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Investigation on un-peened and laser shock peened dissimilar weldments of Inconel 600 and AISI 316L fabricated using activated-TIG welding technique

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ABSTRACT

The joining of Inconel 600 and AISI 316L plates using compound flux of 50% SiO_2 + 50% TiO_2 by activated tungsten inert gas (ATIG) welding process has been addressed in this article. The various mechanical and metallurgical studies were performed on the un-peened ATIG (UP-ATIG) dissimilar weldment. The results portrayed that the tensile failure of UP-ATIG weldment had occurred at the weld zone because of the presence of coarse grains and intermetallic phases. Laser shock peening (LSP) carried out on the UP-ATIG dissimilar weldment divulged that the laser peened ATIG (LP-ATIG) weldment possesses higher tensile strength (630.33 ± 28.02 MPa) than the UP-ATIG weldment (573.11 ± 41.11 MPa) due to the presence of compressive residual (CR) stresses induced by LSP. The residual stress measurements revealed that the UP-ATIG weldment possesses tensile residual (TR) stresses and the LP-ATIG weldment encompasses CR stresses in the weld zone. Potentiodynamic polarization test results show that the corrosion resistance of the LP-ATIG weldment is slightly higher (I_{corr} = 0.19 ± 0.02 mA/cm^2) than the UP-ATIG weldment (I_{corr} = 0.21 ± 0.05 mA/cm^2).

1. Introduction

Nickel based super alloys and austenitic stainless steels have been used frequently for high temperature corrosive environments such as nuclear industries, power plants, cryogenic engines etc. [1–3], owing to their excellent properties against the acidic, high temperature and corrosive atmospheres. Similarly, dissimilar joint involving nickel based super alloy like Inconel 600 and austenitic stainless steel such as AISI 316L is widely used for the fabrication of high temperature components. Srinivasan et al. [4] reported that the mineral insulated cables used for the transmission of high frequency signals at high temperature contains the Inconel 600 and AISI 316L bimetallic joint. Similarly, many researchers [5,6] have divulged that the dissimilar joints of Inconel 600 and austenitic stainless steel are widely used in various industries. The major issues in the dissimilar welding are the selection of suitable welding process and filler metal. Improper selection of filler metal and welding method results in joint failure and poor mechanical and metallurgical properties.

Devendranath Ramkumar et al. [7] investigated the various properties of electron beam weldment of Inconel 625 and UNS 32205 and reported that the tensile failure had occurred in the weld zone due to the Mo segregation in the inter-dendritic regions of the weldment. Gobu and Mahadevan [5] studied the mechanical and metallurgical properties of friction stir weldment of Inconel 600 and AISI 304L and found that the tensile strength of the joint gets plummeted above the temperature of 450 °C because of the disproportionate tensile deformation at high temperature. Das Neves et al. [6] studied the microstructure of Inconel 600 and AISI 304 weldment fabricated using Nd:YAG laser welding and revealed the presence of small pores in the weld zone.

Shah Hosseini et al. [8] examined the Inconel 617 and AISI 310 ASS dissimilar weldments fabricated using Inconel 617, Inconel 82 and AISI 310 ASS filler metals by tungsten inert gas (TIG) welding process. It was reported by the authors that the weldment made by 310 ASS filler contains low melting point and Cu rich secondary phases thereby increasing the susceptibility of solidification cracking. The authors further stated that the cracks were formed at the unmixed zone of 310 ASS base metal because of the presence of Cu precipitates. Jeng et al. [9], on investigation of the microstructure of Inconel 690 and SUS 304L dissimilar weldments produced using Inconel 52 and Inconel 82 filler by TIG welding process, observed the presence of titanium and chromium carbide precipitates (which can affect the mechanical properties) at the grain boundary and inter-dendritic regions of both the investigated filler metal weld zones.

Autogeneous welding is a notable technique to join both similar and dissimilar metals without a filler material. However, this method could

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not join thicker sections in single pass welding because of its poor penetration capability [10]. Use of activating flux in the welding process is the paramount solution to increase weld penetration in single pass welding [11]. Zhang et al. [12] reported that the use of activating flux in the electron beam welding process could improve the weld penetration significantly. Further, the authors stated that the change of surface tension gradient and oxygen content evolved by the activating flux attributed to the enhancement of weld penetration. Huang [13] reported that the use of activating flux in the gas metal arc welding of 1020 carbon steel increases the weld penetration and reduces the angular distortion. The author further stated that the welding arc column extends to the root opening due to the presence of oxide flux resulting in higher penetration.

In the fabrication industries, gas tungsten arc welding (GTAW) is the most widely used joining technique because of its ability to control the bead geometry and the joint properties. But this process has limitations like low productivity and poor depth of penetration. Hence, many researchers investigated the use of activating flux in the GTAW called ATIG welding and reported the significant improvement in the depth of penetration and various mechanical and metallurgical properties. Likewise, many researchers [14–17] examined the role of activating flux towards the weld penetration in the ATIG welding process concluded the mechanisms of arc constriction and marangoni effect.

