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**Assessment of Mechanical Properties of AISI 4140 and AISI 316
Dissimilar Weldments**

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Abstract

Bimetallic joints of low alloy steel and stainless steel are widely used in high temperature corrosive environments. In the present investigation, an attempt has been made to investigate the weldability of AISI 4140 and AISI 316 by Gas Tungsten Arc Welding (GTAW) process with and without filler metal. The filler metal employed for joining these dissimilar metals was ER309L. Microscopic examination was carried out across the composite region of the weldment. Hardness and Tensile studies were performed to characterize the weldments for their mechanical properties. SEM fractography is carried out to get insight information on the mode of fracture. Also SEM/EDAX analysis has been performed to determine the structure-property relationships.

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1. Introduction

Dissimilar welds of low alloy steel and stainless steel are widely employed in the fossil fuel boilers and fossil – fuel fired power generating equipments such as steam generators, water walls surrounding the furnace, economizer assemblies, and in the front and rear portions of the super heater and reheaters [1-3]. These bimetallic joints usually experience hot corrosion problems in these typical components. Energy conversion systems make use of the combinations of austenitic stainless steels and ferritic low alloy steels due to advantageous effects in terms of mechanical properties [4].

It is quite often to have the metallurgical problems such as segregation, formation of inter-metallic compounds that tend to alter the mechanical properties of the weld interface and weld zone associated with the dissimilar combinations of low alloy steel and austenitic stainless steels. Muthupandi et al.[5] reported that segregation within the dendritic structure results in deterioration of the mechanical properties and corrosion resistance of the joints. Reddy et al. [6] conducted the impact studies on the dissimilar weldments of AISI 4140 and AISI 304 and observed the carbon depletion at the weld interface of low alloy side. It was reported that AISI 4140 side should be pre-heat treated before welding for getting the better toughness. As explained by Devendranath et al. [7], it is highly cumbersome to select appropriate filler wire for joining dissimilar metals to cater to the service needs. It was reported by the authors that on

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using the filler wire of E309L to weld Monel 400 and AISI 304, any significant amount of Cu pick up from Monel 400 causes the weld metal to induce hot cracking tendency and also the formation of carbon denuded zone while using ER 309L filler metal. Carbon migration was observed in Cr–Mo weldments, and the occurrence of carbon migration is primarily driven by elemental differences, especially in chromium content, between the weld metal and base metal. The carbon diffuses from the lower-chromium base metal to the higher chromium weld metal side and forms chromium carbide adjacent to the weld interface. The micro-segregation which occurs in weld fusion zones of dissimilar metals leads to a situation where interdendritic regions are enriched in Fe, Cr and C. This segregation within the dendritic structure results in deterioration of the mechanical properties and corrosion resistance of the joints [8] and [9]. Arivazhagan et al. [10] conducted the welding studies of AISI 4140 and AISI 304 using gas tungsten arc, electron beam and friction welding processes. The authors concluded that both GTAW and EBW processes yield better mechanical properties.

As evident from the open literatures, it is well understood that there is a high demand for joining the low alloy steel and stainless steel owing to wide range of applications. In the present investigation, the low alloy steel AISI 4140 and austenitic stainless steel AISI 316 is welded using Gas Tungsten Arc (GTA) welding process employing with and without filler metal. The weldments are characterized to assess the metallurgical and mechanical properties. Combined techniques of optical microscopy and SEM/EDAX analysis have been used to determine the structure-property relationships.

2. Experimental Work

The chemical composition of the candidate metals AISI 4140, AISI 316 and the filler metal ER309L is represented in Table 1. The as-received candidate metals were sliced to the dimensions of 125 mm x 50 mm x 5 mm. Standard V-groove butt configurations on the plates having root face of 1 mm and an included angle of 45° were employed to weld these dissimilar metals by GTAW process employing with and without filler metal. Specially designed fixture containing the copper back plate was used to avoid bending and distortions during welding. Before welding process, the AISI 4140 side was preheated to 200 - 300°C to avoid weld cracking as recommended by other researchers [11]. The process parameters employed in the welding are represented in Table 2. The welded samples were characterized for flaw detection using X-Ray radiography NDT inspection techniques. Ensuating to the results of NDT analysis, the weldments shown in Fig.1 were made into different coupons which were cut using wire-EDM process. These coupons were used to conduct different studies to assess the mechanical and metallurgical behavior which is outlined below.

