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Technical Paper

Development of welding technique to suppress the microsegregation in the aerospace grade alloy 80A by conventional current pulsing technique

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ABSTRACT

Alloy 80 A is prone to hot cracking during conventional arc welding process. Microsegregation of alloying element Cr lead to the formation of $M_{23}C_6$ carbide phase during solidification of fusion zone, and it contributes to hot cracking. The current study employs different welding techniques and filler wires to minimize the microsegregation. The weldments were fabricated by Gas Tungsten Arc Welding (GTAW) and Pulsed Current Gas Tungsten Arc Welding (PCGTAW) techniques using filler wires 263 and ERNiCrMo-3. Scanning electron microscope (SEM) reveals the existence of secondary phase in the interdendritic region for all the weldments. Energy dispersive X-ray spectroscopy (EDS) analysis reports that PCGTAW eliminates microsegregation of Cr precipitate and suppress Nb and Mo precipitates better when compared to GTAW. X-ray Diffraction (XRD) analysis indicate the presence of $M_{23}C_6$ Cr and Mo-rich carbide phase in GTA weldment of 263 filler wire. Whereas in PCGTAW, NiCrCoMo phase is observed. In both GTAW and PCGTAW of ERNiCrMo-3, the intermetallic phases Ni_8Nb and Cr_2Ti are observed. The tensile test was conducted to assess the strength and ductility of the weldments. The results of the PCGTAW weldments have improved compared to their respective GTAW weldments.

Introduction

Alloy 80 A (UNS N07080 (ASTM B637-06)) is a precipitate strengthened nickel based superalloy derived from Ni-Cr system. The alloy was developed for its high strength at an elevated temperature of 815 °C [1]. Alloy 80 A is a solid strengthened material with γ matrix phase. Precipitate strengthening of the alloy 80 A is done through by adding a considerable amount of alloying elements Al and Ti to form γ´ matrix phase such as Ni_3Al, $Ni_3(Al,Ti)$ and Ni_3Ti. Alloy 80 A widely used in gas turbine components such as rings, blades, discs and as exhaust valves in automobile IC engines [1,2]. Alloy 80 A was specially designed for aerospace application such as gas turbine components, but by applying strict specification to its chemical composition and heat treatment, its mechanical performance can be optimized for more demanding application in land-based gas turbines [3]. Compared to other nickel based superalloys, they are commercially less attractive, because of lack of material available in the market outside USSR region [3].

In most of the industrial application, joining of two separate component take place through welding. In this respect, welding of alloy 80 A is possible through conventional welding techniques, which are cost-effective compared to other welding technique [4,5]. However, welding of Ni – Cr system alloy through arc conventional welding techniques leads to some problems in the weldments. The major problem associated with the alloy 80 A is precipitation of intergranular chromium carbides due to the depletion of Cr around the grain boundaries. This precipitate leads to the hot cracking in the weldments during solidification [6–8]. Keienburg et al. [8] reported the refurbishing of the turbine blade of alloy 80 A using Tungsten Inert Gas welding with Inconel 62 filler wire. The presence of larger cracks was observed in the weld interface region of fusion zone. The authors also stated that implanting a piece of Inconel 625 to alloy 80 A using Inconel 625 filler wire reduces the larger cracks into the microcracks in the weldment. Kargarnejad et al. [9] studied the failure assessment of alloy 80 A turbine blade. The authors found that the existence of γ´ ($Ni_3(Al,Ti)$) in the grain boundary causes, the transformation of MC type carbide phase to $M_{23}C_6$ (Cr rich precipitate) + γ´ carbide during the service and these carbides tend to form the brittleness in this alloy. Gao et al. [10] and Yulai Xu et al. [11] investigated the microstructural evolution of alloy 80 A after heat treatment and stated that the segregation of $M_{23}C_6$ Cr- rich carbides are seen in the grain boundary of the alloy, and segregated blocky $M_{23}C_6$ Cr carbides tend to deteriorate the mechanical properties of the alloy.

In regards to the segregation of Cr carbide around the grain boundary, necessary action has to be taken to prevent this issues. This

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Table 1
Chemical composition (Wt.%) of alloy 80 A and filler wires 263 and ERNiCrMo-3.

Base/filler wires	Chemical Composition (Wt. %)								
	Ni	Cr	Fe	Mn	Al	Ti	Mo	Co	other
Alloy 80 A	Bal	20.53	0.042	0.357	1.59	2.48	–	2.0	0.010(S), 0.142(Si), 0.073(C)
263	Bal	21.0	0.70	0.60	0.60	2.40	6.10	21.0	0.08(C)
ERNiCrMo-3	Bal	22.0	1.0	0.5	0.40	0.40	10.0	–	4.5(Nb), 0.5(Si), 0.1(C), 0.5(Cu), 0.015(S)

issues can be sorted out by the proper selection of the filler wire, welding technique and welding parameter for the joining of alloy 80 A. In this present study, welding of alloy 80 A has been carried out by GTAW and PCGTAW mode with two different filler wires. The filler wire chosen for this study are (a) filler wire 263, which has nearly same chemical composition that of alloy 80 A except for the minor difference in the Co content and the addition of some amount of Mo in the composition. Alloy 263 evolved from alloy 80 A and is known for its improved ductility in the weld and high strength at elevated temperature [12]. (b) ERNiCrMo-3 filler wire, which has a high amount of Mo and Nb content in its composition. The Mo and Nb observed in the filler wire have a higher affinity for carbon than Cr and thereby preventing the formation of Cr carbide precipitates [13]. The review of literature reports that the adoption of PCGTAW can alleviate the problem of microsegregation in alloys.

