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An Empirical Research on Dissimilar Metal Weld of SA335 P11and SA312 TP304 Formed by Metal Inert Gas (MIG) Welding

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Abstract: Development of dissimilar metal welds (DMW) presents itself as an important research domain with respect to the industrial requirements. The joints formed by dissimilar metals should have superior metallurgical properties and an ability to withstand severe operational conditions. Due to difference in composition and properties, DMW formed between stainless steel and low carbon alloy exhibits functional limitation under heterogeneous working conditions and leads to components failure. The present empirical study investigates mechanical and metallurgical properties of dissimilar metal weld of SA312 TP304 alloy and SA335 P11 stainless steel that is formed by MIG welding. The mechanical and metallurgical properties of the weld are investigated using tensile test, hardness measurement and microstructural observations. Characterization of as-welded and heat-treated weld specimen has also been conducted to determine effect of heat treatment on material behavior. The lower tensile strengths was measured in MIG welded joints than base metals. The significant decrease in ultimate strength is observed in heat treatment specimens compared to as-welded specimens. In contrary, all regions of treated joints revealed higher hardness than the as-welded joint.

Keywords: Dissimilar, Hardness, Metal, Microstructures, MIG, Tensile

I. INTRODUCTION

This DMWs of stainless steel and carbon steel and alloys are usually used in power plant assemblies. These joints are exposed to high temperature and pressures when used in applications such as nuclear and coal fired boilers and reactors [1]. The detailed study on joining methods suggests that welding is an efficient process that can be used for joining dissimilar metals with high strength [2]. Though welding produces a strong joint, however shows performance issues causing early failure. High amount of stresses are generated at joining interface because of variation in composition and properties of joining metals [3, 4]. The strength of dissimilar metal weld is also affected by other metallurgical phenomena such as precipitation of phases, micro-segregation, solidification cracking, presence of porosities and grain growth in the HAZ The formation of brittle intermetallic compound at the joint interface also leads to crack formation at the interface in some welds [5, 6].

DMW of stainless steels and carbon steel can be commonly produced using various fusion-welding techniques. The use of consumable filler metal during welding gives better control of properties of the joint [7]. As weldability of joint normally depends on carbon content, preheating with controlled heat input was carried on these type joint [8].The selection of proper welding methods and welding process parameters is required to produce high strength welds free from weld defects [9, 10]. Tungsten Inert Gas (TIG) welding produces DMWs of stainless steel and alloys steel with superior tensile strength and other mechanical properties due to finer grains present in weld zone and surrounding area [11]. The strength of dissimilar metal weld of stainless steel with carbon steel alloys is greatly affected by diffusion of the weld metal with the parent metals those having dissimilar thermal expansion coefficients [12]. MIG welding joins the metals generating electric arc between consumable filler metal electrode and work piece is effectively used in to join ferrous and nonferrous metals [13]. The quality of weld depends on proper control over the molten weld pool, which is mainly affected by welding current and travel speed of arc flame [14, 15]. MIG forms the strong joints of dissimilar metals that are immiscible in solid state and miscible in liquid state [16]. There are number of failure mechanisms such as solidification cracking, clad disbanding along the grain boundaries, creep failure at HAZ of carbon steel and reheat cracking are associated with dissimilar metal welds [17, 18]. Failure occurs in HAZ of low carbon steel in vicinity of fusion boundary in thick section welds due to migration of carbon from HAZ to weld metal during welding, post weld heat treatment [19]. The aim of present work is to study the effects of MIG welding parameters on behaviour of welded joint of SA335 P11 and SA312 TP304 in as-welded and heat treat-ed condition. This investigation will be help for further analysis of welded joint formed by other welding methods.

II. MATERIAL AND METHODOLOGY

A. *Specimen Preparation and Welding*

The welded joint of dissimilar SA335 P11 and SA312 TP304 alloys were produced using MIG welding. Table 1 shows chemical composition of two base metals as well as filler metal used.

