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Research Paper

Mechanical Characterization of Duplex Stainless Steel Joined by Gas Tungsten-arc Welding (GTAW) and Shielded Metal-arc Welding (SMAW): A Comparative Study

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Abstract— Stainless steel is among most applicable materials in industries due to its good mechanical properties. The present study compared the mechanical properties of duplex stainless steel when joined together by using gas tungsten-arc welding and shielded metal-arc welding. Two duplex stainless steel were used in this work, whereby each sample was cut to form V-groove butt for welding purpose. After welding of the sample, lubricating oil is used as quencher for 30 minutes before undergoing for the analysis. A microstructure study was carried out by scanning electron microscopy (SEM). The average ferrite volume proportion attained in the GTAW weld zone is greater than that of SMAW. The tensile strength, hardness, and energy absorbed in impact test in the GTAW were all higher than that of SMAW. It is recommended that for the good transformation of the ferrite-austenite, the cooling rate should be high in each welding process.

Keywords— Hardness, Impact Test, Microstructure, Tensile Strength, Weld Zone

1. Introduction

Industries are always need of materials with good mechanical and chemical properties for many applications, stainless steel is only material with these properties compared to other carbon-based materials [1-4]. Some of the applications of stainless steels are manufacturing of steam boilers, heat exchangers and it also be used at cement and glass industries [5].

Duplex stainless steels (DSSs) are one of the classes of stainless steel with equal composition of ferrite and austenite. Some of its famous properties are high tensile strength, yield strength, fatigue strength, weldability and high corrosion resistance [6, 7], duplex stainless steels (DSSs) are economically excellent due to their low nickel content [8–10].

The equal composition of ferrite and austenite microstructure can be altered in welding process of DSSs depending on energy density, cooling rate and chemistry of the electrode [11]. Welding processes in DSSs can either be Gas Tungsten-arc Welding (GTAW) or Shielded Metal-arc Welding (SMAW) and the ratio of ferrite to austenite is strictly depends on heat input in these welding processes [12].

Gas Tungsten-arc Welding (GTAW) is a welding process which result in more ferritic microstructure in the fusion zone (FZ) and the heat affected zone (HAZ) due to high rate of cooling during the process [13, 14]. In the cooling process, the Delta (δ)-ferrite and the ferrite-austenite transformation will occur by atomic nitrogen diffusion in the microstructure [15]. For the DSSs to maintain its equal composition of ferrite and austenite, nitrogen addition to the shielding gas is used in industrial applications [16–18]. Shielded metal arc welding (SMAW) is a welding process that is simple with flexibility and portability in its process [6].

Many researches have been done on both gas tungsten arc welding (GTAW) and Shielded metal arc welding (SMAW) [19–22]. Kotecki *et al.*, [23] reported that for the better property of HAZ and autogenous weld, the nitrogen composition in the base metal should be at least 0.14%. They have also indicated that higher amount of ferrite in HAZ causes damage in the corrosion properties as well as mechanical properties.

Our research aimed to compare the mechanical characterizations of gas tungsten-arc welding (GTAW) and shielded metal-arc welding (SMAW) on duplex stainless steel.

Section 1 contains the introduction, Section 2 gives out the materials and method adopted, Section 3 describes the results obtained and discussion of the results and Section 4 drawn out the conclusions of the research.

2. Materials and Method

2.1 Materials
The major material used in this study was duplex stainless-steel grade 2205 rod of 20 mm diameter and 150 mm length. Two duplex stainless steel were purchased in steel market at Kano and the chemical composition of the steel was given in the table 1 after undergoing X-ray Fluorescent (XRF) analysis. Other materials used in this study were lubricating oil, acetone and wire electrodes.

2.2 Method
2.2.1 Procedures for Welding the Samples
Two duplex stainless steel were cut into two equal parts using milling machine at V-groove 45^o butt form for better welding processes. Each of these samples were welded together, one using shield metal-arc welding and another using gas tungsten-arc welding processes. After welding, grinding machine was used to remove all the welding spots from the samples and the quenched in air and engine oil for 30 minutes respectively in order to have better characterization results.

