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Investigations on Mechanical and Metallurgical Properties of Dissimilar Continuous GTA Welds of Monel 400 and C-276

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Abstract

Bimetallic combinations of Monel 400 and Hastelloy C276 are widely used in the high temperature applications. This paper investigates the weldability of these metals by Gas Tungsten Arc Welding technique employing ERNiCrMo-3 filler wire. Studies were carried out to characterize the weldments for its mechanical and metallurgical properties. Tensile tests confirmed that the strength of the weld zone is higher as compared to the parent metals. Structure-property relationships have been studied using the combined techniques of optical microscopy and SEM/EDAX analysis.

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Keywords: Dissimilar metal welding; Monel 400; Hastelloy C276

1. Introduction

Monel 400, a Ni-Cu alloy, is a solid-solution alloy is widely preferred in industrial applications owing to its high strength and toughness over a wide temperature range and excellent resistance to many corrosive environments. Similarly Ni–Cr–Mo based Hastelloy C-276 has widespread applications in components used in chemical and nuclear industries such as pumps, valve parts and spray nozzles due to its excellent corrosion resistance. Due to the high concentrations of Cr and Mo, Hastelloy C276 offer better corrosion resistance than the stainless steels. The combinations of Monel 400 and Hastelloy C-276 are more corrosion resistant than stainless steels. This characteristic together with their good ductility and easy of cold working make them generally very attractive for a wide variety of applications, nearly all of which exploit their corrosion resistance in atmospheric, salt water and various acid and alkaline media [1].

Vicente et al. [1] carried out welding thin foils of Monel 400 and Hastelloy C276 using Pulsed ND:YAG Laser. It was reported that the need for joints often appears in complex components, especially the combination with a more corrosion resistant material. Due to differences in thermal conductivity, fusion temperature and solubility of the materials, brittle phases can appear and deteriorate the tensile strength of the joint. Osborne et al. [2] conducted the studies for molten salt

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reactor experiment conversion project where the dissimilar tubing is made use of Hastelloy C276 and Monel 400 to carry HF acid.

Devendranath et al. [3] studied the weldability of Monel 400 and AISI 304 using GTA welding using ER309L and ERNiCu-7 filler wires. It was reported that these bimetallic combinations are widely employed in the high temperature environments where the weldments are usually prone to corrosion. Sadek et al. [4] employed SMAW for joining Monel 400 and low carbon steel; this combination finds its application in the petro-chemical and nuclear industries where these joints are prone to hot corrosion. It was reported by the authors that the use of Nb rich filler wire would enhance the mechanical properties.

As evident from the open literatures, no work has been reported hitherto on the weldability of these bimetallic joints using Ni rich filler wire even though these combinations have potential benefits in the industries where the corrosion is aggressive and operating at high temperatures. This paper investigates the weldability, mechanical and metallurgical properties of the bimetallic combinations of Monel 400 and Hastelloy C276 employing GTA welding process using ERNiCrMo-3 filler metal. A detailed structure-property correlationship was made and the outcomes of this study would be beneficial for the industries employing these joints.

2. Experimentation

The candidate metals and the filler metal employed in this study were Monel 400, Hastelloy C276 and ERNiCrMo-3 respectively and their chemical composition is represented in Table 1. Before welding, the samples were cut to the required dimensions of 200 mm x 50 mm x 5 mm using wire cut EDM process. Standard V-groove Butt configurations were employed for the welding of these dissimilar samples. Specially designed fixture with a copper back plate was used in the welding process to avoid distortion and bending. The process parameters employed in the welding of Monel 400 and Hastelloy C276 was employed after conducting bead on plate studies and represented in Table 2.

