Effect of Filler Wires on Welding Strength and Microstructural Changes of Inconel 718 and AISI 316L Dissimilar Weldments

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Abstract. In this research, the effect of fillers wires on weldability, welding strength and structural changes of dissimilar welds of Inconel 718 and AISI 316L are studied. Pulse arc mode in TIG welding with multiple passes were used to join V-groove configuration with 1.6 mm filler diameter. Constant welding parameters were used for both the weldments to study the effect of alloying elements of filler wires. Tensile properties were evaluated by conducting tensile test on universal testing machine as per ASTM E/8 standards. To reveal the structural changes at various zones of weldment, optical microscope was utilized. The dissimilar metals were joined successfully using two-filler wires without any internal defects. The highest tensile strength of 553 MPa was observed in Hastelloy filler weldment when compared with ERNiCrMo-4 filler weldment (530 MPa). Also, the better yield strength properties were observed in Hastelloy filler weldment. Well defined with clear grain boundaries were observed in both the filler weldments. Due to the pulsed arc mode, segregation of alloying elements was reduced.

1 Introduction

Inconel 718 is a nickel-based super-alloy renowned for its outstanding mechanical characteristics, such as remarkable strength, toughness, and resistance to corrosion when exposed to high temperatures [1]. AISI 316L is a type of stainless steel having low carbon percentage. It has excellent resistance to corrosion, particularly when exposed to nitric acid and other slightly acidic surroundings [2]. ERNiCrMo-4 is a filler metal alloy including Nickel, Chromium, and Molybdenum. It is specifically formulated for the purpose of welding Nickel-based alloys and metals that are dissimilar. It has exceptional resistance to corrosion, especially in situations with reduced oxygen levels [3]. Hastealloy, Nickel based super-alloy offers resistance to corrosion, high temperature and harsh environment [4]. Gas Tungsten Arc Welding (GTAW) is a highly precise welding method that utilizes a non-consumable tungsten electrode to create the weld. An inert gas, usually argon, is used to protect the weld zone from ambient impurities, assuring a clear and superior weld [5]. TIG welding process

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works on both constant and pulse arc mode, which are used widely in many industrial applications. Constant current mode offers several benefits, such as enhanced precision in weld quality and ease of weld. However, its limited control can lead to heat-affected zones and potential warping or distortion in thinner materials. The pulsed current arc mode in TIG welding entails the periodic alternating low and high levels of current, which enables enhanced regulation of heat input and mitigates the potential for overheating [6, 7].

Kumar et al. [8] studied the microstructural properties of dissimilar GTAW of Inconel 718 and austenitic stainless steel 304L, using Inconel 625 as a filler material. The study found significant strain at grain boundaries and a refined texture in the weld zone and the IN 625 weld metal has a higher tensile strength compared to the ASS 304L base metal. %. Ioannidou et al. [9] studied the impact of welding currents on the microstructure and mechanical properties of dissimilar welds of IN718 and SS304L and found that no porosity or metallurgical flaws in the joints, but hard and brittle Laves phases were observed. Alomairi et al. [10] studied the microstructure of welded joints in a turbine blade made of Mar-M247 alloy using AWS ERNiCrMo-3 filler alloy and found the dendritic and inter-dendritic structures within the fusion zone, with epitaxial growth at the boundary. The HAZ had greater hardness than the base metal and weld metal zones, with carbide clusters at grain boundaries. Prabu et al. [11] studied the hot corrosion characteristics of Inconel 625 joints using PCGTAW. It is found that ERNiCrMo-4 filler showed marginally greater strength than ERNiCrCoMo-1, but cracks were observed in the base metal.

From the Literature review, it is observed that the selection of base metals for desired application and selection of suitable filler wire plays vital role to produce sound welded structures under any welding processes. In this research, Inconel 718, Super-alloy and AISI 316 low carbon grade alloy is used to produce the dissimilar welded structures. Two different fillers, ERNiCrMo-4 and Hastealloy, are used to join aforementioned base metals with multi-pass welding technique. Constant welding parameters are employed for both the filler wires to study the effect of alloying elements on weldability and welding strength. Microstructures of base metals, macro and microstructures of welded structures are revealed using optical microscope. Comparative analysis has been made on both the filler weldments and reported in this research paper.

