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Effect of post-weld heat treatment on the mechanical and microstructural properties of dissimilar SS 304 and MS joints welded by using Gas Metal Arc Welding

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ABSTRACT

This article investigates the effect of post-weld heat treatment (PWHT) on the mechanical and microstructural properties of dissimilar SS 304 and Mild Steel welded joints using Gas Metal Arc Welding (GMAW). The experimental work involves welding dissimilar SS 304 and MS plates using GMAW, followed by subjecting the welded joints to various post weld heat treatment conditions. The PWHTs used on the samples were case hardening and tempering. The mechanical properties, including tensile strength and hardness, are assessed for both as-welded and PWHT specimens. Furthermore, scanning electron microscopy (SEM) is employed to analyse the microstructural changes in the heat-affected zone (HAZ) and weld metal resulting from PWHT. From the results, the PWHTs were able to enhance the mechanical properties and microstructure characteristics of the dissimilar SS 304 and Mild Steel welded joints by the GMAW.

1. Introduction

Manufacturing industries including automotive, railway, aerospace, shipbuilding, and petrochemical develop products ranging from simple to big in complex shapes. Conventionally, stainless steels are joined by metal inert gas welding, tungsten inert gas welding, friction stir welding etc. In MIG welding, the common variations of power supplies, shielding gases, and copper coated wire have significant effects resulting in several different and important process parameters [1]. MIG welding frequently accepted globally due to high productivity rate and spatter free quality [2]. AISI 304 is frequently used in structural industries for fabrication purpose as it is more economical and anti-corrosion resisting steels as compared to other steels. Stainless steel sheets are increasingly used for boiler, vessels, pharmaceutical, aerospace, thermal power plant, kitchen, building, transportation, etc., because of their high corrosion resistivity, beautiful appearance, superior strength, toughness, and low temperature toughness [3-5]. AISI 304 can be welded with several welding process such as MIG, TIG, friction, laser beam welding etc. Extensive studies were carried out on the effect of heat input [6, 7] on the microstructure and mechanical properties of AISI 304 (Austenitic stainless steel).

Mild steel, also known as plain carbon steel and low carbon steel, is a type of steel that contains a low carbon content, typically around 0.05% to 0.25% by weight. It is one of the most used types of steel due to its affordability, versatility, and relatively good mechanical properties. The low carbon content in mild steel makes it relatively soft and malleable compared to other types of steel. It is easy to work with and can be easily formed into various shapes such as sheets, rods, and tubes. Mild steel is widely used in construction, automotive manufacturing, furniture making, and general fabrication. One of the main advantages of mild steel is its weldability. It can be welded using various methods, including arc welding, MIG welding, and TIG welding, making it suitable for a wide range of applications where joining pieces of steel is required. However, mild steel is not as strong or durable as some other types of steel, such as stainless steel or high-strength alloy steels. It has relatively low tensile strength and hardness, which means it is susceptible to deformation and wear over time. It is also prone to corrosion if not properly protected, as it lacks the corrosion-resistant properties of stainless steel. To improve the strength, hardness, and corrosion resistance of mild steel, it can be subjected to additional processes such as heat treatment, surface coating (e.g., galvanizing or painting), or alloying with other elements. Overall, mild steel is a widely used and readily available type of steel that offers good affordability, workability, and weldability, although it may not possess the same level of strength and corrosion resistance as some other types of steel.

In comparison with mild steel, the austenitic stainless steels have several characteristics that require some revision of welding procedures that are considered standard for mild steel. The melting point of the austenitic grades is lower, so less heat is required to produce fusion. Their electrical resistance is higher than that of mild steel so less electrical current (lower heat settings) is required for welding. These stainless steels also have a lower coefficient of thermal conductivity, which causes a tendency for heat to concentrate in a small zone adjacent to the weld. The austenitic stainless steels also have coefficients of thermal expansion approximately 50% greater than mild steel, which calls for more attention to the control of warpage and distortion.

Welding stainless steel (SS) 304 to mild steel can be accomplished using various methods. However, it is important to note that welding dissimilar metals like these requires careful consideration due to their different physical properties. Before attempting any welding, it is crucial to thoroughly clean the welding surfaces and remove any contaminants, such as oil, grease, or rust.

