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Investigations on the structure – property relationships of PCGTA welds involving Inconel 718 and AISI 430

K. Devendranath Ramkumar*, T. Harsha Mohan, Rachit Pandey, Vimal Saxena, S. Aravind, Shubham Singh

School of Mechanical Engineering, VIT University, Vellore - 632014, India

Abstract

The present investigation deals with the weldability, structure – property relationship of dissimilar metallurgical joints involving Nickel based superalloy Inconel 718 and ferritic stainless steel AISI 430 using pulsed current gas tungsten welding (PCGTAW) process employing ER2553 and ERNiCrMo-4 filler wires. NDT analysis and macrostructure examination corroborated for defect free weldments. Microstructure studies revealed the presence of unmixed zone at the weld interface of Inconel 718 whereas grain coarsening effect was observed at the heat effected zone (HAZ) of AISI 430. Both cellular and equiaxed dendrites were dominated at the fusion zone of ERNiCrMo-4 weldment; whereas different types of ferrite morphologies such as delta and widmanstätten ferrite were observed at the cap and middle zones of ER2553 fusion zone respectively. It was opined that the tensile failures occurred at the parent metal of AISI 430 for both the fillers. Charpy V-notch studies showed that ERNiCrMo-4 weldment exhibited better impact toughness than ER2553 weldment. Similarly the bend test also recommended the use of ERNiCrMo-4 filler due to the acquaintance of excellent bending strength and soundness. This study also addressed the structure – property relationships of these weldments. The outcomes of the study would be highly beneficial to the nuclear, aerospace and petrochemical industries.

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Keywords: nickel based super-alloy; ferritic stainless steel; pulsed current gas tungsten arc welding; structure – property relationship.

1. Introduction

Joining of dissimilar materials has progressed significantly in the recent past owing to their accrued demand in aerospace, nuclear, chemical and thermal power plants. The assortment and application of the dissimilar joints are directed by the in-service requirement wherein involvement of each material is localized for the optimal utilization of their properties, economic feasibility of the materials and ease of fabrication.

Inconel 718, a precipitation hardened Ni based superalloy, finds its application in high temperature stringent operating conditions. Even though high Ni content imparts the required thermo-mechanical properties to sustain stringent environment, this super alloy isn't an economically feasible option while operating at lower risk conditions. Hence a low cost alloy, AISI 430 can be employed at low risk zones to alleviate the cost. AISI 430 is the most used ferritic grade stainless steel as reported by International Stainless Steel Forum (ISSF) [1] which can be used at elevated temperatures. AISI 430 is a medium chromium ferritic stainless steel with a probable chance of grain boundary martensite (GBM) formation during solidification [2]. The presence of grain boundary martensite at the fusion zone was believed to impoverish the impact toughness. It was reported that the addition of Ti or Nb prevents the formation of GMB as both the elements act as delta-ferrite stabilizer suppressing formation of austenite [3]. On the other hand, Hayden et al. [4] and Wright et al. [5] reported that the duplex ferritic-martensitic microstructure formed while welding has greater impact toughness relative to fully martensitic or fully ferritic steels. Due to low carbon content in this steel,

* Corresponding author.
E-mail address: ramdevendranath@gmail.com (K.D. Ramkumar)

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the martensite formed would be softer compared to high carbon martensite and is known as plate martensite [6]. Also ferritic stainless steels have lower coefficient of thermal expansion and higher thermal conductivity than the austenitic stainless steel and can be advantageous when cyclic temperature resistance is obligatory as reported by Sedricks [7]. Several researchers [2, 8] have addressed the problem related to solidification and liquation cracking during the welding of Nickel based alloys. It was reported by Dupont et al. [8] the susceptibility of solidification and liquation cracking increases due to the formation of Nb precipitates (Ni_3Nb) which segregate into the inter-dendritic region thereby decreasing the solidus temperature. Similar problems were also reported by Odabasi et al. [9] during laser welding of Inconel 718. As reported by various researchers [10-12], the formation of laves phase in the fusion zone as well as in the HAZ of Inconel 718 had detrimental effect on the weld mechanical properties. Also the presence of this laves phase serve as the notable sites for easy crack initiation and propagation which affects the mechanical properties such as tensile and rupture properties, ductility, fracture toughness and fatigue life of the welded component.

Radha Krishna and Prasad Rao [13] proposed various methods of controlling the laves phase formation by the use of (a) current pulsing technique (b) low Nb fillers (c) faster cooling rate (d) heat extraction technique (e) steep thermal gradients and (f) electron beam oscillation techniques. Pulsed current gas tungsten arc welding (PCGTAW) is an extensively used welding technique and has several advantages over the conventional arc welding process. Several researchers [14-16] experimented using PCGTAW and all reported that the use of pulsed current technique significantly improved the metallurgical and mechanical properties of the weld.

Devendranath et al. [12] investigated the continuous and pulsed current GTA welding of Inconel 718 and AISI 316L using ER2553 and ERNiCu-7. The authors reported that these fillers were effective in controlling laves phase. Farahani et al. [16] compared the microstructure and impact strength of continuous current gas tungsten arc (CCGTA) and PCGTA weldments of alloy 617. The authors reported that the impact toughness was better for the PCGTA weldment due to the grain refinement.

It is often witnessed that the ductility and toughness of weldments of ferritic stainless steels are adversely affected by the grain coarsening in both weld and HAZ occasioned by the absence of phase transformation during solidification to room temperature as reported by Pickering [17] and Kou Sindo [18]. Alizadeh [19] performed resistance spot welding of AISI 430 and the author observed the formation of ferrite- martensite dual microstructure in the medium temperature HAZ with the highest hardness being in that region. Dissimilar friction welding of austenitic and ferritic stainless steel has been performed by Sathyanarayana et al. [20], the work cited that the weldments offered better toughness and strength relative to the ferritic base metal.

Dissimilar welding of nickel based alloys and ferritic stainless steel faces certain challenges such as formation of cracks at the interface, abrupt variation in hardness close to weld zone occasioned by their difference in coefficient of thermal expansion (CTE) which might result in in-service failure. It is evident from these works [12,20,21] that prime focus was laid on bimetallic joints of Nickel based alloy and austenitic grade stainless steels. Ferritic grade stainless steel on the other hand offers comparable mechanical properties, relatively better stress corrosion cracking resistance and low cost as compared to austenitic grade stainless steel. Adding to this AISI 430 is relatively less susceptible to weld solidification cracking compared to AISI 304 [2]. Despite ferritic stainless steel's aforementioned properties, they are seldom used in dissimilar combinations with Ni based alloys. Hence a study is required to assess the microstructure changes and the corresponding effects in the mechanical properties during the PCGTA welding of Inconel 718 and AISI 430. In this research article, an attempt has been made to achieve the dissimilar combination of Inconel 718 and ferritic stainless steel AISI 430 using pulsed current gas tungsten arc welding (PCGTAW) employing ER2553 and ERNiCrMo-4 filler metals. A detailed structure-property relationship has been carried out to underline the potential of the dissimilar joint.

2. Experimental

2.1. Base metals and welding procedure

The chemical compositions of the base metal and that of consumables were ascertained by dry spectroscopic method and are enlisted in Table 1.

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