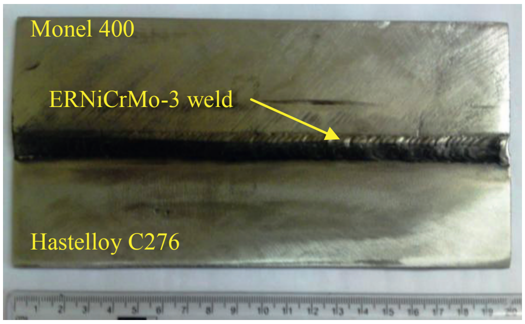

Fig.1 Photograph of the as-welded samples of Monel 400 and Hastelloy C276

After welding, the weldments were characterized to determine for any macro/microscopic defects using X-Ray radiographic technique. Ensuing to the results of NDT analysis, the as-welded samples were cut to different coupons to carry out metallurgical and mechanical tests. Macro and Microstructure studies were performed on the coupons covering all the zones of the weldments known as 'composite zone'. Standard metallographic procedures including the polishing using emery sheets of various grit sizes followed by disc polishing were adopted. Marble's reagent was used to examine the microstructure of the heat affected zone (HAZ), parent metal of Monel 400 and on the weld region; whereas a solution comprising of 15ml HCl, 10ml HNO_3 and 10ml glacial acetic acid was used to reveal the microstructure on the HAZ and parent metal side of Hastelloy C276. Further, Vickers micro-hardness test was carried out on the entire width of composite zone of the weldment at regular intervals of 0.25mm under the load of 500gf and dwell time of 10 seconds. Tensile test trails were conducted on the ASTM E-8 standard samples using Instron universal tensile testing machine with a strain rate of 2 mm/min. Three trails on each weldment were carried out to check the reproducibility of the results. Further Scanning Electron Microscopy (SEM) analysis was performed on the fractured samples to investigate the mode of fracture. In addition, the various zones of the weldments have been characterized by using the combined technique of optical microscope and SEM/EDAX analysis for assessing the structure-property relationships.

Table 1. Chemical Composition of the candidate and filler metals

Base metal/filler wire	Chemical Composition (% Weight)								
	Ni	Cu	Cr	Mo	Fe	Si	Mn	C	Others
Monel 400	65.4	30.3	---	---	2.11	0.4	1.07	0.1	---
Hastelloy C276	57	---	16	16	5	0.08	1	0.01	V- 0.35 Co - 2.5 W - 4.0
ERNiCrMo-3	61.0	---	20.0	9.0	2.0	0.18	0.25	0.08	Nb - 3.15 Al - 4.0 Ti - 0.3

Table 2. Process Parameters employed in GTA welding

Welding	Filler Wire	Diameter of the filler wire (mm)	No. of pass	Voltage (V)	Current (Amps)
GTAW	ERNiCrMo-3	2.4	4	12.5	130

3. Results and Discussions

3.1. Macro and Microstructure Examination

Visual examination, NDT analysis and the macroscopic studies clearly showed that the weldments obtained from the GTA welding process were free from any of the macro/microscopic defects that include lack of penetration, fusion, porosity etc. Microstructure examination on the GTA weldments of Monel 400 and Hastelloy C276 as shown in Fig. 2 clearly depicted the dendritic growth at the weld zone; coarse, equiaxed grains were also seen at the HAZ of Monel 400 and Hastelloy C276 side. The average width of the HAZ at Monel 400 and Hastelloy C276 was found to be 445 µm, 385 µm respectively. The width of the HAZ was found to be greater owing to the higher heat input developed during the GTA welding process. It is also to be noted the formation of partially melted zone or partial liquation zone at the HAZ of Monel 400. As reported by other researchers, the reason for the formation of partial liquation zone at the HAZ is due to the higher heat inputs developed during the welding.