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The dissimilar metal weld pipe joint of SA335 P11 alloy and SA312 TP304 steel formed by MIG welding process is as shown in Fig.1. Dissimilar metal weld pipe joint of 48 mm OD, 5 mm thickness and 300 mm length was formed. E309 filler material is used during welding of pipe joint

Table. I Chemical Composition of Welded Materials

Element %	Base Metal 1 SA335 P11	Base Metal 2 SA312 TP304	Filler Metal ER 309 L
C	0.083	0.030	**0.019**
S	0.007	0.003	0.003
P	0.019	0.037	0.013
Mn	0.40	1.72	2.28
Si	0.69	0.32	0.40
Cr	1.60	18.72	21.01
Ni	0.046	8.32	12.30
Mo	0.47	0.19	0.14

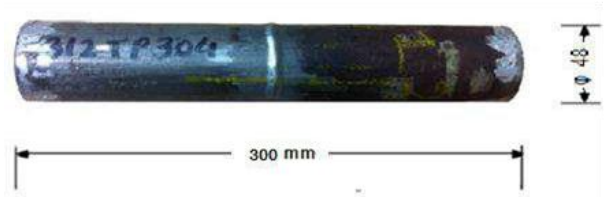


Fig.1. MIG Welded Pipe Joint

The ESAB make MIGMATIC 250 MIG welding machine was used to form the welded joint. The welding was carried out at constant voltage DC power source with electrode positive that produced stable arc and gave smooth and spatter-free metal transfer. The current and voltage used during MIG welding were 200 A and 25 V respectively. ER309 L filler wire of 2 mm diameter was used during the welding. The CO2 gas is used for shielding the weld zone and Heat Affected Zone (HAZ) from atmospheric contamination. The detailed process parameters of MIG welding are presented in Table 2. The preheating at 125°C was carried out on SA335 P11 side of the joint to avoid thermal cracking. It also helps to transform austenite to ferrite and carbide at weld zone during solidification. The resistance heating blankets were used for preheating. The maximum interpass temperature was 175°C and preheat temperature was 125°C. It is carried out only on P4 ferritic steels side, as it is easily prone to hydrogen cold cracking.

Post weld heat treatment was carried out on one set of the specimens to remove the internal stresses in the joint, as most of nickel-based alloys are usually susceptible to solidification cracking when welded. It also avoids hydrogen induced cold cracking by diffusing hydrogen in the weld or heat affected zones. The welded specimens were heated up to 680°C at the heating rate of 50°C/hour and was soaked for one hour. The heated specimens were then cooled to room temperature at very slow cooling rate of 50°C /hour. The loading and unloading temperature kept was 300°C. Tensile test and microhardness measurement were used for mechanical characterization of the welded joints. The standard metallographic investigation procedure was used for microstructural characterization of the welded joint.

Table II MIG Welding Process Details

Sr. No.	Parameters	Details
1.	Shielding Gas	Aragon and CO2 (98 %)
2.	Current	200 A DC EN
	Voltage	25 V
3.	Heat Input	3 kJ/mm
4.	Pass	Multiple
5.	Filler Rod	ER309L , 0.8 mm dia.

B. Tensile Test

The strength of welded joints produced were measured using tensile test using an Instron 300DX universal testing machine. The specimens for tensile test were extracted from the welded joint as shown in Fig. 2. The tests were conducted on both as-welded and heat-treated samples at room temperature. The test was conducted conforming to ASME SEC-IX.