It has become more and more important to weld stainless steels as the usage of these steels in industrial applications has increased rapidly [8, 9]. Stainless steels can be welded by both fusion and solid-state welding methods, such as metal inert gas (MIG), tungsten inert gas (TIG), flux cored arc welding (FCAW), submerged arc welding (SAW), friction welding (FW), friction stir welding (FSW), friction stir spot welding (FSSW), and explosive welding (EW) [10–12]. The necessity to weld both similar and dissimilar stainless steels has emerged in engineering applications [10, 13]. MIG is a welding process that enables to control parameters and obtain clean, cost-effective, and rapid weld seams and has a wide area of usage. Furthermore, the MIG welding method is an important manufacturing technology that has been gaining popularity of stainless steels nowadays for obtaining high-quality joints in industrial applications [12, 14]. Solid welding wires are used in this method. A shielding gas is automatically sent to the weld zone together with the wire during the welding process. Meanwhile, high heat produced by the arc melts the welding wire and causes local melting in the pieces to be welded. The primary function of shielding gases in the welding process is to protect the molten weld metal against negative impacts of nitrogen and oxygen in the atmosphere [15, 16]. Selecting the shielding gas and/or gas mixtures that are most appropriate for welding stainless steels through MIG welding is a difficult process. The type and composition of the selected gas have a significant effect on the microstructure and mechanical properties of the welded material [16–19]. Also, the shielding gases affect the heat input, the type of metal transfer, and the arc characteristics. On the other hand, when a need of welding dissimilar stainless steels appears, the situation becomes more complicated due to differences in their metallurgical properties. Argon (Ar) and helium (He) gases can be used alone in the welding of stainless steels through MIG welding; however, some studies in the literature have showed that different gases such as oxygen (O2), carbon dioxide (CO2), nitrogen (N2), and hydrogen (H2) at varying rates have recently been added to these gases [8, 11–19].

2. Experimental Methods

The materials used in this experiment are Stainless Steel 304 and Mild Steel with a thickness of 3mm. The materials were cut according to the required dimensions. After that, materials were wiped with ethanol before the welding process to remove impurities, such as oil and grease, that are typically present after the cutting process. Then, the 3-mm thick sheets of Stainless Steel 304 and Mild Steel, were welded by the MIG welding. As welding wire, a 1.6-mm diameter ER308L stainless steel wire was used in the welding process. Table 1 shows the chemical compositions of SS 304 and Mild Steel, as well as welding wire and the welding parameters used during the process are shown in Table 2. The welding samples were divided into two groups: as-welded and PWHT samples.

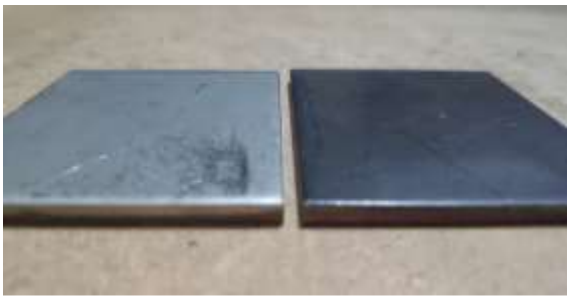

Fig 1. Prepared specimens for butt joint

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The PWHTs used were case hardening, tempering and oil quenching. The samples were heat treated in the furnace at 900^0 C for 8hrs. The samples were then cooled down rapidly by immersion in an oil bath.

Specimens for the tensile test were made according to the ASTM E8 standards. Tensile tests were performed using the BME-T series 100kN universal tensile testing machine. Scanning electron microscopy (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that are derived from electron-sample interactions reveal information about the sample, including external morphology (texture), chemical composition, crystalline structure and orientation of materials making up the sample. The micrograph produced shows surface topography and chemical contrast for the shortest time.

Table 1. Chemical composition of the base metals and the welding wire (wt. %).