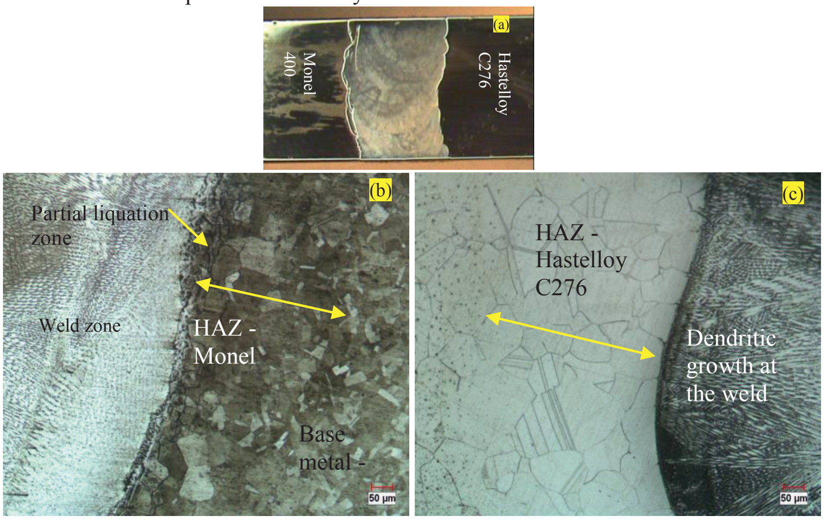

Fig. 2 (a)Macro-photograph of the as-welded sample; Microstructure showing (b) weld - HAZ - parent metal of Monel 400 (c) weld - HAZ - parent metal of Hastelloy C276

3.2. Mechanical characterization of the weldments

Hardness profile of the dissimilar weldments of Monel 400 and Hastelloy C276 [Fig.3] clearly showed that Monel 400 side has lower hardness as compared to the Hastelloy C276. The average value of hardness at the Monel 400 side was found out to be 184.5 HV; whereas the weld zone has the average hardness value of 218.8 HV and the average hardness of 284 HV was observed at the Hastelloy C276 side. The variations in the hardness, as indicated from the graph, could be attributed by presuming that there might be some amendments in the concentration of secondary phases or the formation of intermetallic compounds at theat the weld and weld interface region owing to the presence of elements such as Cu, Nb, Al, Ti. Further tensile studies [Fig.4] also confirmed the results obtained from the hardness plot. The tensile failure occurred at the parent metal side of Monel 400 in all the trials. The average tensile strength obtained from the studies would be 537.33 MPa with a ductility of 29.7%. In addition, SEM fractograph of the specimen displayed that the fracture occurred due to

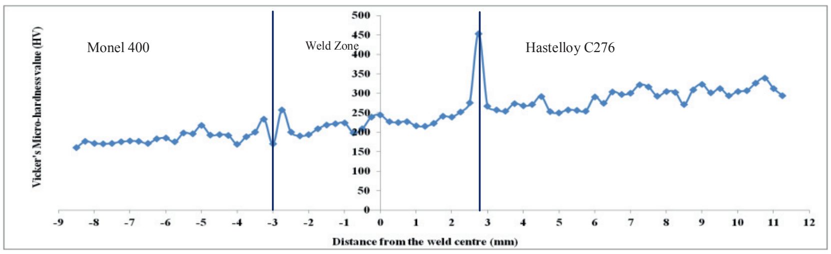

Fig. 3 Hardness profile of the GTA weldments of Monel 400 and Hastelloy C276

micro-void coalescence as voids were observed along with the presence of spherical dimples with a fibrous network. The results give a clear indication that the weldments undergo ductile fracture with considerable amounts of plastic deformation.

3.3. SEM/EDAX analysis on the weldments in as-welded conditions

SEM/EDAX analysis on the composite region of the weldment [Fig. 5] clearly showed the presence of richer amounts of Ni, Cu at the HAZ of Monel 400; similarly the weld zone and the heat affected zone has higher amounts of Ni, Cr, Fe and C. The carbon would have probably combined with the other elements present in the matrix to form intermetallics. SEM/EDAX analysis confirmed the results obtained in terms of hardness and strength. Presence of Mo and Co at the Hastelloy C276 will enhance the corrosion properties as reported by other researchers. As reported by Naffakh et al.[5], Niobium not only lowers the melting point constitutionally, but also forms low-melting carbide-austenite eutectics during solidification. This statement is in agreement with the results obtained from the studies such that the formation of probable intermetallics NbC, (Nb, Ti)C at the weld zone contributed for higher strength as evident from the analysis.

