Journal of Manufacturing Processes 32 (2018) 685–698

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Investigations on the microstructure and mechanical properties of dissimilar welds of inconel 718 and sulphur rich martensitic stainless steel, AISI 416

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ARTICLE INFO

Keywords:
Inconel 718
AISI 416
Pulsed current gas tungsten arc welding
Laves phase
Tensile strength
Impact toughness

ABSTRACT

Turbine blisk and shaft assembly in aero-engines make use of dissimilar joints of Inconel 718 and martensitic stainless steel, AISI 416. The joining of these 5 mm thick aerospace alloys carried out by adopting current pulsing in Gas Tungsten Arc Welding (GTAW) has been addressed. Two Nb free consumables namely ERNiCrMo-4, ERNiCu-7 and a duplex filler ER2553 were used to join these dissimilar combinations. The weldments were systematically characterized using optical microscopy (OM) and scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectroscopy (EDS). It is endorsed from the studies that the welds obtained from these fillers were free from deleterious Laves phase. Irrespective of fillers, the tensile failures were experienced at the base metal side of AISI 416. Room temperature Charpy V-notch impact test indicated that the weld joints employing ERNiCu-7 witnessed better impact toughness than other weldments. This study is highly in demand in aerospace industries and successfully addressed the choice of fillers in supressing the Laves phase.

1. Introduction

Joining of Nickel based super alloys and martensitic stainless steels has been of major interest in the gas turbines, aero engine components of aircraft application. In recent days, these dissimilar combinations have been increasingly employed for boilers in Ultra-supercritical (USC) power plants. It has been reported that Inconel 718 is used for super heater boiler tubing at steam temperature of 700^{o} C and the pipes connecting super heaters and re-heaters in USC boilers are made of martensitic stainless steel [1]. Inconel 718, a precipitation strengthened Ni based super alloy has an outstanding combination of strength and high temperature creep and corrosion resistance and hence finds applications in aircraft industries especially in turbine blades and combustion chamber of aero engine turbines [2,3]. Similarly, a low cost, high sulphur content, martensitic grade stainless AISI 416 has been used especially in the Impeller of centrifugal compressor and discs, drum of axial compressor [4].

One of the prime challenges encountered during welding of Alloy 718 is the micro-segregation of Nb rich phases and the consequent formation of a brittle, intermetallic compound named Laves phase [(Ni, Fe, Cr)$_2$ (Nb, Mo, Ti). This phase is believed to have a detrimental effect on the weld mechanical properties and corrosion resistance. Although AISI 416 exhibits better machinability, this alloy is not readily weldable owing to the greater amounts of sulphur in it. Mortensen et al. [5] recommended to employ friction welding process for joining AISI 416 instead of conventional fusion welding techniques. Further the authors have reported a loss in ductility as well as impact toughness due to the reorientation of sulphide inclusion.

Although these dissimilar joints are highly in demand and receive major attention in terms of reduction in material cost, the important and critical issue is to obtain joints which are devoid of metallurgical issues [6]. On account of the large differences exhibited by the alloys in terms of chemical composition, thermal expansion coefficients and the melting points, the welding of dissimilar metals becomes extremely difficult and challenging [7]. The mismatch in values leads to the development of residual stresses, segregation, solidification and hot cracking which in turn lowers the mechanical and fatigue strength of the welded joints [8,9]. Many researchers have emphasized the importance of the use of fillers with dissimilar alloy combinations involving Alloy 800-316L [7], Inconel 625- AISI 310 [10], Inconel 718 and 310 S [11].

Recently Hejripour and Aidun [1] investigated the use of twisted consumables namely 718-410 and 82–410 for fabricating dissimilar joints involving Alloy 718 and AISI 410 using Cold Wire Gas Tungsten Arc Welding (CWGTAW). However, the authors witnessed the Laves phase formation along with Ni_3Nb, NbC in the fusion zone of both the weldments. Sidharth Dev et al. [12] studied the dissimilar combinations of Alloy 718 and sulphur rich AISI 416 obtained from both continuous

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https://doi.org/10.1016/j.jmapro.2018.03.035
Received 14 January 2018; Received in revised form 16 March 2018; Accepted 30 March 2018

Table 1
Chemical Composition of base and filler metals.

Base / Filler metal	Chemical Composition (% weight)							
	Ni	**Cr**	**Nb**	**Mo**	**C**	**Fe**	**Cu**	**Other elements**
Inconel 718	52.1	17.69	4.9	2.9	0.031	20.7	0.11	P-0.09; Al-0.29; Ti-0.72; Co-0.36; S-0.012; Si-0.1; Mn-0.2
AISI 416	Nil	12.81	Nil	Nil	0.111	Rem	Nil	P-0.03; Si-0.325; P-0.03; S-0.0154
ER2553	6.32	25.85	Nil	3.34	0.015	Rem	1.56	P-0.04; Mn-1.25; Si-0.35; S-0.005; P-0.02;; N-0.2
ERNiCu-7	62.85	Nil	Nil	Nil	0.026	0.785	29.94	Mn-3.610; Si-0.130; S-0.004; P-0.005;; Ti-2.55; Al- 0.1
ERNiCrMo-4	57.88	15.66	Nil	15.81	0.009	Rem	0.026	Si-0.055; Mn-0.520; S-0.004; P-0.007; V-0.041; W-3.98

Table 2
Process parameters employed in PCGTA welding of Inconel 718 and AISI 416.