Metallographic examination was carried out on the region named as composite region which covers all the zones of the weldment. The composite region of the weldments were polished using the emery sheets of SiC with grit size varying from 220 to 1000 and followed by disc polishing using alumina to obtain a mirror finish of 1µ on the weldments. Nital (5 % Con. HNO₃ and 95% distilled water) is used as etchant for low alloy steel, AISI 4140; while a mixture containing hydrochloric acid nitric acid and acetic acid (at 3:2:2 ratio) is used as etchant for AISI 316. Tensile studies were performed on the ASTM E8 standard samples of the weldments. Three trials on each weldment were conducted to check the reproducibility of the results. A strain rate of 2 mm/min. was employed in the tensile studies. The fractured samples were characterized to understand the mode of fracture by SEM analysis. Hardness studies were conducted on the mounted sample by keeping weld as centre using Vicker's Microhardness tester employing a load of 500 gf and 10 s dwell time at the regular intervals of 0.25 mm. Further the SEM/EDS analysis was performed on the various zones of the weldments to determine the presence of various elements and also helpful to assess the structure - property correlations. The following chapter addresses the results and discussions of the experimental work.

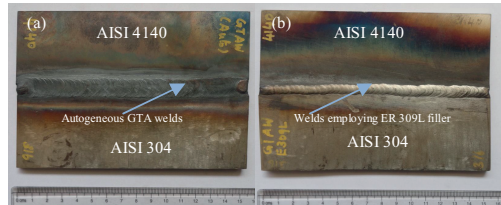


Fig.1 Dissimilar weldments of AISI 4140 and AISI 304 employing (a) without filler (b) with filler metal

Table 1. Chemical Composition of the Base/Filler metals

Base material /filler wire	Chemical Composition (% Weight)						
	C	Si	Mn	Cr	Ni	Fe	Others
AISI 4140	0.4	0.23	0.825	1.1	0.016	97.07	0.019(Al); 0.007 (Co); 0.01 (Cu) 0.001 (Nb); 0.002 (Ti); 0.004 (V); 0.014 (P); 0.022 (S)
AISI 316	0.06	0.39	1.64	18.01	8.13	Bal	1.85 (Mo); 0.022(P); 0.006 (S)
ER309L	0.035	0.175	1.58	23.45	12.6	61.76	9.0 (Mo); 3.15 (Nb); 4.0 (Al); 0.3 (Ti); 0.024 (P); 0.021 (S)

Table 2. Process Parameters employed in GTA welding

Welding technique	Voltage (Volts)	Current (Amps)	Shielding gas flow rate (lpm)	Filler wire diameter (mm)
GTAW (Filler)	16-18	150-170	15	2.4
GTAW (Auto)	18-19	170-175	15	Nil

3. Results and Discussions

3.1. Macro and Microstructure Studies

It is well observed from the NDT analysis and macrostructure examination [Fig.2] that there were no observable macro/micro-scale deficiencies such as porosity, undercut and lack of fusion etc. Microstructure studies revealed the formation of martensite at the HAZ of AISI 4140 in both the GTA weldments. Martensitic

formation could be probably due to the higher heat inputs developed during the welding and also due to lower cooling rates. Columnar austenitic grain growth was observed at the weld region which would be due to the enrichment of Ni at this zone as reported by other researchers [10]. The presence of carbides was witnessed at the HAZ of AISI 316 side in case of autogenous GTA weldments. The reason would be probably due to the carbon migration from the low alloy steel to the stainless steel side as investigated by other researchers [10].