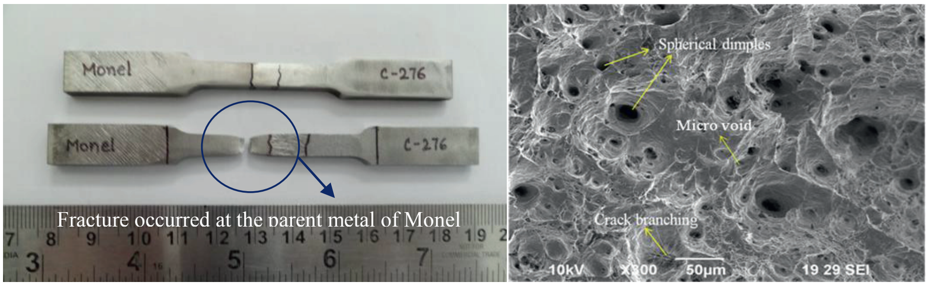

Fig. 4(a) Fractured tensile sample (b) SEM Fractograph showing the dimples and micro-voids

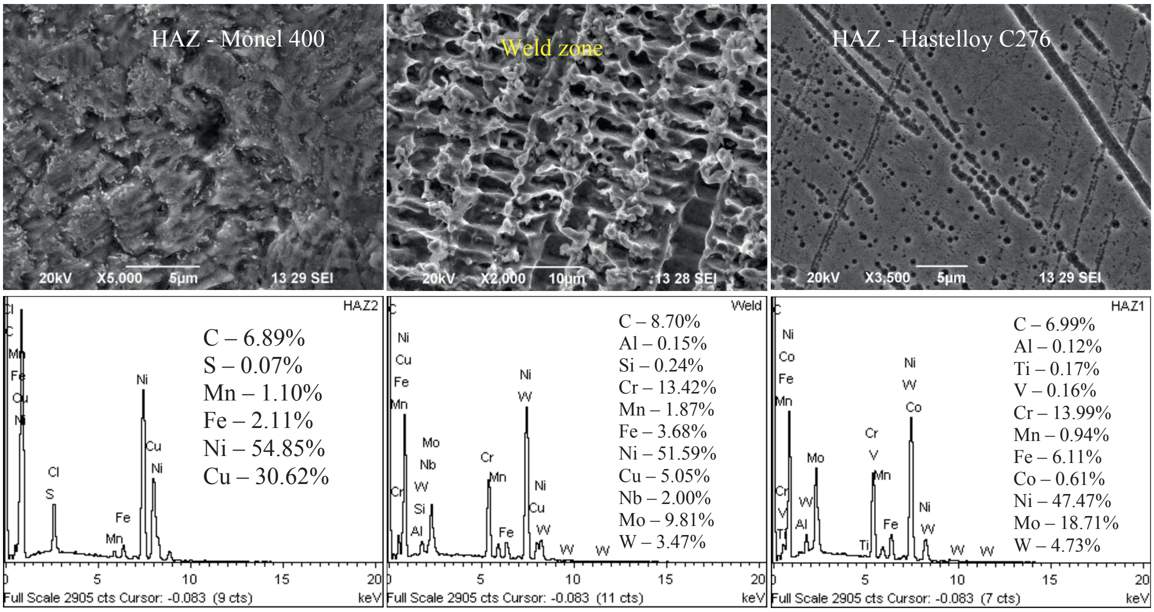

Fig. 5 SEM EDAX analysis on the GTA weldments in the as-welded conditions

Conclusions

The major conclusions drawn from this study is reported as follows:

1. Successful, defect free welds of Monel 400 and Hastelloy C276 could be obtained by GTA welding process employing ERNiCrMo-3 filler metal

2. Due to the higher heat inputs, there is the prominent formation of coarse grains at the heat affected zones of both the metals
3. Fracture occurred at the parent metal of Monel 400 contributing for the ductile mode of failure
4. SEM/EDAX analysis reports the formation of inter-metallics at the weld zone and the HAZ of Hastelloy C276 contributed for greater strength and hardness.

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