2 Materials & Experimentation

The base metals, Inconel 718 and AISI 316L, of dimensions 150 × 80 mm were sliced from the specimens using wire EDM process. The chemical composition of base metals were tested using X test and their main alloying elements are represented in Table 1. The standard butt V-grove configuration was prepared with root gap of 1.5 mm. The weld area of each sample was cleaned with steel wire brush. The pulse arc mode in TIG welding (Make: LINCOLN) technique was used to join the base metals at constant pulse frequency. To fill the standard V-groove joint of 5 mm thick plates, multiples passes (root and filling) were used. The weld parameters are listed in Table 2 used for both the filler materials. The developed dissimilar weldments are shown in Fig. 1. After joining, the samples were inspected visually as well as radiography test. The welded samples were sliced into different weld coupons for tensile testing and macro/microstructural studies. A 3D model along with weld coupons are shown in Fig. 2. Uni-axial tensile loads were applied on each sample to evaluate the welding strength and to study the effect of filler wires using UTM machine as per ASTM E/8 standards [12]. The shear load of 2 mm/min was applied constantly on the weld coupons. To reveal the structures at various zones, the weld surface was cleaned thoroughly using emery sheet with different grit sizes. A mixture of 2% HCl and 98% ethanol was used as etchant to get the scratch free weld surface area. The structural changes at various zones were revealed using optical microscope (Make: OLYMPUS). The following section will discuss the results of tensile test and structural changes and discussion on filler wire contribution for desired properties.

Table 1. Chemical Composition of base/filler materials [1, 2].

Base/filler material	Mn	Cr	Si	P	C	Cu	Mo	Ni	Fe	Others
Inconel 718	0.2	17.26	0.1	0.09	0.03	0.12	2.8	Bal.	20.08	Co-0.38, Nb- 4.9, Al-0.28, Ti-0.73, S-0.012
AISI316L	2.00	17.98	0.45	0.002	0.03		2.12	10.44	Bal.	--
ERNiCrMo-4	0.51	15.84	0.04	0.007	0.02	0.06	16.26	Bal.	5.5	Ti-0.1, W-3.5, Co-0.38, V-0.18, Al-0.31
Hastealloy	0.86	16.26	0.08	0.001	0.01	--	16.82	Bal.	4.8	W-3.8, Co- 2.1,

Table 2. Welding parameters used for joining dissimilar metals.

S.No	Materials (Thickness)	Filler wire/Diameter	Current (I_p)	Back current (I_b)	Frequency (Hz)
1st pass	Inconel 718 TO SS 316L (5 mm)	ERNiCrMo-4/1.6	180	120	4
2nd pass		Hastelloy /1.6	180	120	4

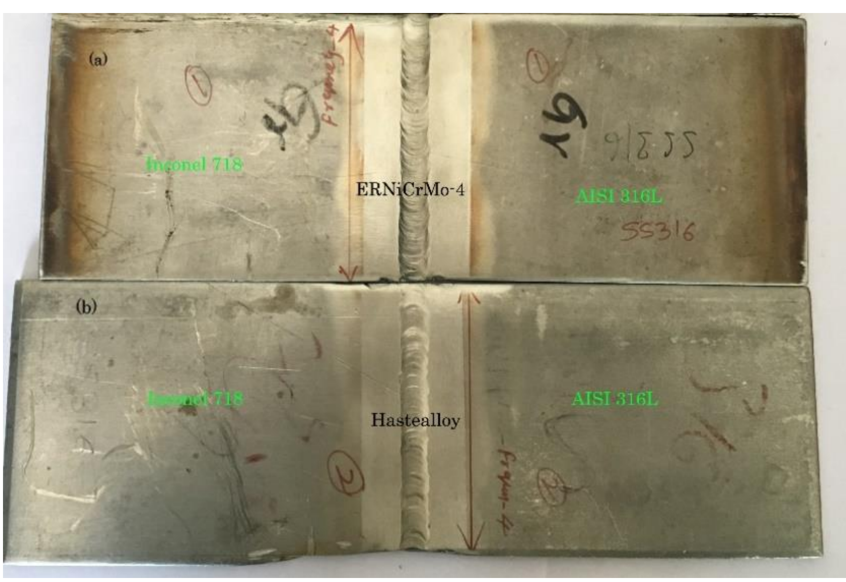

Fig. 1. Developed dissimilar weldments (a) ERNiCrMo-4 and (b) Hastealloy fillers.