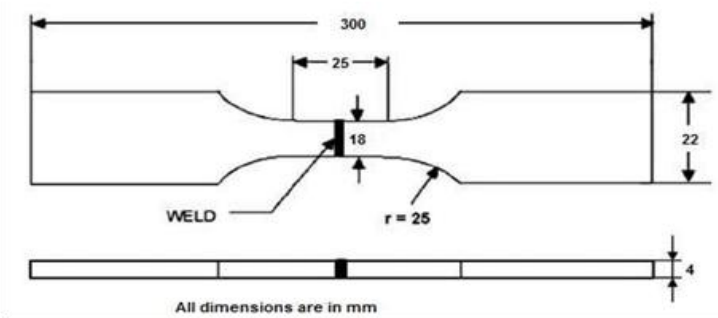


Fig. 2. Tensile Test Specimen

C. Hardness Measurement

The hardness measurements were carried out on as-welded and heat-treated samples. The hardness test was conducted at different regions of weldment to quantify the relationship between the microstructures and mechanical properties of the weld. A Vickers's hardness tester was used for determining the hardness. The load of 1 kg was applied for 10 seconds to make indentations. The hardness at different regions of weldment were messaged using Vickers micro hardness test. The tests were performed at the load of 1 kg in accordance with ASTM E 384 standards.

D. Metallography

Microstructural investigations of weld were carried out in transverse direction cut of the weld joint to study weld characteristics, phase changes in base metals, HAZ, and weld zone. The specimens were etched using Nital solution diluted 2 % to reveal different regions of weldment. The polishing of the weldment regions were carried out with alumina and distilled water, with the use of different polishing papers.

After polishing process, the regular metallographic procedure was carried out to obtain perfect mirror finish of approximately 1 µm. Microstructural investigations of welds was performed using optical microscope attached with a digital camera. The structural characteristics and their possible effects on properties of weldment were investigated.

III. RESULTS AND DISCUSSION

Mechanical and metallurgical properties of as welded and heat-treated joints formed by MIG welding processes were investigated. The results obtained in these tests were analyzed to understand structural changes, existence of different phases and effect of different welding parameters on different regions of weldment.

A. *Tensile Test*

The welded joints revealed lower ultimate tensile strength than the base metals. It is also evidenced by fracture occurred in weld zone of the specimen. This was due to due to grain coarsening of the weld zone that resulted because of slow cooling during solidification after welding as result of high heat input. Another reason for fracture in weld zone can be attributed to lack of fusion. The maximum ultimate tensile strength was measured in as-welded samples. The ultimate strength of joint decreased after heat treatment. This can be associated with formation of soft ferrite in heat-treated samples. It also due to re-precipitation of Cr-rich carbides those were formed during welding process. However, little decrease of 3 % was observed in percentage elongation and reduction in cross section area in the heat-treated test specimens compared to as-welded samples.

Table III Tensile Test Results

Properties	As welded Specimen		Heat-treated Specimen	
	Test 1	Test 2	Test 1	Test 2
Ultimate load KN	29.65	21.34	22.46	22.96
U.T.S. MPa (N/mm^2)	502	437	384	396
Proof Stress (N/mm^2)	305	340	310	290
% reduction in area	46.3	42.1	38.8	39.7
% elongation	34.3	35.8	36.6	36.2

B. *Hardness Measurement*

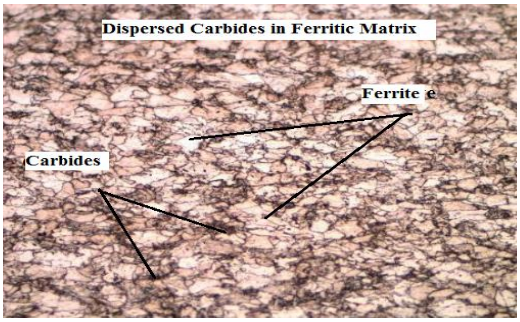
The details of the hardness measured are given in Table 4. The increase in hardness was measured in all regions of weldment of heat-treated joints compared to as-welded samples. The maximum hardness was measured at HAZ of SA335 P11 of the heat-treated specimen. The increase in hardness in HAZ than the base metal can be associated with sensitization of the grain boundary. Moreover, secondary phase observed in microstructures as exposed for long time during heat treatment was also attributed for strengthening effect. It is evidenced by formation of dark network of pearlite, ferrite and carbide precipitates in HAZ of SA335 P11. The minimum hardness was measured in weld zone in as-welded as well as heat-treated samples. This can be associated with dissolution of strengthening precipitates in gamma matrix of weld zone. The weld zone contained Υ' Gamma prime precipitate melted in the matrix of austenite due to uses of austenite stainless steel filler metal. The solidification of these alloys after welding produced austenite phase at room temperature. It is evidenced by microstructures of weld zone showing dendritic structures with presence primary austenite. This phase dissolves maximum amount of ϒ--Gamma prime precipitate at higher temperatures during primary welding thermal cycles causing dissolution of strengthening precipitates.

