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Experimental investigation on mechanism and weld morphology of activated TIG welded bead-on-plate weldments of reduced activation ferritic/martensitic steel using oxide fluxes

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ABSTRACT

This work attempts to investigate the influence of different single component oxide fluxes in the activated TIG welding of reduced activation ferritic/martensitic (RAFM) steel. Six different fluxes Al_2O_3, Co_3O_4, CuO, HgO, MoO_3, and NiO were used for bead-on-plate welding, carried out under same conditions and process parameters. The weld dimensions such as depth of penetration (DOP), depth/width (D/w) ratio, bead width (BW) and Heat affected zone (HAZ) width were studied and compared in addition to the peak welding temperatures. Experimental results indicated that enhanced penetration was achieved with use of fluxes Co_3O_4, CuO, HgO and MoO_3. Further investigation of weld dimensions and the peak temperature values indicated that the reversed Marangoni effect was present with the use of these fluxes. However, fluxes Co_3O_4 and CuO gave through penetration (greater than plate thickness) under the additional effect of arc constriction. Thus a dual mechanism effect is proposed in this study with the use of these two fluxes. Furthermore, the metallurgical characterisation of the weldment produced with Co_3O_4 and CuO fluxes were evaluated using optical microscopy and Vickers micro-hardness and compared with TIG welded sample. The resultant microstructures and hardness profile indicated presence of coarser and harder martensitic structure in the weld and HAZ regions.

1. Introduction

Activated TIG (A-TIG) welding is a relatively novel joining process, invented at Paton institute of electric welding in 1960 [1]. This process can be considered as one of the variants of TIG welding process in which an activating flux layer comprised of metal oxides, prominently halides, oxides or sulphides is applied on the weld surface before welding. During welding, this fine layer of flux is melted and vaporised at arc temperatures and penetration capability is reported to be increased up to 300% while using A-TIG compared to conventional TIG process [2–4]. The need for the development of this process was attributed to the incapability of the TIG welding process to give inadequate penetration in single pass operation. This technique of using fluxes during TIG welding enabled steels of around 6 mm to be welded with single pass in square butt configuration without addition of filler metal [5]. The idea for developing this technique was imbibed from the characteristic sensitivity of TIG process to base material chemical composition in form of cast to cast variation [6]. In line with this, A-TIG welding has also been successfully applied on low alloy steels [1,7–9], stainless steels [6,10–14], duplex stainless steels [15] as well as dissimilar metal combinations [2,12]. However, the A-TIG welding is greatly influenced by the chemical composition and hence the technique needs to be developed for new steels with different chemical composition.

Reduced activation ferritic/martensitic (RAFM) steels form a major structural composition of fusion reactors involved in harnessing the nuclear energy for meeting energy requirements. Previously, it was thought of using Cr–Mo steels in fabrication of various components of these reactors, however the major challenge was the disposal methods for these components after their service lifetimes are exhausted [16,17]. This was due to the radiological activation and swelling phenomenon owing to the elements such as molybdenum (Mo), niobium (Nb), nickel (Ni), nitrogen (N) and copper (Cu) present in Cr–Mo steels. In order to counter these Mo was replaced by Tungsten (W), Ni by tantalum (Ta) and the content of vanadium (V) was increased to reduce the activation tendency. These steel was termed as RAFM steel. In addition to this, RAFM steel also possess good mechanical properties, adequate

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creep resistance up to 550 °C, limited radiological activation combined with reduced swelling and high recycling potential [17,18]. Thus RAFM steel was selected as a primary candidate for major structural material in International Thermonuclear Experimental Reactor (ITER) test blanket module across countries like India, France, Japan and USA [19–23]. As fabrication of this RAFM steel for reactors are mainly by welding [23,24], A-TIG welding of RAFM steel can be considered as an emerging field for study. However limited literatures are available on A-TIG welding of RAFM steels. Vasantharaja et al. [25] reported the use of A-TIG welding for RAFM steel in 10 mm thick plates. Using undisclosed flux constituents, maximum penetration of 5.7 mm was reported at heat input of 2.2 kJ/mm. At this heat input values, the impact properties were found inferior compared to conventional welding process. However, the use of oxide fluxes in A-TIG welding of RAFM steel is yet to be reported.

Moreover, as the A-TIG welding is sensitive to the chemical constituents, the selection of flux becomes an important criterion. There are available literatures reporting the use of oxide fluxes in A-TIG welding on different steels. Arunkumar et al. [26] studied the effect of SiO_2 and ZnO fluxes on incoloy 800H and reported an increase in penetration compared to TIG welding without flux. Tathgir et al. [27] studied the effect of TiO_2 on different steels and reported subsequent increase in penetration. Thus oxide fluxes have a promising effect which makes them candidate compounds for A-TIG welding.