3.2. Mechanical Characterization of the weldments

3.2.1. Hardness Measurement

Hardness profile on the GTA weldments employing with and without filler wire clearly epitomized that the maximum hardness was found to be at the HAZ of AISI 4140 in both the weldments and weld zone in autogeneous GTA weldments. The average hardness of GTA weldments employing without filler wire would be 410.6 HV and with filler wire as 262.4 HV. As evident from the microstructure examination, the greater hardness at these regions would be due to the martensite formation. The weld region of the GTA weldments employing ER 309L filler showed the lesser hardness value which could be probably due to the formation of coarse austenite grains in the matrix.

3.2.2. Tensile Properties of the weldments

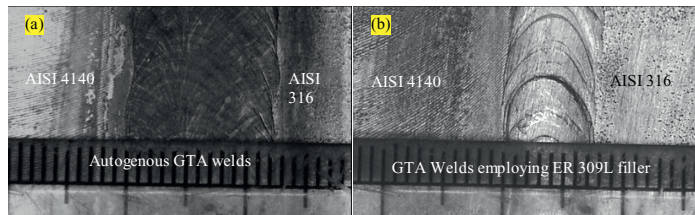


Fig. 2 Macrographs of the GTA (a) Autogenous welds (b) employing ER309L welds

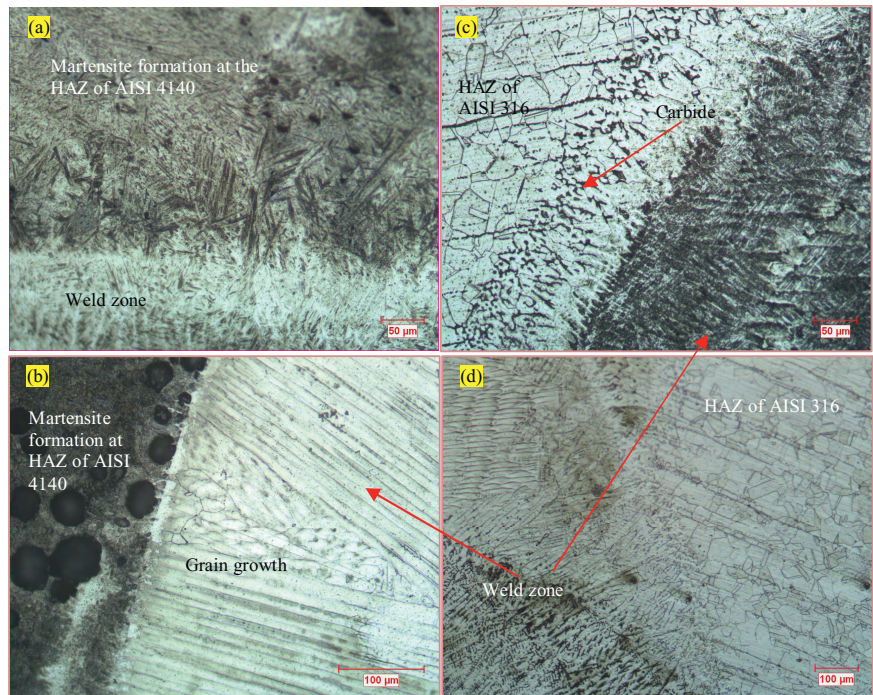


Fig. 3 Microstructure representing Weld zone - HAZ of AISI 4140 of (a) Autogenous weldments (b) GTAW employing ER309L filler; Weld - HAZ of AISI 316 of (c) Autogenous weldments (d) GTAW employing ER309L filler respectively

Tensile studies were conducted on the ASTM E8 standard samples to assess the strength and ductility of the weldments. It is clearly inferred from the results that in both the cases, the tensile failure occurred at the parent metal of AISI 316. Large amount of plastic deformation was witnessed before the fracture in both the weldments. The average ultimate tensile strength of the autogenous weldments was found to be 600 Mpa and 580 Mpa for the weldments employing ER 309L filler. Ductility in both the cases was found to be approximately 34%. It is evident from the tensile studies that the strength of the both type of welds are higher and comparable with the candidate metals of AISI 4140 and AISI 316.

