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Technical Paper

Investigations on the microstructure, tensile strength and high temperature corrosion behaviour of Inconel 625 and Inconel 718 dissimilar joints

K. Devendranath Ramkumar[a,*], Winston Sunny Abraham[a], Vedha Viyash[a], N. Arivazhagan[a], Arul Maximus Rabel[b]

[a] *School of Mechanical Engineering, VIT University, Vellore, 632014, India*
[b] *Centre for Nanoscience and Nanotechnology, Sathyabama University, Chennai, India*

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ABSTRACT

In this article, an attempt has been made to investigate the effect of fillers on the pulsed current gas tungsten arc welding (PCGTAW) of Inconel 625 and Inconel 718. Two different Ni-Mo rich fillers namely ERNiCrMo-4 and ERNiCrMo-10 were employed for joining 5 mm thick plates of Ni based super alloys. The deleterious Laves phase was completely suppressed, while using these fillers. Mo rich segregation was observed in the fusion zones for both the fillers without much depletion of Mo in the fusion matrix. Tensile failures were observed at the parent metal of Inconel 718 in both the cases. It was attested from the notch tensile studies that the notch strength ratio was greater than unity, which attested that the weldments were ductile in all conditions. Impact studies showed that the weldments employing ERNiCrMo-10 exhibited better impact toughness at room temperature conditions. Hot corrosion studies were performed on the coupons exposed in the synthetic molten salt environment of 60%Na_2SO_4–40%V_2O_5 at 900 °C. Studies showed that both the parent metal Inconel 625 followed by the fusion zone of ERNiCrMo-10 exhibited better corrosion resistance in the high temperature environment. Surface analytical techniques were adopted to investigate the hot corroded species.

1. Introduction

Austenitic nickel based superalloys such as Inconel 625 and Inconel 718 are widely employed in aero-engine hot section components, aerospace structures, tooling and liquid rocket components involving cryogenic as well as high temperature operating environments in gas turbines, submarines and nuclear reactors. These alloys exhibit superior properties at high temperatures (between 150 and 1500 °C) in terms of higher strength, resistance to corrosion, stress-rupture strength, toughness and resistance to thermal fatigue. Inconel 718 is a precipitation strengthened, age-hardenable alloy containing the alloying elements such as Nb, which is added to form hardening precipitates γ'' (a meta-stable inter-metallic compound Ni_3Nb, centred tetragonal crystal). It is reported that due to the sluggish precipitation kinetics of γ'' precipitates, alloy 718 is found to be resistant to strain age cracking [1]. Inconel 625 is a solid solution strengthened, face centred cubic alloy containing molybdenum and niobium on its nickel-chromium matrix resulting in the high strength which can be retained without any precipitation heat-treatment [2]. This alloy may also contain carbides, in the form of MC and M_6C (rich in Ni, Nb, Mo and C). However, there are a few issues related to the weldability of Inconel 718 such as heat affected zone (HAZ) micro-fissuring and solidification cracking. One of the major concerns during welding of Inconel 718 could be attributed to the segregation of Nb and consequent formation of Nb rich inter-metallic compound (known as) Laves phase ($(Ni, Fe, Cr)_2$ (Nb, Mo, Ti)), which is believed to deteriorate the weld mechanical properties. The formation of Laves phase requires a niobium concentration ranging from 10% to 30%. Some methods have been proposed by Radhakrishna and Prasad Rao [3] to control the formation of Laves phase by the use of (a) fast weld cooling rates, (b) low weld heat inputs, (c) heat extraction techniques such as chilling blocks in tooling, (d) steep thermal gradients, (e) pulsing techniques, (f) low-niobium fillers, and (g) electron beam oscillation techniques, etc. Studies showed that the Laves phase was controlled with the use of techniques such as electron beam and

* Corresponding author.
E-mail addresses: deva@vit.ac.in, ramdevendranath@gmail.com (K.D. Ramkumar).

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laser beam welding which utilizes low heat input and faster cooling rates at the fusion zone [4,5].

Manikandan et al. [6] reported that the conventional gas tungsten arc (GTA) welding process aided with liquid nitrogen cooling resulted in minimized Laves phase and also that the weldments were free from heat affected zone (HAZ) micro-fissures. Current pulsing in the conventional GTA welding process is one of the most novel approaches used to minimize the micro-segregation in the fusion zone. Devendranath et al. [7] compared the microstructure and mechanical properties of the as-welded and post weld heat treated Inconel 718 weldments obtained from pulsed current GTA (PCGTA) welding technique employing different fillers. The studies recommended the use of post weld heat treatment (PWHT) and the Nb free filler with the view of controlling Laves phase.

Arafin et al. [8] studied the transient liquid phase (TLP) bonding of Inconel 625 and Inconel 718. In another study, Yeni and Kocak [9] performed fracture analysis on laser welded 12 mm thick plates of dissimilar joints of Inconel 625 and Inconel 718. Abbasi-Khazaei et al. [10] investigated the TLP bonding of FSX414/IN738 superalloys using MBF80 interlayer. The authors investigated the microstructure and harness by varying the bonding time and temperature. In a study, Huang et al. [11] investigated the inertia friction welding of dissimilar Ni based superalloys namely Inconel 718 and Inconel 720Li. The authors performed metallographic analysis on the welds both in the as-welded and post weld heat treated conditions. It is inferred from the published literature that a very limited emphasis has been laid on the weldability of the dissimilar joints involving Inconel 718 and Inconel 625. Also, these articles have not systematically addressed the microstructure and mechanical properties hitherto.