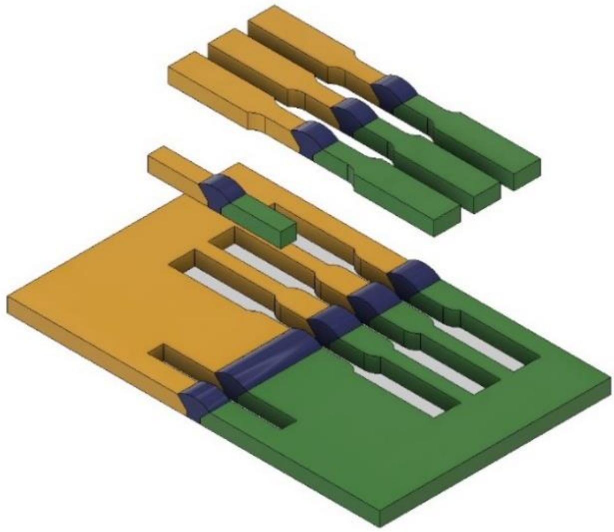

Fig. 2. 3D Weld model and test specimen coupons.

3 Results and Discussion

3.1 Tensile properties

The tensile properties of both the filler weldments were evaluated with standards and the results are presented in Table 3. The strain rate during loading and their stress related data is presented in Fig. 3. The maximum weld strength of ERNiCrMo-4 and Hastealloy filler wires was observed as 530 MPa and 553 MPa, respectively. The yield strength values of ERNiCrMo-4 and Hastealloy filler weldments were observed 254 MPa and 261 MPa respectively. The ratio of yield strength (YS) to welding strength is observed as 0.47, which is same in both the filler weldments. It is inferred from the data that the better properties were observed when Hastealloy filler wire is used to join the dissimilar metals. However, the ductility properties especially % of elongation is observed high in ERNiCrMo-4 filler wire due to the alloying elements present in the filler wire. In all the cases, the weld samples were fractured at steel 316L side. Due to the low arc heat input, the samples were fractured at base metal side, which may be because of reduction of new-phase and segregation of alloying elements [18].

Table 3. Summary of tensile properties of both the weldments.

S.No	Filler wire	Yield Strength (MPa)	Ultimate Tensile strength (MPa)	%EL	Ratio of YS to UTS	Fractured location
1.	ERNiCrMo-4	254	530	37.06	0.47	Steel side
2.	Hast alloy	261	553	35.20	0.47	Steel side

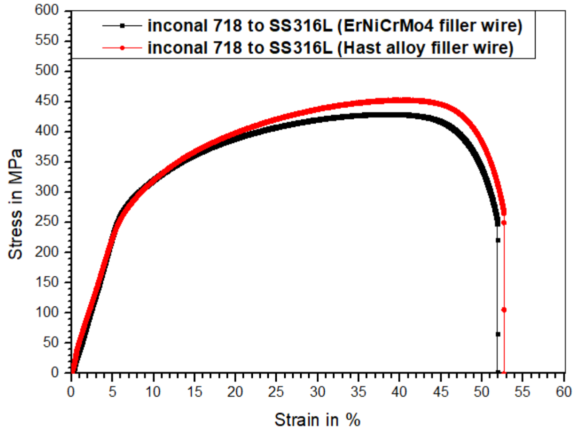

Fig. 3. Stress-Strain plot of filler weldments.

3.2 Macro/microstructures

The microstructure of base metals, Inconel 718 and AISI316L are shown in Fig. 4. The base metal Inconel 718 (shown in Fig. 4 (a)) consist of Ni, Cr and Fe alloying elements as main composition whereas the base metal AISI 316L (shown in Fig. 4 (b)) consist of Fe, Ni and Cr alloying elements.

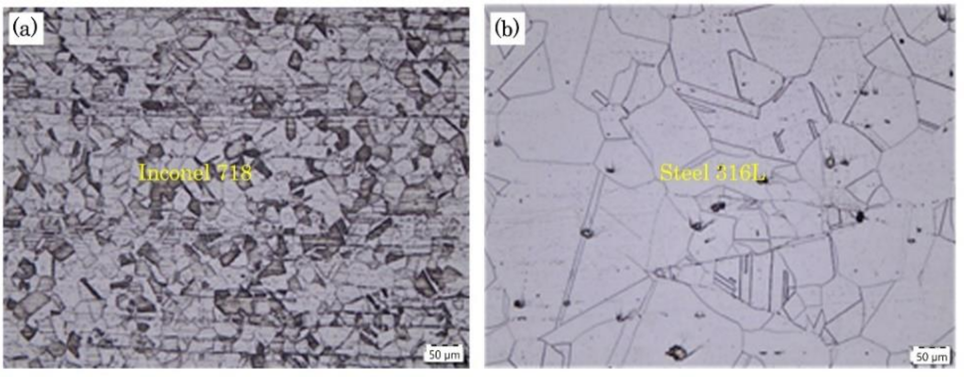

Fig. 4. Microstructures of base metal (a) Inconel 718 and (b) Steel 316L.