As noticed from the hardness studies, the lower hardness values are found to be at the parent metal side of AISI 316. Hence the tensile failures were occurred at the parent metal of AISI 316 side. SEM fractographs proved that there were quite numerous tiny voids and dimples spread across the fibrous network of the fractured zone. These results gave the clear indication that these weldments had undergone ductile type of fracture. Table 3 represents the average tensile properties of the weldments.

3.2.3. SEM/EDAX analysis of the weldments

SEM/ EDAX analysis on the GTA weldments employing with and without filler wire is represented in Fig. 6. The EDAX analysis on the HAZ of AISI 4140 of Autogenous GTA weldments clearly showed considerable amounts of Fe and C and traces of Ni, Cr and Mn; On the other hand, the presence of Ni and Cr in the weld zone was found to be more in case of weldments employing filler wire as compared to autogenous weldments. The presence of richer amounts of Ni, Cr could have been provided by the filler wire. The formation of carbides at the HAZ of AISI 316 in the autogenous weldments as shown in Fig.3 could be confirmed with the presence of higher percentage of C, Cr as evident from the EDAX analysis. Also the presence of carbon was observed to be in considerable amounts at the HAZ. This could be reasoned due to the carbon migration as reported by other researchers [10].

Conclusions

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

1. Successful welds of AISI 4140 and AISI 316 could be obtained by GTA welding process employing with and without filler wire
2. Martensite formation is observed at the HAZ of AISI 4140 in both the cases
3. Tensile failure occurred at the parent metal of AISI 316 in all the trials for both the weldments. The strength of the welds are found to be higher and comparable with AISI 4140/AISI 304 candidate metals.

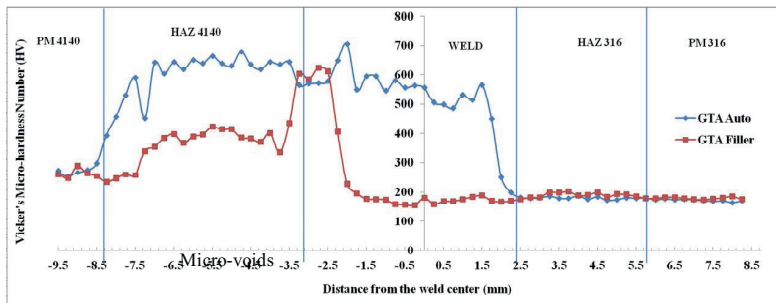


Fig. 4 Hardness Profile of the GTA weldments employing with and without filler wire

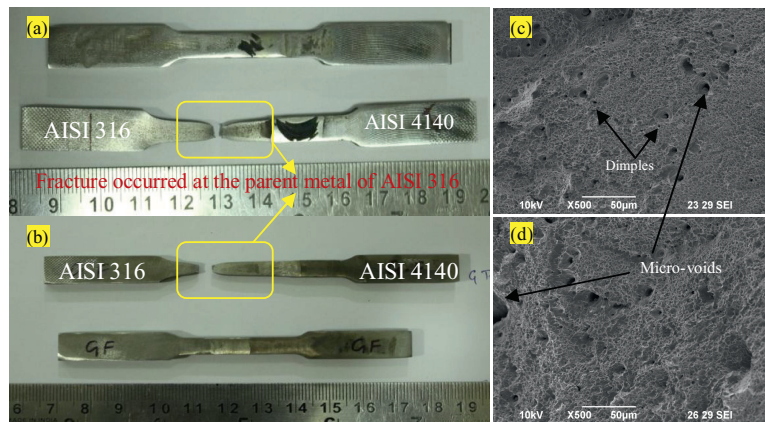


Fig. 5 Fractured tensile samples of GTA weldments employing (a) without filler (b) with filler; SEM fractographs of GTA weldments employing (c) without filler (d) with filler