Dissimilar joints involving Ni based super-alloys are generally exposed to aggressive molten salt environments at high temperatures. It was reported that degradation by high-temperature oxidation, hot corrosion and erosion are the main failure modes observed in components of hot sections of gas turbines, turbine engines, boilers etc. Usually they are exposed to extremely high temperatures and harsh environments and therefore tend to suffer from significant material degradation during service. Hot corrosion is basically the result of attack by fuel and/or ash compounds, arising from the presence of salts like NaCl, Na_2SO_4, and V_2O_5 in the combustion chamber. Mahobia et al. [12] reported that the oxidation of sulphur, present in the fuel and its reaction with NaCl leads to the formation of Na_2SO_4. The residual vanadium in the fuel gets oxidized to V_2O_5. In addition, vanadium present in the fuel in the form of vanadium porphyrin, would transform during combustion into V_2O_5. These V_2O_5 and Na_2SO_4 form low melting point compounds, which undergo eutectic reaction below 600 °C and result in the formation of a eutectic mixture [13]. Devendranath et al. [14] investigated the hot corrosion behaviour on the PCGTA welds of Monel 400 and AISI 304. The authors investigated the behaviour of the fusion zones obtained by various fillers exposed to a Na_2SO_4 + 60%V_2O_5 environment at 600 °C. Shukla et al. [15] investigated the hot corrosion behaviour of Inconel 718 in the molten salt environment containing Na_2SO_4 + 75%V_2O_5 at 900 °C. The authors indicated that the spallation and corrosion rates were more vigorous in the molten salt environment than in the same observed during air oxidation. However, the information available on the hot corrosion behaviour of the dissimilar weldments operating at extreme temperatures is scanty.

In the present study, an attempt has been made to investigate the joining of dissimilar Ni based superalloys involving solid solution strengthened Inconel 625 and precipitation strengthened Inconel 718 using PCGTA welding process. Two different Ni-Mo rich fillers namely ERNiCrMo-4 and ERNiCrMo-10 were employed for joining these dissimilar metals with an emphasis to control the Laves phase. The main objective of the study is to investigate the effect of the fillers on the fusion zone microstructure. These dissimilar welded joints were characterized for their metallurgical and mechanical properties. Further the high temperature corrosion behaviour of these dissimilar weldments was evaluated by exposing them to a synthetic molten salt environment containing Na_2SO_4 + 60%V_2O_5 at 900 °C for 50 cycles. The cyclic condition was chosen so as to investigate the alloys in the rigorous conditions which resemble actual service conditions. The hot corrosion products have been systematically analysed using X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDAX) analysis. The outcomes of this specific study will be highly helpful to the end user operations involving dissimilar welds comprising Ni based superalloys.

2. Experimental procedure

2.1. Base metals and welding

The base metals employed in the study were 5 mm thick hot rolled plates of Inconel 625 and Inconel 718 and the chemical compositions of the base metals were investigated by dry spectroscopic methods. The nominal chemical composition of the base and filler metals are represented in Table 1. The average mechanical properties of the base metals in room temperature conditions are also represented in Table 2. In the present study, Nb free Ni-Mo rich fillers namely ERNiCrMo-4 and ERNiCrMo-10 were used, mainly to suppress the formation of Laves phase in the fusion zone of the dissimilar joints. The microstructure of the base metals were obtained, using both optical microscopy (OM) and SEM techniques. It is inferred from Fig. 1 that both the superalloys showed the presence of (a) Ni rich austenitic matrix; the formation of twin boundaries along with Nb, Ti rich phases in the form of precipitates were observed in Inconel 718; whereas Inconel 625 displayed the elongated Ni rich austenitic grains with streams of Nb, Mo rich phases consecutively formed along the grain boundaries.

Table 1
Chemical composition of base and filler metals.

Base Metal	Composition (% Weight)						
	C	Mn	Cr	Mo	Fe	Nb	Ni	Others
Inconel 718	0.029	0.128	17.84	3.28	16.66	5.42	Rem.	P – 0.012; S – 0.005; Si – 0.102; Cu – 0.051; Al – 0.539; Ti – 1.03; V – 0.024; Co – 0.488
Inconel 625	0.042	0.085	21.71	8.25	4.53	3.26	Rem.	P – 0.009; S – 0.005; Si – 0.152; Cu – 0.05; Al – 0.108; Ti – 0.201; W – 0.07; V – 0.023; Co – 0.207
ERNiCrMo-4	0.018	0.41	15.9	16.3	5.45	–	Rem.	P – 0.0002; S – 0.001; Al – 0.30; Ti – 0.05; W – 4.0; Si – 0.02
ERNiCrMo-10	0.012	0.55	22.4	13.8	2.5	–	Rem.	P – 0.00001; S – 0.001; Co – 0.22; V – 0.01; W – 3.34; Si – 0.05; Cu – 0.2