The macro and microstructure of ERNiCrMo-4 filler weldment are shown in Fig. 5. It is observed from the macrostructure Fig. 5 (a) shown that the groove was filled in two passes using ERNiCrMo-4 filler wire. The higher amount of filler wire was distributed towards the AISI 316L base metal side than the towards Inconel 718 side. Figure 5 (b) shows the HAZ of Inconel 718 with fine grain structures and clear grain boundaries. The interface of weld zone has shown the less segregation of alloying elements than the AISI 316L side (shown in Fig. 5 (c)). The columnar with equi-axes elements were observed at the HAZ of AISI 316L side due to the low pulse frequency of 4 Hz. It is revealed that both the HAZ of base metals have shown clear grain structures with uniform distribution of thermal cycles towards the base metals.

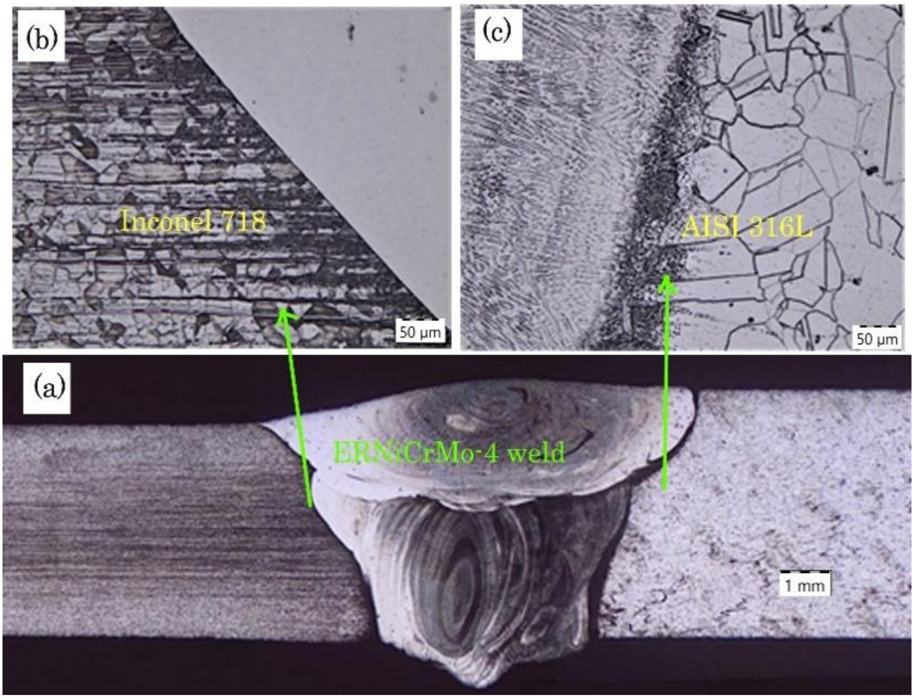

Fig. 5. Macro/Microstructure of ERNiCrMo-4 weldment (a) Macrostructure, (b) HAZ of Inconel and (c) HAZ of AISI 316L.