Arulmurugan and Manikandan [14] reported the welding of 21st-century nickel based superalloy 686 by PCGTAW mode results in refined microstructure and reduced microsegregation of alloying element in fusion zone which improves the metallurgical and mechanical properties of the alloy compared to that of GTAW mode. PCGTA welding technique shows several advantages compared to GTA welding technique in terms of reduced heat input required for welding, narrower of weld width, minimum distortion, residual stresses and reduction in the microsegregation of the alloying element in the weld., etc. and the same has been reported by several other researchers [4,15].

Manikandan and Sivakumar et al. [16] investigated the segregation of alloying element in the fusion zone of alloy 718 through different cooling rate. It is also reported that segregation of alloying element is reduced in the fusion zone of the alloy 718 by the high cooling rate that had been achieved by employing current pulsing mode.

Comparative studies between GTAW and PCGTAW process of alloy 600 with three different wires were carried out by Srikanth and Manikandan [13]. The authors state that PCGTAW process resulted in refined microstructure and reduced microsegregation of alloying element compared to GTAW process. It is also observed that Nb and Mo in the filler wire ERNiCrMo-3 resulted in the formation of Nb or Mo carbides (MC) compared to Cr carbide and thereby improving the mechanical property of the alloy.

Devendranath Ramkumar et al. [17] investigated the metallurgical and mechanical properties of the alloy X750 welded with two different filler wires. The authors reported that absence of Cr precipitate and the presence of a slight amount of Mo segregation in the grain boundary resulted in good mechanical properties. Alloy 600 and Alloy X750 come under the Ni-Cr system which is similar to that of Alloy 80 A. As such same improvement can be expected out of alloy 80 A for the present investigation.

Based on the literature survey gathered by the authors it is believed that there is a need to develop an arc welding technique suitable to alloy 80 A without the occurrence of hot cracking. The developed arc welding technique tend to reduce the microsegregation of Cr carbide precipitate around the grain boundary and thereby preventing the formation of hot cracking. Hitherto, there is no literature reported on welding of alloy 80 A through the approach based on switching over from GTA to PCGTA to suppress or eliminate the $Cr_{23}C_6$ segregation. The aim of the current study is to improve the metallurgical and mechanical characteristic of the alloy 80 A by minimizing the microsegregation of the alloying elements around the grain boundary. The improvement has been achieved by employing the PCGTAW technique to minimize the microsegregation of the alloy 80 A and thereby eliminating the formation of hot cracking has been reported in this document. The knowledge gained in the present study can be readily adopted by industries without changing their actual welding process for production of defect free welds during fabrication or refurbishing.

The effect of GTAW and PCGTAW technique in terms of microstructure and the mechanical behavior of the alloy 80 A shall be documented.

Materials and methods

Materials and welding procedure

Alloy 80 A was obtained in the form of 6 mm thick plate in the solution annealed condition. The base metal chemical composition test was carried out using Optical Emission Spectroscopy (OES) method, and the result is shown in Table 1. The as-received plates were machined to the size of 170 × 50 × 6 mm using electrical discharge machining (EDM) processes to carry out the welding process. Acid pickling was carried out on the plates to remove impurities such as rust and strain. The plates were subjected to acetone cleaning to remove the oil, dirt and other markings prior to usage. Single V-groove configuration was prepared with an included angle of 60° prior to welding. The machined plates were adequately clamped to fixtures to avoid distortion during welding. Welding was carried out manually with direct current electrode negative (DCEN) polarity in both GTAW and PCGTAW mode using KEMPI DWE 400 AC/DC machine. The joints were fabricated using filler wires (263 and ERNiCrMo-3 filler wires) by melting and filling the V-grooves. The chemical composition of filler wires was reported in Table 1. During welding, argon gas with the flow rate of 15 Lit/min is used for its easy arc inition and to protect the molten region of the weld bead from the atmospheric impurities. The high energy core and outer covering of less thermal energy of argon arc plasma produces stable arc for easier metal transfer in the form of metal droplet from filler wire to groove. As a result of that full penetration is achieved. The interpass oxide layer was removed using a wire brush for every pass. The defect-free weldments were achieved, and its corresponding process parameters were shown in Table 2. The weldments photograph are shown in Fig. 1(a–d).

Welding heat input was calculated for both GTAW and PCGTAW process and are tabulated in Table 2. The constant current was used to calculate the heat input in GTAW process, whereas in the PCGTAW process mean current (Im) was used.

$$I_m = \frac{I_P \times t_p + I_b \times t_b}{t_p + t_b} \, amps$$

Heat Input (H.I.) is derived by exploiting the following Eq.

$$HI = \eta \times \frac{I_m \times V}{S}\left(\frac{kJ}{mm}\right)$$

whereas, I_p - pulse current, amps; I_b - background current, amps; t_b – duration of background current, ms; t_p - duration of pulse current, ms; S - welding speed, mm/min; V- voltage, V; efficiency of the welding