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Studies on the structural property, mechanical relationships and corrosion behaviour of Inconel 718 and SS 316L dissimilar joints by TIG welding without using activated flux

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ABSTRACT

This research article addresses about the joining of 4 mm thick plates of Inconel 718 and ferritic stainless steel (S.S) 316L by Tungsten Inert Gas (TIG) welding process without using the activated flux. Trial experiments were conducted to find the influence of welding current on the depth of penetration and depth to width (D/W) ratio. The studies proved that a complete penetration could be achieved in multi pass. Microstructure examination using optical and Scanning Electron Microscope (SEM) clearly exposed the development of unmixed zone and also the Heat Affected Zone (HAZ) of Inconel 718. The chemical components of the Inconel 718 and SS316L were determined using Energy Dispersive Analysis (EDAX). Tensile and bend failures were observed at the parent metal of Inconel 718, SS316L and Inconel 718 & SS316L dissimilar joints. It was indicated from the notch tensile studies that the notch strength ratio was better than unity, which established that the weldments were ductile in all circumstances. The corrosion studies were carried out in the Nacl solution and it was found that Inconel 718 and SS316L dissimilar joint possess less corrosion resistance than similar SS316L weldment. It was inferred from the current study that the ultimate tensile strength of dissimilar weldments was better compared to similar weldments and the failure was observed in the parent metal for all the cases. Bend test results portrayed that dissimilar weldments possess better strength compared to SS316L weldments.

1. Introduction

Austenitic nickel based super alloys such as Inconel 718 are extensively employed in aero engine hot section components, aerospace structures, liquid rocket components involving cryogenic engines and gas turbines. These alloys show extensive properties at high temperatures in terms of higher strength, corrosion resistance, toughness and resistance to thermal fatigue. One of the most significant issues, in case of dissimilar weldments, is the assessment of proper filler materials for welds between super alloys and austenitic stainless steels. Inconel 718 is a precipitation strengthened and age hardened alloy containing the alloying elements such as Nb and Cr which is added to form hardening precipitates γ (meta-stable inter-metallic compound Ni_3Nb, centred terragonal crystal). It is reported that due to the sluggish precipitation kinetics of γ precipitates, alloy 718 is established to be resistant to strain age cracking [1]. Nb- rich phases have unfavorable effect on weldability and mechanical properties such as ductility, fracture toughness, fatigue and creep rupture as well as significant amounts of beneficial alloying elements [2]. Furthermore, the occurrence of huge amount of chromium in the alloy composition leads to a reduction in heat conduction. Heat attentiveness in the joint edges can cause cracking, distortion or localized melting. Austenitic stainless steels are by far the most extensively used stainless steels constituting 70–80% of stainless steel production. Resistance to corrosion is its foremost quality, along with the other characteristics such as good strength, ductility and weldability. Low carbon grades of Stainless steels (SS316L) are chosen for the structural components of prototype fast breeder reactor due to their high temperature, mechanical and compatibility properties

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[3]. Presence of δ ferrite in the autogenous welding of 316L stainless steel can also improve solidification cracking of the weld metal. Fine dendritic structure of weld in this steel enriches the fracture toughness and ductility. Further, 316L is mainly used in aerospace industries and nuclear power plants. Henderson et al. [4] reported that the GT10B has a 10-stage compressor rotor, in which the final four high-pressure stages are made from Inconel 718 and the lower pressure stages are made from SS316L. TIG welding is one of the predominantly applied welding methods in stainless steel industry on nonferrous metals and its alloys such as Al, Mg and Ni – based alloys for high quality weld and low investment [5]. TIG welding feature is intensely characterized by the weld bead geometry. The weld bead geometry plays a vital role to govern the mechanical properties of the weld [6]. Nevertheless, the moderately shallow penetration ability and low productivity are the foremost disadvantages in the TIG welding process. Several researchers [7–10] have reported the problem associated while welding Inconel 718 that embraces solidification cracking, micro-fusing and segregation of Nb rich phase at HAZ and weld zone. The formation of Nb rich phase labeled as Laves phase deteriorates the mechanical properties such as ductility, strength and stress-rupture properties. Devendranath Ramkumar et al. [11] studied the microstructure and corrosion behaviour of Inconel 625 and Inconel 718 dissimilar joints using pulsed current gas tungsten arc welding and reported that the migrated grain boundaries were formed without any solidification cracking. In addition Laves phase was also totally controlled in the PCGTA weld zone which contributed towards the improvement of the mechanical properties. Hinojos et al. [12] reported that Inconel 718 and SS 316L dissimilar joints have a wide range of applications. The author has investigated the use of CCGTA and PCGTA welding processes on dissimilar joints without liquid cracking. The outcome of this experimental work will be beneficial to the end users who are working with these dissimilar combinations. Limited research is carried out in TIG welding of Inconel 718 alloy that focuses on investigation and selection of welding parameters for attaining optimal welding performance. None of the authors has carried out their research in dissimilar joints, study and analysis of physical and mechanical properties of the TIG weld and weldability. Therefore an attempt has been made to investigate the microstructural features i.e weld metal (WM), heat affected zone (HAZ), partially melted zone (PMZ), un mixed zone (UZ), mechanical properties of the joints and corrosion behaviour of the joints, between Inconel 718 and SS 316L super alloy, that have been individually and jointly welded under constant welding parameters.

