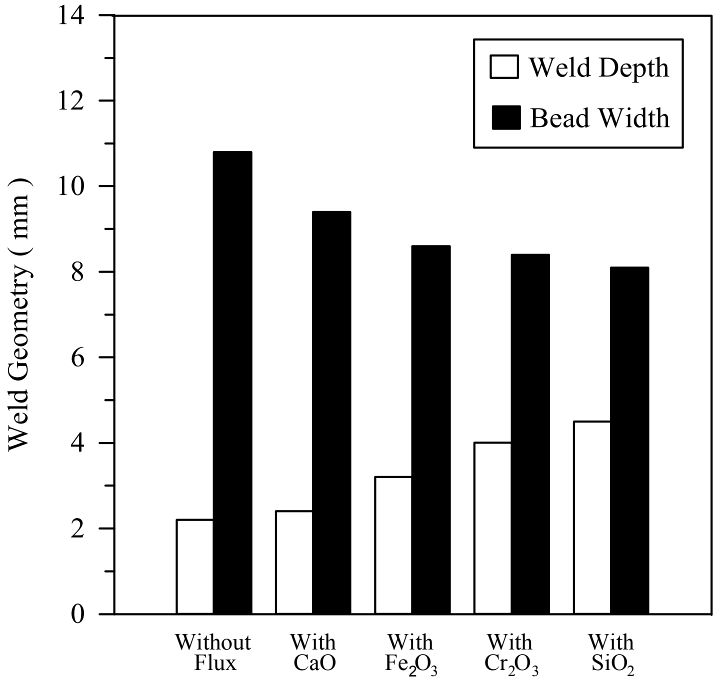


Fig. 4 Characteristics of TIG weld geometry produced with and without flux

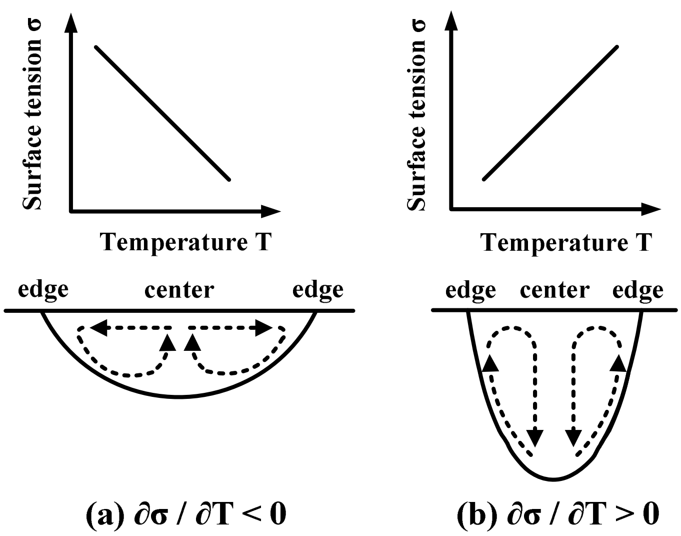


Fig. 5 Schematic diagram of fluid flow pattern in the molten pool

Effect of Oxide Flux on Angular Distortion. Angular distortion often occurs in a weldment when non-uniform thermal shrinkage in the thickness direction causes the angular change close to weld line. The degree of angular distortion depends on several factors such as the relative weld depth and the shape and dimensions of weld metal [10,11].

The effect of oxide flux on angular distortion is shown in Fig. 6. For TIG welding without flux, the weld depth is not more than the half of plate thickness. The shallow depth causes lower angular distortion, and with increasing weld depth to plate thickness ratio, the angular distortion of the weldment with Fe_2O_3 flux increases to a critical point (weld depth to plate thickness ratio equivalent to 0.55), and then weld depth exceeds 50% of the plate thickness, the angular distortion of the weldment with use of the SiO_2 flux decreases. TIG welding with SiO_2 flux produced a substantial increase in joint penetration and weld depth-to-width ratio, which is characteristic of a high degree of energy concentration during welding process [11]. This contributes to a reduction in the quantity of supplied heat, which prevents overheating of the base metal and reduces the incidence of thermal stress and incompatible strain due to shrinkage in the thickness. Therefore, TIG welding with SiO_2 flux can significantly reduce angular distortion of the weldment.