2.2.2 Experimental Procedures
Each sample undergo the following experimental procedures so as measure the mechanical properties of the samples after welding processes:

- **i)** ***Tensile Test:*** The samples were machined to have ASTM E8 standard for tensile test using milling machine and these tests were done using a Hounsfield Tensiometer with a capacity of 250 kN maximum load. The standard samples were mounted by their ends into the holding grips of the testing apparatus. The machine is designed to elongate the sample at a constant rate, and to measure the instantaneous applied load and the resulting elongations simultaneously.
- **ii)** ***Hardness Test:*** The samples undergo the hardness test using Rockwell hardness tester according to ASTM E18-79. The machine consists of steel ball indenter and maximum and minimum loads of 60 kg and 10 kg respectively. Before the test, the mating surfaces of the indenter, plunger rod and the test samples were thoroughly cleaned by removing the dirt, scratches and oil.
- **iii)** ***Impact Test:*** A Charpy "V" notch impact testing machine was used for impact testing in accordance with ASTM A370 and ASTM E23.
- **iv)** ***Microstructure Analysis:*** The microstructural evolution of the welding zone of both samples were investigated using a JEOL JSM-7600F scanning electronic microscope (SEM). Before investigation, the samples were polished and then etched using glycerol solution. The areas image processing software from Micro-vision Instruments was used to measure the ferrite volume proportions.

3. Results and Discussion

3.1 Chemical Compositions of the Samples
Table 1 present the chemical compositions of the sample using X-ray florescence test. These results show that the sample is a duplex stainless steel since the percentage composition of Iron (Fe), Chromium (Cr), Nickle (Ni) and Manganese (Mn) were very higher compared to other elements present. This result concord with the chemical composition of Duplex Stainless Steel (DSS) grade as stated by [24].

3.2 Tensile Test Results
Tables 2 shows the recorded tensile tests results of the samples. The tensile strength values of Gas Tungsten-arc welding (GTAW) was found higher than the Shielded Metal-arc welding (SMAW). It was also found that the ductility of welding zone (WZ) is lower as compared to base material, whereas the tensile strength of these zones was greater than the base metal for both samples. It was also observed that when the samples were treated with lubricating oil as a quencher after welding, the ductility of the samples increased which makes the sample's deformations to increase, these results agreed with the results obtained by [25-29].

3.3 Hardness Test Result
The hardness at the weld zone of the sample A (GTAW) (average 235 HV) shows little variation compared to that of the sample B (SMAW) (229 HV). The average hardness value in the (GTAW) weld zone (WZ) (235 HV) is roughly equal to that of the (SMAW) weld zone (WZ) (229 HV) weld. The highest value of hardness (238 HV) is located at the (GTAW) weld zone at the nearest point of base material, as shown in Table 3. The standard deviations are less than 4 HV, which indicates good hardness homogeneities in the joints and it is in agreement with previous observations [30, 31].

3.4 Impact Test Result
Figure 1 shows the impact test results for the weld zone of the samples (GTAW and SMAW). The average energy absorbed in the weld zone in the case of the GTAW (259 J) is slightly higher than that of the SMAW (256 J). The standard deviations are less than 8 J. The variation in the impact energy of the samples agrees with results found by other researchers [32-37].

3.5 Microstructural Analysis Result
Figures 2 and 3 present the scanning electron microscopy (SEM) of the base metal and weldments (GTAW and SMAW) respectively. The microstructure of the base metal shows a fine grain boundary and an indication of a better blending of the material and the alloying elements (Figure 2).

Figure 3 indicates the existence of delta ferrite (δ) and austenite (γ) phases for both samples (GTAW and SMAW). In figure 3(a), the solidification of molten metal results in the formation of ferrite matrix immediately after solidification, and then the nucleation of austenite phases starts upon a further cooling cycle. Whereas in figure 3(b), SMAW associated with low heat input is characterized by a relatively rapid cooling rate in comparison to that of the GTAW [38]. In the GTAW weld zone, a slow cooling rate allows for more transformation of ferrite to different types of austenite. However, the SMAW sample executed using double passes receives more heat transferred to the joint and, consequently, more formation of austenite is expected, as well as higher ferrite volume proportions that influence the mechanical properties and reinforce the strength and hardness properties [39].