	C	Mn	Si	P	S	Cr	Cu	N	Ni	Fe
SS 304	0.08	2.0	0.75	0.045	0.03	18.0-20.0	-	0.10	8.0-10.5	Bal
MS	0.25-0.29	1.03	0.28	0.04	0.05	-	0.20	-	-	Bal
ER308L	0.03	1-2.5	0.3-0.65	0.03	0.03	19.5-22	0.75	-	9-11	Bal

3. Results and discussion

Figure 2 shows the fracture behaviour of tensile test samples for as-welded and heat treated. The figure shows that the samples were broken inside the weld while conducting the tensile testing. When the tensile test results were examined, it was determined that As-welded sample has the highest mechanical properties. The tensile test results for as-welded sample are tensile strength was 362.22MPa, yield strength was 257.47MPa, and elongation (%) was 6.40 %. The tensile test results for Post weld heat treatment sample are tensile strength was 200.29MPa, yield strength was 188.81MPa, and elongation (%) was 1.44%. When the tensile strength results of the as-welded sample were compared with those of PWHT sample, it was found that the yield strength and tensile strength decreased by 68.66MPa and 161.93MPa respectively. Also, the elongation (%) was decreased by 4.96%. The fracture location for both as-welded and post weld heat treated samples were broken inside the weld.

Fig 2. Fracture behaviour of tensile test samples as-welded (top) and Heat treated (bottom).

3.1. Tensile test results

Fig 3 and 4 shows the bar chart representation of tensile strength and percentage of elongation (%) for As-welded and heat-treated samples.

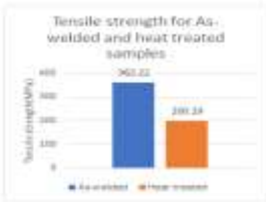

Fig 3. Bar chart of tensile strength of as-welded and heat treated samples

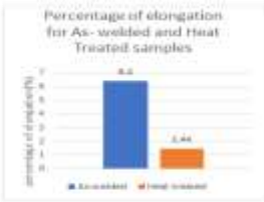

Fig 4. Bar chart of percentage of elongation of as-welded and heat treated samples

3.2 Hardness test results

A Vickers microhardness test was done for as-welded and heat-treated samples from the distance of SS304 to Mild steel. The Vickers hardness values are located for every 2mm distance from SS 304 to Mild steel. The results showed that the SS 304 has the high hardness values compare to Mild steel. But after the heat treatment the hardness value percent has more increased to mild steel than SS 304.Also the hardness value on the top of weld centre for as-welded and heat treated are obtained. The Vickers hardness value for as-welded on the weld centre is 232HV and Vickers hardness value for heat treated on the weld centre is 329HV. This shows rapid increase in the hardness of the weld after the heat treatment.

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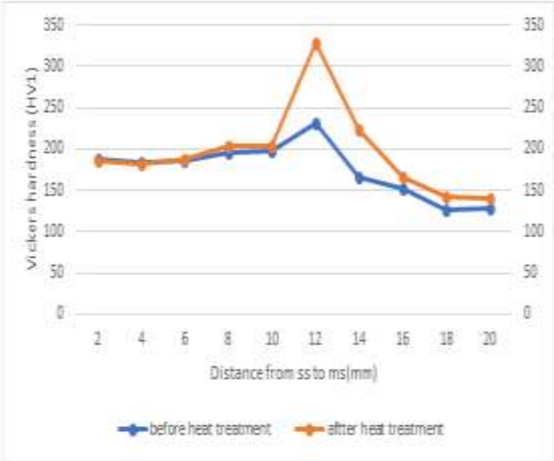

Fig 4. Graph representation of hardness values from distance SS 304 to MS

3.3 SEM fractographs

The fracture surfaces of the tensile specimens and welded specimens for before and after heat treatment were characterized using SEM to understand the failure patterns of the as-welded and heat-treated samples. SEM micrographs were taken at different locations: the top surfaces, the middle regions and the bottom (root) portions of the joints. All the fractographs are presented in the below Figs.

The figures shows the different variations in the fractographs. Fig 7 and 8 shows the fractography images of the fractured tensile samples and root regions of dissimilar SS 304 and mild steel weld joints. The fracture surface exhibits deeper elongated dimples along the grain boundaries. In addition, along with the micro and macro voids, both secondary cracking and smooth surface are observed due to cleavage fracture. Such secondary cracking and smooth cleavage in the fracture surface could adversely affect the ductility by rapid crack initiation and propagation.