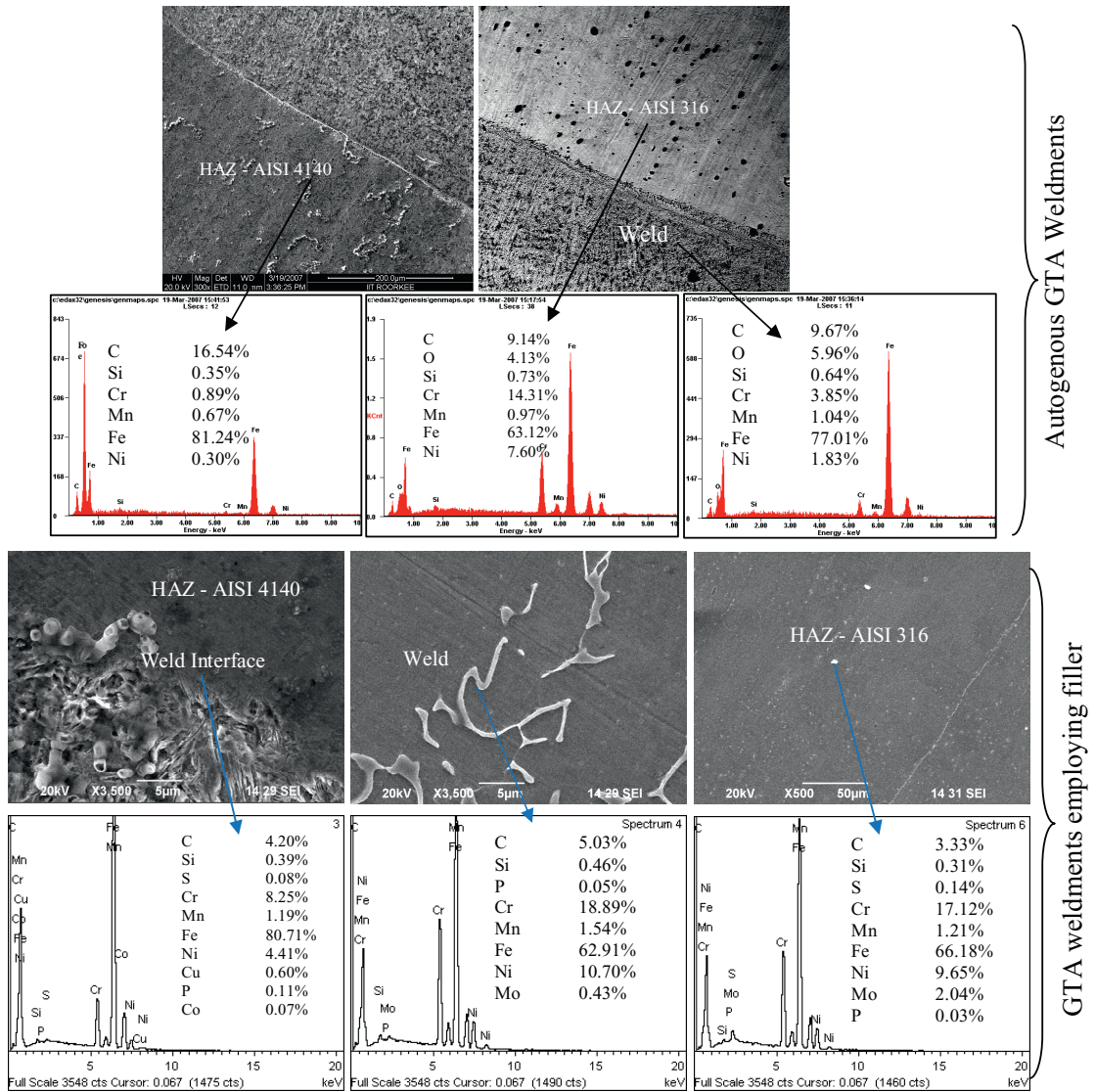


Fig. 6 SEM /EDAX analysis on the GTA weldments in the as-welded conditions

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