To best of our knowledge, no research work has yet been reported on the use of oxide fluxes in A-TIG welding of RAFM steel. Additionally, there is no general agreement in the available literature on the penetration enhancing mechanism through which the flux increases TIG joint penetration [28,29]. Several researchers have demonstrated that the reversed Marangoni effect is the principal mechanism for increasing the joint penetration [1,30]. In addition to this, the several researchers have also suggested arc constriction as a mechanism to obtain a deep joint penetration in the TIG welding [13,14]. However, the exact mechanism of deeper penetration still remains unclear with respect to type of flux and base material [31]. Based on the evident research gap mentioned above, an attempt has been made in present study to investigate the effect of oxide fluxes on RAFM steel and to identify the exact dominant mechanism for deeper penetration. The present study deals with studying weld bead dimension such as DOP, BW, HAZ width and D/w ratio for bead on plate welds by A-TIG process using 6 different oxide fluxes such as Al_2O_3, Co_3O_4, CuO, HgO, MoO_3, and NiO and further correlating the same with temperature profiles to suggest an exact mechanism.

2. Experimental work

2.1. Base material and fluxes

RAFM steel used in the present study was produced by M/S Mishra Dhatu Nigam Ltd. Hyderabad, India. The base material with chemical composition is as shown in Table 1. The heat treatment condition was hot rolled, quenched and tempered. Additionally, the oxide fluxes used in the study were in packed and powdered form. Six different fluxes used in the study are as listed in Table 2.

2.2. Application of flux

The flux available in powdered form is not possible to apply evenly on the weld surface. For the same, the powder is converted to paste form by mixing it with acetone as shown in Fig. 1(a). Acetone has a tendency to vaporise quickly leaving the evenly distributed oxide flux on the surface. Base material plate of 6 mm thick was cut into strips of 75 × 25 (mm) for bead on plate trials and flux paste was applied on 10 mm width at the centre of strip throughout the length as shown in Fig. 1(b) with a paint brush. Flux thickness was taken approximately as 0.15 mm. In order to ensure this, the quantity of flux was calculated as shown in Table 2 and entire amount of flux was applied over the desired area. For having a uniform amount of flux constituents over entire length of strip, the brush was moved in both forward and reverse direction over the desired area until entire flux paste was consumed. In order to measure the peak welding temperatures, a contact type "K" type thermocouple was fixed at the centre of the plate by drilling a hole of approx. 2 mm diameter and 3 mm depth as shown in Fig. 2 during the welding trials.

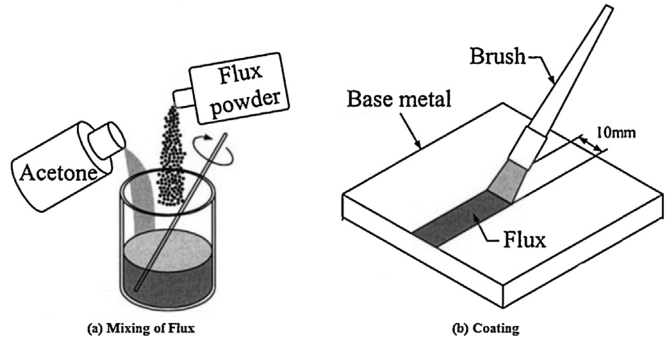

Fig. 1. Preparation and application of flux paste.

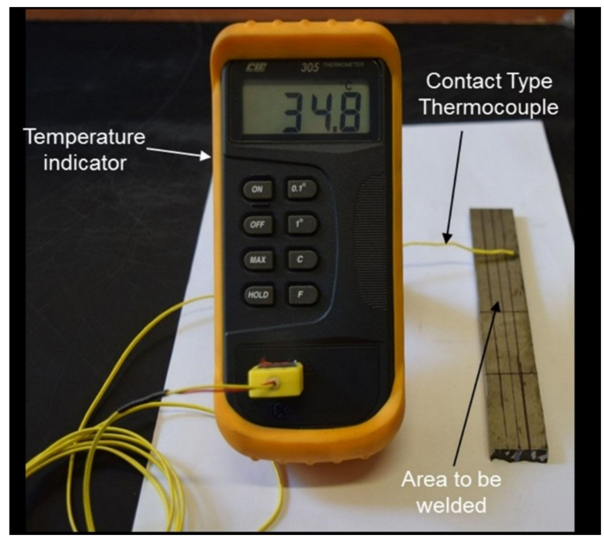

Fig. 2. Temperature measurement set-up.

2.3. Welding set-up

Extensive welding trials were conducted in autogenous mode with Panasonic make GTAW power source having capacity of 200A with 25% duty cycle and customised special purpose machine for torch movement as shown in Fig. 3. This in house developed set up available at Pandit Deendayal Petroleum University was developed under the sponsored research project from BRFST (board of research in fusion science and technology) and have been used extensively for the A-TIG welding application by Dhandha and Badheka [5] as well as Nayee and Badheka [2]. The welding parameters used are as shown in Table 3. The arc was moved along the centre line of the welds and all the welding parameters were controlled, however arc voltage which is not normally a control parameter was measured. In order to compare the effect of oxide fluxes, samples

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