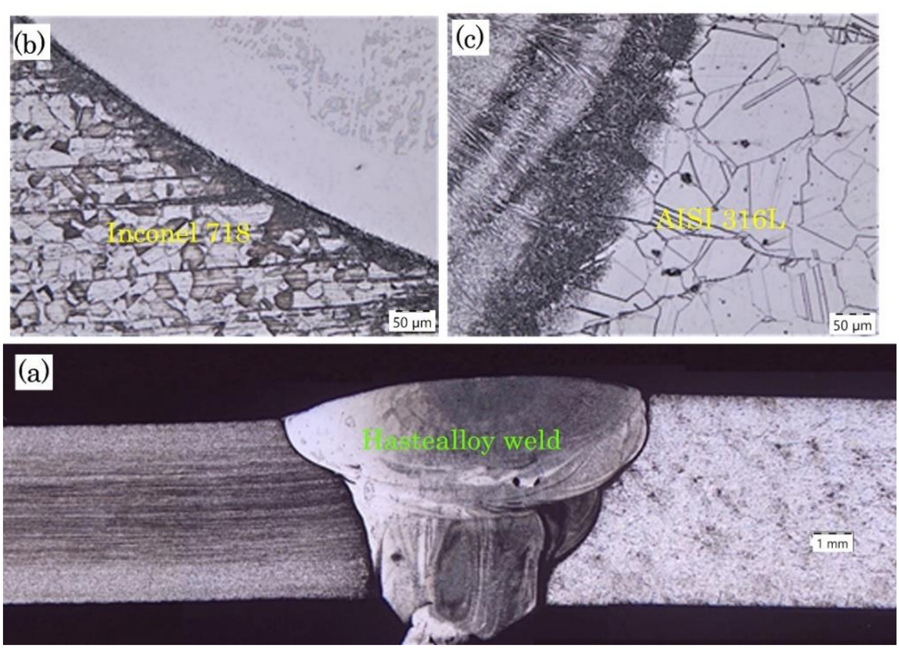

Fig. 6. Macro/Microstructure of Hastealloy weldment (a) Macrostructure, (b) HAZ of Inconel and (c) HAZ of AISI 316L.

The macro and microstructure of Hastealloy filler weldment are shown in Fig. 6. It is observed from the macrostructure Fig. 6 (a) shown that the groove was filled in two passes using Hastealloy filler wire. The equal amount of filler wire was distributed towards the both the base metals. Fig. 6 (b) shows the HAZ of Inconel 718 with uniform grain size and clear structures boundaries. The twin grain boundaries with equi-axes elements were observed at the HAZ of AISI 316L (shown in Fig. 6 (c)) side. It is observed that the HAZ of steel side have shown micro-segregation of low dense alloying elements whereas the minimal segregation effect and new phase formation at Inconel 718 side. The weld zone of both the filler weldments is shown in Fig. 7. The weld zone comprises with high dense elements from filler wire and uniform distribution of alloying elements at the fusion, which could be attributed to increase the hardness number at the fusion zone. Also, the fine grains were observed at the fusion zone of both the weldments. It is confirmed that both the filler wire have shown clear mixing with the base metals and high rate of dissolve of filler alloying elements which may result in increasing the welding characteristics.

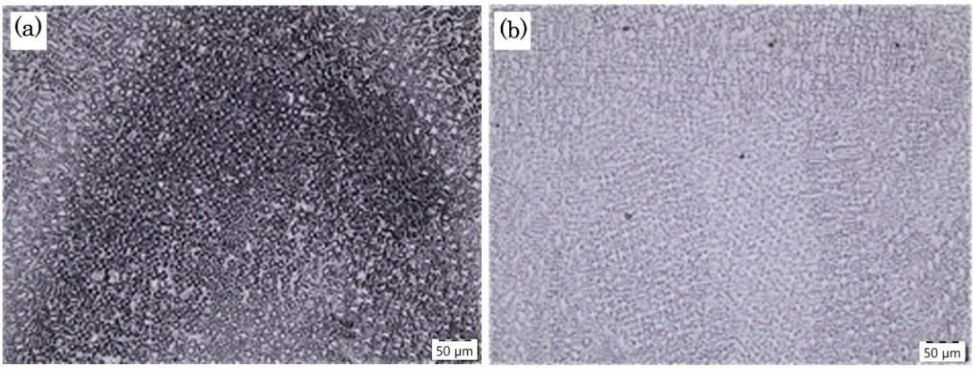

Fig. 7. Weld zone of (a) ERNiCroMo-4 and (b) Hastealloy fillers.

4 Conclusions

The effect of filler wires on weldability, strength and structural changes during welding process are studied on dissimilar weldments of Inconel 718 and AISI 316L. The following key findings were drawn from this study as follows:

- The dissimilar metals were successfully joined without defects by employing ERNiCrMo-4 and Hastealloy filler wires using pulsed TIG welding technique.
- Hastealloy filler weldment exhibited better tensile strength of 553 MPa with yield strength of 261 MPa than the ERNiCrMo-4 filler weldment.
- The ratio of yield strength to weld strength of 0.47 was observed in both filler weldments.
- Fine and clear grain structures were observed in both the filler weld zones with uniform and high dense alloying elements. Also, the segregation of alloying elements and higher grain size were reduced in both the filler weldments due to low pulse frequency. It may recommended that both the fillers are suitable for joining Ni-based super-alloys and low-grade steels.

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