Filler wire	Pass	Current (A)		Voltage (V)	Frequency (Hz)	Duty cycle (%)	Heat Input at every pass (kJ/mm)	Total Heat Input (kJ/mm)
		I_b	I_p					
ER2553	Cap	80	140	10.4–12.1	8	50	0.6027	2.1796
	Filling pass 1	80	140	11.2–12.6	8	50	0.7013	
	Filling pass 2	80	140	11.6–12.5	8	50	0.4013	
	Root	80	140	10.5–12.0	8	50	0.4743	
ERNiCrMo-4	Cap	80	140	11.2–12.6	8	50	0.7992	2.5496
	Filling pass 1	80	140	11.3–13.2	8	50	0.5895	
	Filling pass 2	80	140	10.5–11.7	8	50	0.4691	
	Root	80	140	10.3–11.3	8	50	0.6917	
ERNiCu-7	Cap	80	140	10.2–11.5	8	50	0.7992	2.0389
	Filling pass 1	80	140	11.1–11.6	8	50	0.5575	
	Filling pass 2	80	140	10.0–11.5	8	50	0.4691	
	Root	80	140	10.5–11.7	8	50	0.6917	

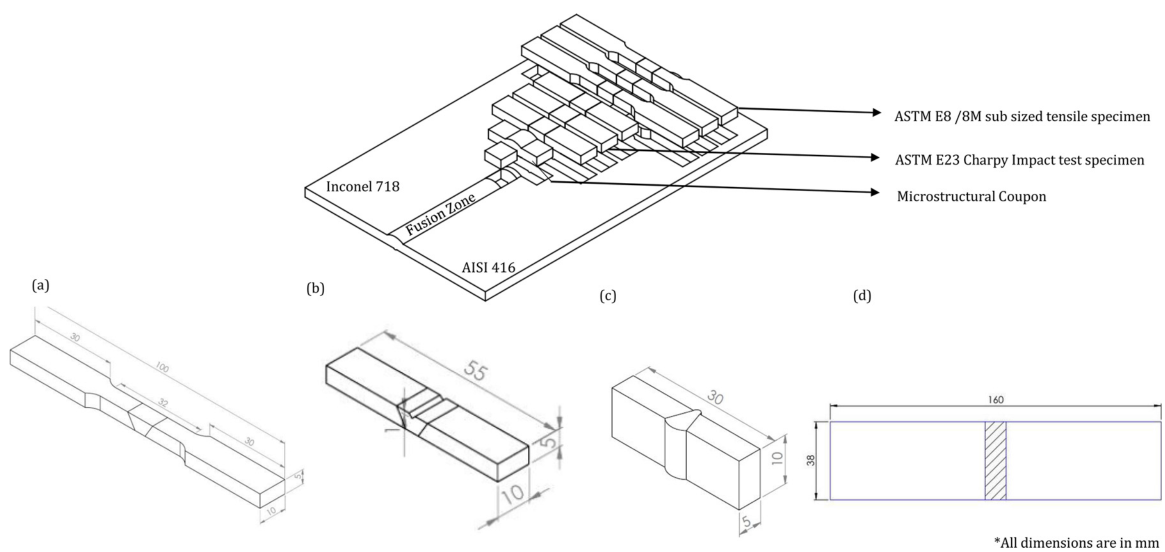

Fig. 1. Schematic representation of butt joint and various test specimens used (a) Tensile Test specimen (b) Impact test specimen (c) Microstructural coupon (d) Bend test specimen.

and pulsed current techniques of GTA welding employing ER410. The authors perceived the existence of Laves phase in the fusion zones of both the welding techniques. The authors concluded that the Laves phase and the presence of carbide and sulphide inclusions lowered the impact toughness of these dissimilar joints. However the authors could not successfully combat the problem of suppressing or eliminating the Laves phase. Devendranath et al. [13] observed the welds involving Inconel 718 and austenitic stainless steel, AISI 316 l and found them to be Laves free and therefore recommended the use of ERNiCu-7 filler for joining these bimetallic combinations. However the selection of consumables for welding Inconel 718 and the sulphur rich stainless steel, grade AISI 416 has not been adequately reported. In another study, Devendranath et al. [14] investigated the mechanical properties, microstructure and high temperature corrosion studies on the dissimilar welds of Inconel 625 and Inconel 718. Although the authors obtained the fusion zones that were free from Laves phase, they observed the Mo segregation in the inter-dendritic regions while using Ni-Cr-Mo rich fillers. Recently, Seyed Hamzeh Baghjari et al. [15] investigated the effect of Ni interlayer on the microstructure and tensile strength of dissimilar welds of Nb and AISI 410 stainless steel. The authors observed the formation of eutectic Laves phase in the fusion zone irrespective of faster cooling rate in the laser welding process.

It is evident from the literature that the welding of dissimilar metals is a challenging and interesting task as there are issues concerning the metallurgical aspects. Although this high sulphur content martensitic stainless steel AISI 416 has the potential for applications in the aerospace sector owing to high mechanical properties and machinability, limited emphasis has been laid on utilizing this alloy. Thus, this resulted