Table IV Hardness at Different Regions of Weldment

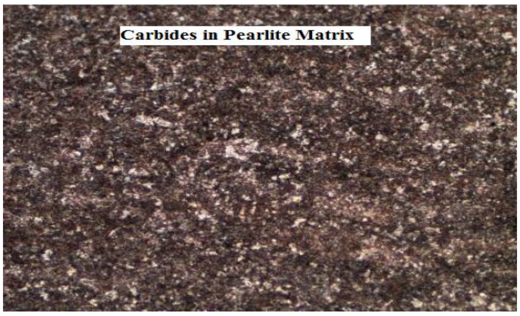
Materials	Region	Average Hardness (HV)	
		As-welded Specimen	Heat-treated Specimen
SA 312 TP304	Base Metal	189	203
	HAZ	383	390
	Weld Zone	273	291
SA 335 P11	Base Metal	183	201
	HAZ	337	350

C. *Microstructures*

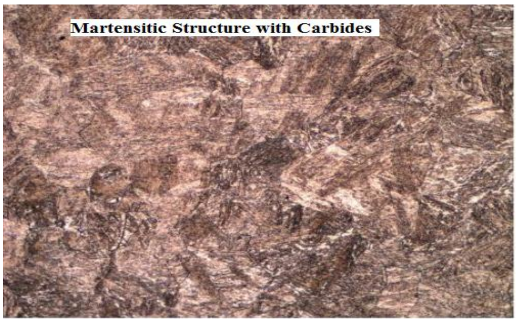
The microstructures of weld metal greatly affect the mechanical properties of weld. Figure. 3 (a) to (e) and Figure. 4 (a) to (e) show micrographs of as-welded and heat treated specimens respectively. The base metal and HAZ of SA312 TP304 revealed twinned equiaxed grains of austenite with carbide precipitation throughout the grains. The HAZ of SA312 TP304 was found to be free from grain boundary precipitation in as-welded samples whereas precipitation along the grain boundaries was observed in heat treated condition. This grain boundary precipitation of carbides makes the joint susceptible to intergranular corrosion. The base metal and HAZ of SA335 P11 revealed pearlitic structures with dispersion of alloy carbide particles in a matrix of ferrite in as-welded and heat-treated samples. It is due to sensitization along the grain boundary during welding. The weld zone revealed martensitic structure in as welded samples and dendritic structure in heat-treated samples. The formation of marten-sites in weld zone makes it brittle lowering the strength. It is also evidenced by fracture occurred in weld zone.