In the arc constriction mechanism, the applied activating flux decomposes at arc column temperature and produces enormous positive ions. These ions attract the free electrons present in the arc column to create arc constriction which results in melting of base metal to enhance deeper penetration. In the marangoni effect mechanism, the decomposition of activating flux supplies the surface active element of oxygen to the weld pool. This oxygen content changes the fluid flow pattern by altering the surface tension gradient to the center of the molten pool from the weld pool edges which results in deeper penetration. Fig. 1 shows the fluid flow pattern of conventional GTAW and ATIG welding processes and improvement of weld penetration of ATIG welding than the GTAW.

Tseng et al. [18] examined the effect of five different kinds of fluxes namely MnO_2, TiO_2, MoO_3, SiO_2, and Al_2O_3 on various weld characteristics of type 316L stainless steel. It was found that the use of all those activating fluxes had improved the weld penetration and width to depth ratio. Nayee et al. [19] investigated the effect of TiO_2, ZnO and MnO_2 fluxes on the mechanical and metallurgical properties of dissimilar weldments of carbon steel and 304 stainless steel. The authors found that the fluxes TiO_2 and ZnO influence depth of penetration and the use of TiO_2 flux results in lower angular distortion in the welded plates.

Devendranath Ramkumar et al. [20] studied the autogeneous TIG and ATIG welding processes in the dissimilar metal joining of Inconel 718 and AISI 416 plates and reported that the complete penetration could be obtained in single pass welding using ATIG process rather than the autogeneous TIG process. Kumar and Sathiya [21] examined the influence of SiO_2, ZnO, and 50% ZnO + 50% SiO_2 in the welding of Incoloy 800H and identified that the SiO_2 flux enhances the weld penetration by the mechanism of reversed Marangoni convection whereas ZnO flux deteriorates the weld penetration. The authors further conveyed that the compound flux of 50% ZnO + 50% SiO_2 produces higher amount of penetration than the single component flux ZnO.

Lin and Wu [14] compared the influence of single component and mixed activating fluxes on the depth to width ratio (DWR) of Inconel 718 alloy and reported that the mixed activating fluxes show better DWR than the single component activating fluxes. Chandrasekar et al. [22] investigated the effect of single component fluxes SiO_2, TiO_2 and compound flux 50% SiO_2 + 50% TiO_2 on the depth of penetration of AISI 316L stainless steel and found that the compound flux offers improved penetration with small and narrow weld bead. The authors further revealed that the compound flux provides more free oxygen to the weld pool to create marangoni effect which enhances depth of penetration than that of the single component fluxes.

Laser shock peening (LSP) is a successful strengthening technique, which enhances the properties of the metals such as strength, wear resistance and corrosion resistance etc. [23,24]. In this LSP process, high energy laser beam strikes a metal surface and creates high-pressure plasma which generates shock waves into the metal resulting in CR stresses. Due to the CR stresses, a plastic deformation occurs enhancing the mechanical and metallurgical property. Devendranath Ramkumar et al. [23] investigated the influence of LSP on the mechanical properties such as tensile strength and impact toughness of the dissimilar weldments and reported that the LSP process could improve the tensile properties of the weldments. Chandrasekar et al. [25], on comparison of the un-peened and laser shock peened weldment of Inconel 600, reported that the laser peened weldment shows better mechanical properties than the un-peened weldment. The authors further stated that during LSP process, the TR stresses of un-peened weldment were transformed to CR stresses which enhance the mechanical properties.

It is assimilated from the literature that only scant information is available in the dissimilar welding of metals using compound flux and the effect of laser peening on the dissimilar weldments of nickel based super alloy and austenitic stainless steel. Hence, this research work has been carried out in the joining of Inconel 600 and AISI 316L plates using compound flux of 50% SiO_2 + 50% TiO_2 by ATIG welding and strengthening of weldment using LSP process. Further, the various characterizations such as corrosion, mechanical and metallurgical have been carried out on the un-peened and laser peened dissimilar weldments.

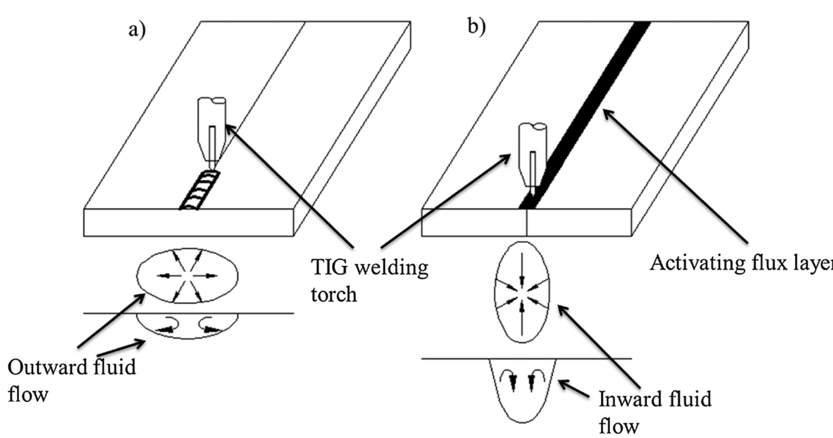

Fig. 1. The schematic diagram of fluid flow pattern a) GTAW b) ATIG welding.