A quasi-cleavage fracture with river line markings in addition to dimples structure is noticed in the fracture surface of the weld metal. The quasi-cleavage mode of fracture in the weld metal is due to the presence of hard secondary phases like NbC and Laves phases along the SGBs and interdendrites in the coarse columnar grains. Tis secondary phase could initiate the crack leading to crack propagation and causing a reduction of ductility in the weld metal.

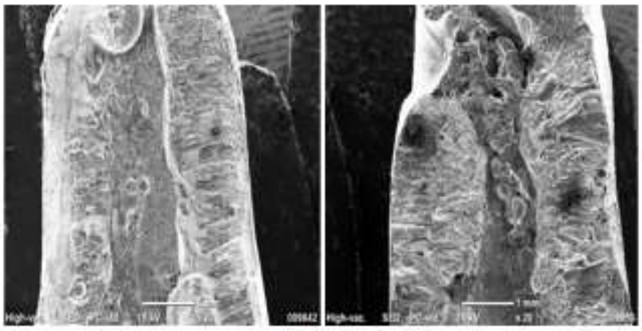

Fig 5. SEM fractographs of the top surfaces of welded specimens; (a) Before heat treatment; (b) After heat treatment.

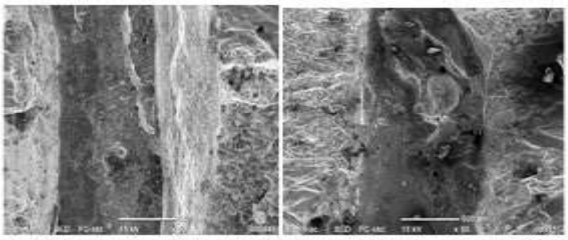

Fig 6. SEM fractographs of the middle region of welded specimens; (a) Before heat treatment; (b) After heat treatment.

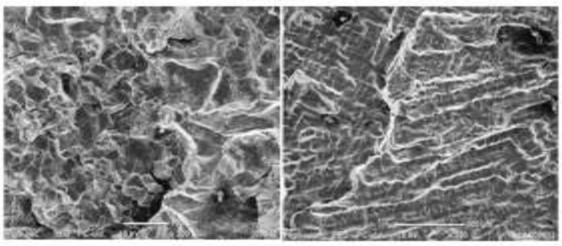

Fig 7. SEM fractographs of the root regions of welded specimens; (a) Before heat treatment; (b) After heat treatment.

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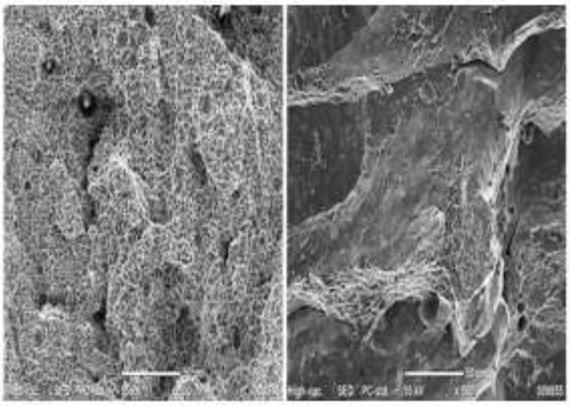

Fig 8. SEM fractographs of tensile tested specimens; (a) as-welded; (b) heat treated

4. Conclusion

In this paper, the effect of post-weld heat treatment on the mechanical and microstructural properties of dissimilar SS 304 and MS joints welded by using Gas Metal Arc Welding has been analysed. From this investigation, the following important conclusions have been derived:

- The decrease in tensile strength and elongation was recorded due to hardening process of PWHT. This proves that PWHT was unable to enhance the tensile properties of dissimilar SS 304 and MS welded joints using GMAW.
- By implementing the PWHT, the higher increase was recorded for hardness values. The higher values of hardness are due to the fact that PWHT produces a fine and uniform distribution of precipitates at the weld joints. The good characteristics of the GMAW method, which produce weld joints with spatter-free welding,
- outstanding gap bridging properties and a low heat input, were also involved.
- From SEM fractographs, the increase in grain size, gaps between the grains and relatively less voids were observed for the PWHT joints.

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