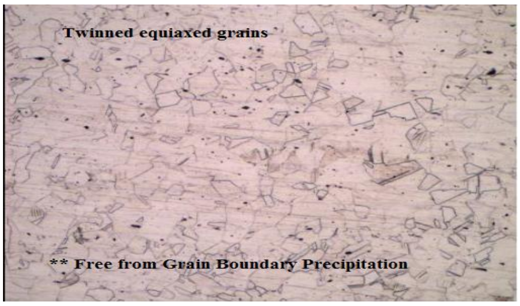
(a) Base Metal SA335 P11



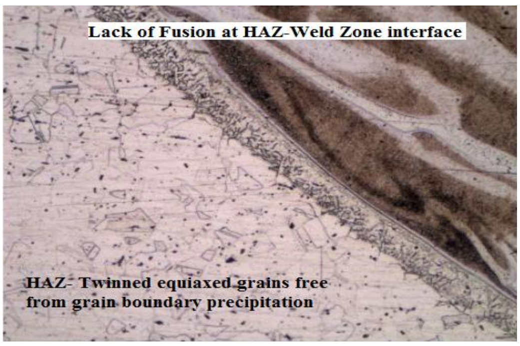
(b) HAZ SA335 P11



(c) Wed Zone

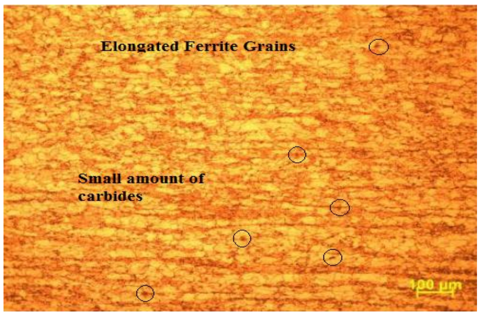


(d) Base Metal SA312 TP 304

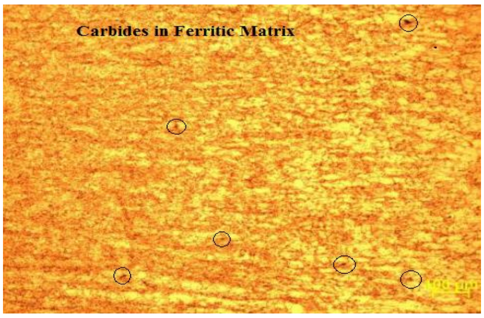


(e) HAZ SA312 TP 304

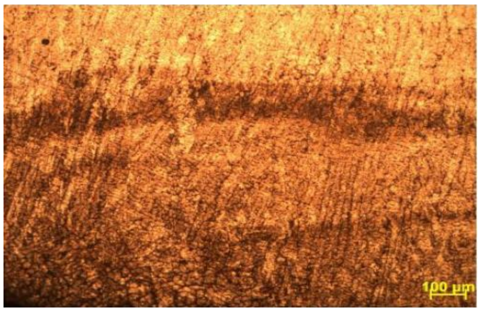
Fig. 3. Micrographs of As-welded Weld Specimen



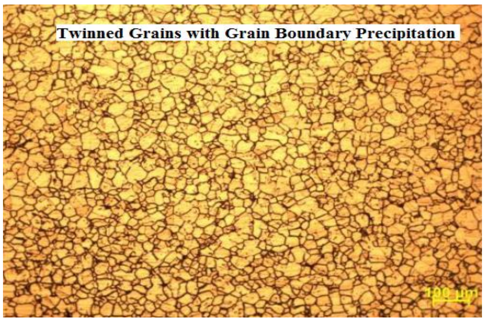
(a) Base Metal SA335 P11



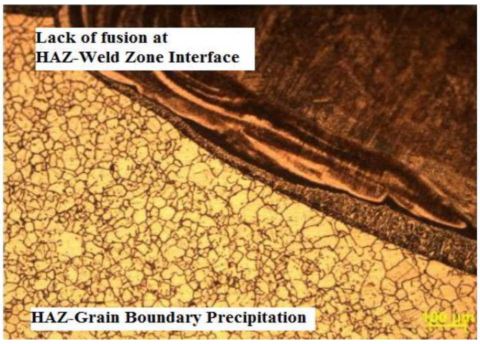
(b) HAZ SA335 P11



(c) Wed Zone



(d) Base Metal SA312 TP 304



(e) HAZ SA312 TP 304

Fig. 4. Micrographs of Heat Treated Specimen

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IV. CONCLUSION

1. MIG welded joint showed lack of fusion on macroscopic examination indicating that the process is unsuitable for joining of SA335 P11 alloys and SA312 TP304 steel.
2. MIG welded joints showed decrease in tensile strength in heat treated samples where joint fractured in weld zone. This is attributed to lack of fusion and grain boundary segregation of carbides.
3. Heat Treatment does not improve the strength of the joints. This is also supported by higher hardness observed in heat-treated condition. The anomaly observed is attributed to the sensitization occurring in heat-treated condition. This is also indicated in the microstructure where grain boundary precipitation of carbide is observed.
4. The carbide precipitation along the grain boundary was observed in base metal of SA312 TP304 in as-welded sample indicating sensitization during welding. This makes the joint susceptible to stress corrosion cracking.

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