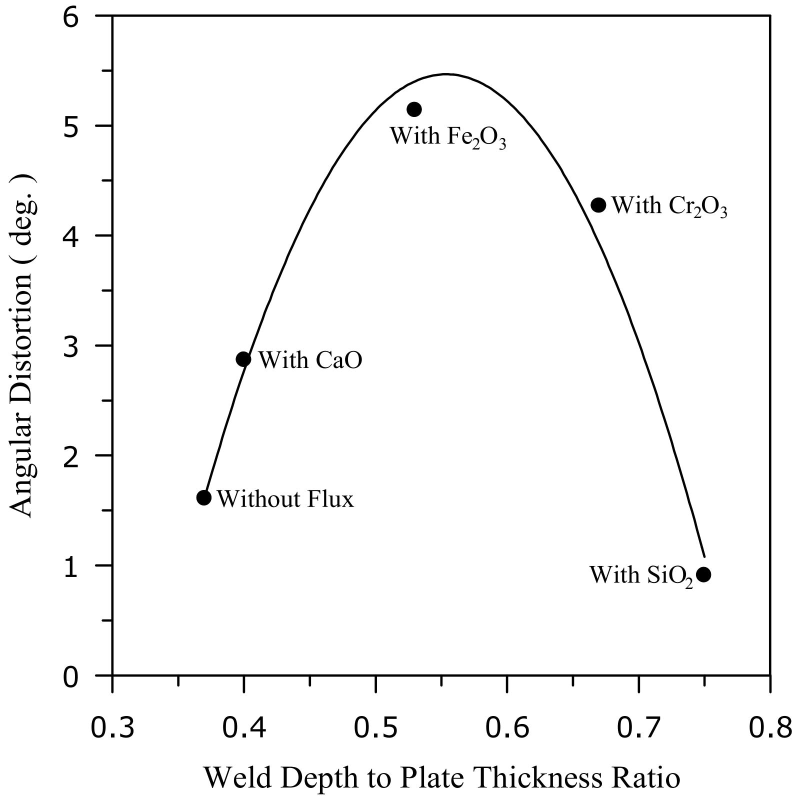
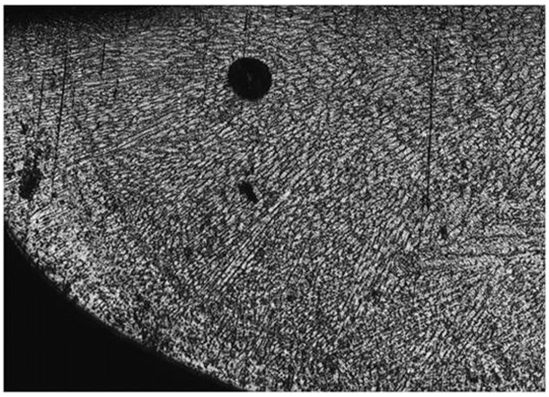


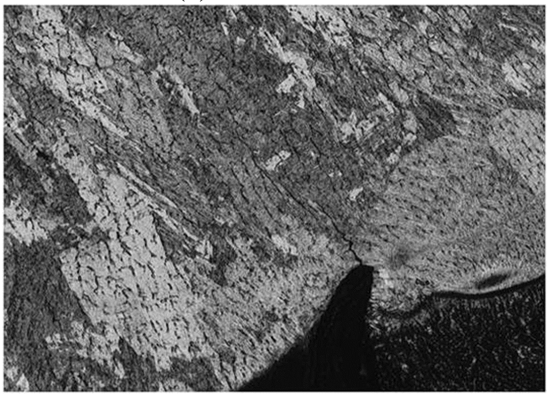
Fig. 6 Effect of oxide flux on angular distortion

Effect of Oxide Flux on Weld Defect. Fig. 7 shows the effect of TIG welding with and without flux on defects of G3131 mild steel to 316L stainless steel dissimilar welds. Fig. 7a shows the results of TIG welding without flux, which produced voids in weld metal of G3131 mild steel. Fig. 7b-d shows the results of TIG welding with Fe_2O_3, Cr_2O_3, and CaO fluxes, which produced cracks in weld metal of 316L stainless steel. When TIG welding with SiO_2 flux is used, no voids and cracks are present in the weld metal, and have a beneficial effect in improving the joint quality of the dissimilar welds.

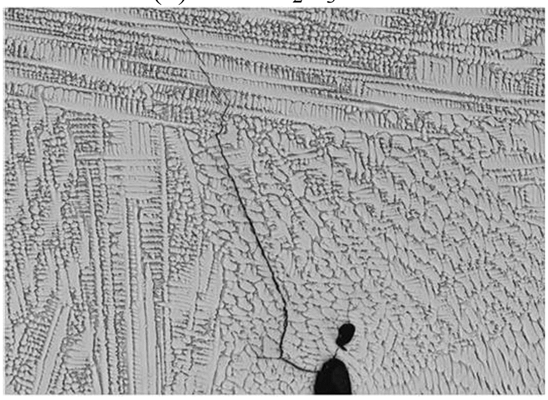


(a)Without flux

(b)With Fe_2O_3 flux



(c)With Cr_2O_3 flux



(d)With CaO flux

Fig. 7 Effect of oxide flux on weld defect

Conclusions

The experiments were conducted to investigate the effect of CaO, Fe_2O_3, Cr_2O_3, and SiO_2 fluxes on surface appearance, weld morphology, angular distortion, and weld defect when using TIG process to weld 6 mm thick dissimilar metals between G3131 mild steel and 316L stainless steel. The main conclusions reached in the present study are summarized as follows:

1. The surface appearance of TIG welds produced with oxide flux tended to form residual slag.
2. The SiO_2 powder can give the greatest improvement in joint penetration and also a satisfactory surface appearance of G3131 mild steel to 316L stainless steel dissimilar welds.
3. TIG welding with SiO_2 powder can increase weld depth-to-width ratio, which indicates a high degree of energy concentration during welding process, and tends to reduce angular distortion of the weldment. Furthermore, the defects susceptibility of the welds can also be reduced.

Acknowledgements

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