Table 1: Chemical Compositions of the Sample

Elements	C	Mn	Si	P	S	Cr	Ni	Mo	N	Cu	Co	Fe	V
% of wt	0.023	1.42	0.39	0.03	0.025	20.93	6.82	2.04	0.19	0.27	0.14	68.5	0.12

Table 2: Tensile Test for the Samples

Load (kN)	Sample A (GTAW)		Sample B (SMAW)	
	Tensile Strength (MN/m^2)	Deformation (mm)	Tensile Strength (MN/m^2)	Deformation (mm)
10	178	3.11	159	2.92
15	192	3.69	174	3.04
20	217	4.38	197	3.23
25	330	5.02	216	3.38
30	363	5.65	238	3.51

Table 3: Hardness Test of the Samples

Samples	Testing Zone	Maximum HV	Minimum HV	Average HV	Standard Deviation (SD)
Sample A (GTAW)	WZ	238	231	235	2.73
Sample B (SMAW)	WZ	233	225	229	2.98

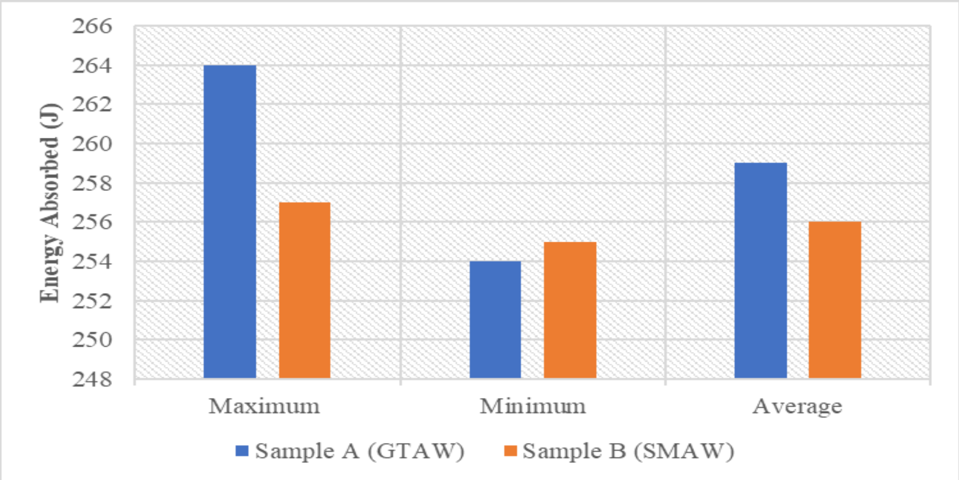

Figure 1: Impact Tests for the Samples

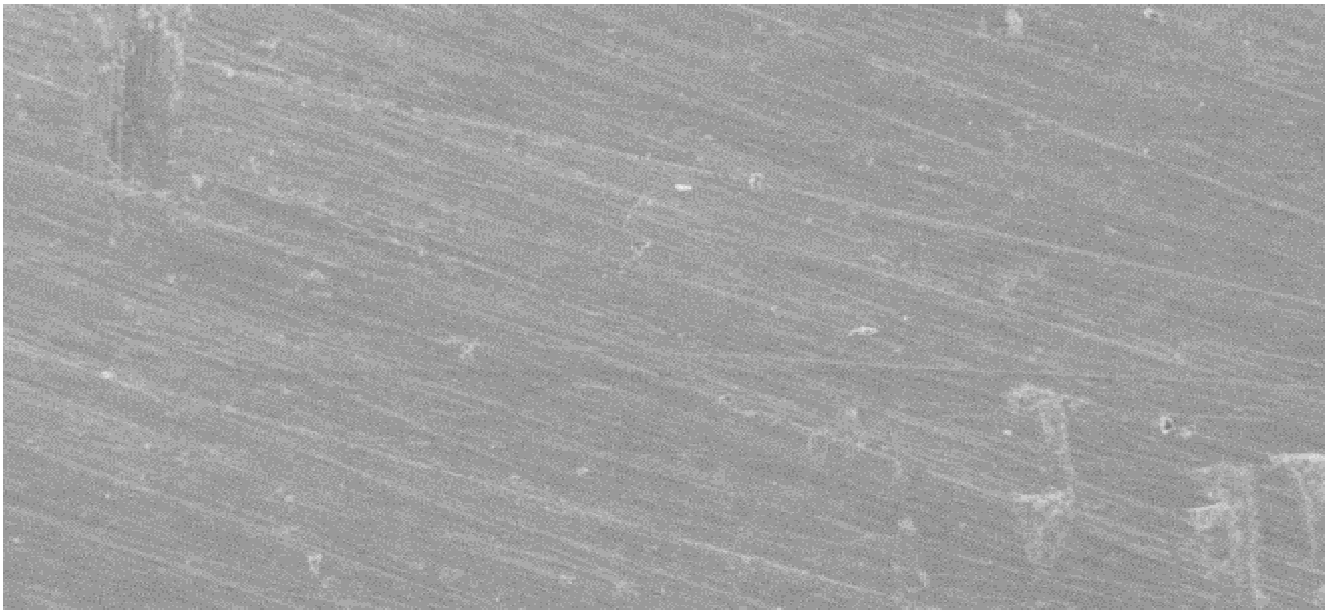

Figure 2: Scanning Electron Microscopy of the Base Metal

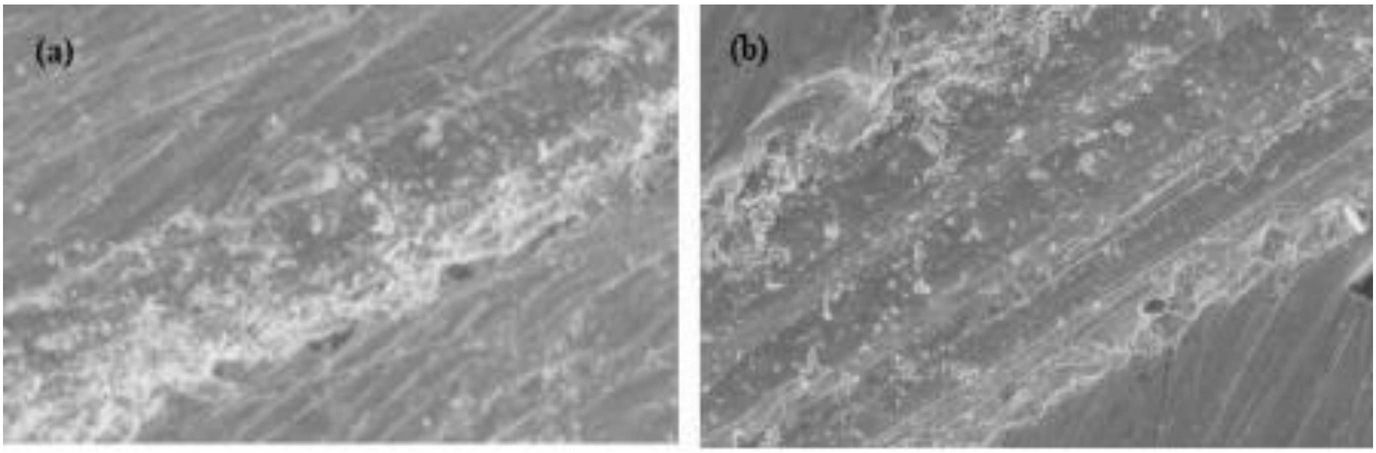

Figure 3: Scanning Electron Microscopy of the (a) GTAW and (b) SMAW

4. Conclusion

In this study, a comparison between GTAW and SMAW of Duplex Stainless Steel (DSS) was conducted to investigate the mechanical behaviors of each welding processes on DSS. And finally, the following remarkable conclusions were drawn out:

I. The tensile strength value of the GTAW is higher than that of SMAW by 125 MN/m^2 which makes it to elongated more.
II. The hardness measurements at the weld zones shows close results for both GTAW and SMAW, with average values of 235 HV and 229 HV respectively.
III. The average energy absorbed during the impact test reaches 259 J for the GTAW compared to 256 J for the TIG weld.
IV. SEM analysis shows that the average ferrite volume proportion in the GTAW weld zone is greater than that of the SMAW weld zone. And rate of cooling plays vital role in transforming ferrite and austenite after both welding processes.

Conflict of Interest
Authors declare that there no any conflict of interest.

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Authors' Contributions
Jamilu Ya'u Muhammad: Brought the Idea and Planned the method.
Usman Shitu Adam and Abubakar Abdulkarim: Conducted the literature review and found the research gap.
Anas Abdullahi Muhammad and Haruna Abba Usman: Performed the experiments and analyse the results.
Jamilu Ya'u Muhammad: Wrote the manuscript.
Jamilu Ya'u Muhammad and Usman Shitu Adam: Re-examined the spelling and grammar of the article.

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