2. Experimental details

2.1. Base metals and welding process

The base metal considered in the study of Inconel 718 and SS 316 L thick plates were purchased from Metline Industries Ltd., Mumbai. The microstructure of the base metals was obtained, using optical microscopy as shown in Fig. 1. The presence of Ni rich austenitic matrix and Nb. Ti rich phases in the form of precipitates were also perceived in Inconel 718 boundaries.

The as-received plates of Inconel 718 and SS 316 L were machined to rectangular samples of dimensions 150 mm x 50 mm x 5 mm using wire-cut electrical discharge machining (WEDM). These samples were first acid preserved to remove any filth, burs etc. Before welding, standard V-Butt configurations were employed on the samples. Based on the review (2, 5 & 7), the optimum weld process parameters employed in this study is listed in Table 1. High purity argon gas was used as shielding gas, with a flow rate of 15 *L* per minute. The diameter of the filler wire considered in this study was 1.5 mm, the electrode tip angle was 60° at a constant welding speed of 80 mm/min. After welding, the weldments were machined to different coupons of various dimensions according to ASTM E3 standards for carrying out the metallurgical, mechanical tests to establish the structure- property relationship for these weldments. Further, the weldments were exposed to a corrosive environment consisting of the Nacl solution at room temperature. The procedure involved in the metallurgical, mechanical tests and corrosion studies are explained in the sub-sequent sections.

Table 1
Process parameters for TIG-welding of Inconel 718 and SS 316L weldments.

Process Parameter	Values
Voltage	12 *V*
Current	120 *A*
Electrode diameter	1.5 *mm*
Electrode tip angle	60°
Shielding gas	Argon
Flow Rate	15 *L*
Welding speed	80 *mm/min*

2.2. Metallurgical and mechanical characterization

Microstructure investigation of the weldments was carried out on machined (Perpendicular to the welding direction) coupons of dimensions 25 mm x 10 mm x 4 mm which covered all the composite zones such as Parent metals, HAZ & Weld zone. The surface of the coupons was prepared to get mirror like finishing using typical metallographic procedures such as mechanical and disc polishing were engaged because SS316L and Inconel 718 are relatively easy to polish. Electrolytic etching was used to expose the microstructures at various zones of the weldments. It is similar to chemical etching, in which acids and bases are used for modifying the pH. However, the electrochemical potential is controlled electrically by varying either the voltage or current externally. Electrolytic etching is often used for harder-to-etch specimens that do not respond well to basic chemical etching techniques. Both Optical Microscope (OM) and Scanning Electron Microscope (SEM) techniques were engaged to examine the microstructure changes on the weldments. The elemental validation of the weldments was determined using Energy Dispersive Analysis (EDAX) technique.

Tensile and bend test were conducted on the fabricated weldment as per the ASTM: E8/8M and ASTM: E190-92 standards, using Instron Universal Testing Machine. Microhardness measurements were also taken on the weldments, using Vicker's microhardness tester. The hardness computations were done at steady intervals across the entire width of the dissimilar weldments in order to estimate the precise changes. A load of 500 gf and a dwell time of 15 s were employed to compute the hardness deviations of the weldments.

2.3. Corrosion behaviour

Corrosion studies were performed on the weldments of dimensions 10 mm x 10 mm x 4 mm and on the composite zones of the dissimilar weldments using WEDM. Mirror polished surfaces were prepared before conducting the corrosion experiment. The test samples were exposed to 3.5 wt.% Nacl solution with pH value of 6.5–7.25 [15]. Weight losses were taken at the end of every cycle, using digital weighing balance with a sensitivity of 0.01 mg. The above procedure was repeated for five samples and the average results were taken. Weight measurements were taken for 24 h, 48 h, 72 h, 96 h and 120 h respectively.