

## **Effects of shield metal arc welding techniques on the mechanical properties of duplex stainless steel**

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### **ABSTRACT**

*The study has compared the effects of shielded metal arc welding process on some mechanical properties of duplex stainless steel. The samples were welded and given post weld heat treatment which in lubricating and neem oils. After the analyses, it was established that duplex stainless steel can be weld successfully using shielded metal arc. Both engine oil and neem oil can serve as quenching medium for post welding heat treatment of duplex stainless steel. It was also noted that the heat treatment improved some mechanical properties of the alloy after welding, stress relief heat treatment gives better strength, compared to those that were quenched in lubricating oil and neem oil but the reverse is the case in terms of toughness.*

**Key words:** Duplex Stainless Steel, welding, mechanical properties, and heat treatment.

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### **INTRODUCTION**

Duplex stainless steels are two phase alloys based on the iron-chromium- nickel system. These alloys usually comprise of equal proportions of the body centered cubic (BCC) ferrite and face centered cubic (FCC) austenite phase in their microstructure and generally have low carbon content as well as additions of molybdenum, nitrogen, tungsten, and copper. Typical chromium contents range from 20% to 30% by weight, nickel ranges from 5% to 10% by weight. [1]

Duplex stainless steels solidify as 100% ferrite, but about half of the ferrite transforms to austenite during cooling through temperatures above 1040°C. This behavior is accomplished by increasing Cr and decreasing Ni content as compared to the austenitic grades. [1]

Duplex stainless steels are increasingly used as structural materials in building and architecture because of their exceptional mechanical properties. Their room temperature yield strength in the solution annealed condition is more than twice that of standard austenitic stainless steels not alloyed with nitrogen. Over the last few years, they have started playing an increasingly important role in the construction of bridges, wherever specific environmental conditions combine with the need for high load-bearing capability. Duplex stainless steels are mostly selected because of their combination of high strength and corrosion resistance. Their full potential is used in locations where the material comes into contact with salt water, or where high concentrations of chlorides are present in the ambient air or where de-icing salts are of a concern.

Other researchers have carried out different studies on different grades of duplex stainless steel. Labanowski and Krzysztofowicz[22] studied the influence of welding thermal cycles on corrosion resistance of duplex stainless steel. The susceptibility of heat affected zone (HAZ) of duplex stainless steel weldments to stress corrosion cracking was investigated. Corrosion tests were performed with the use of slow strain rate test technique in boiling  $MgCl_2$  corrosive environment. Nowacki, and Rybicki [21], worked on the corrosion resistance of SAW duplex stainless steel Joints welded with high heat input. Their aim was to find out if the welding heat input exceeding the recommended value (2.5kJ/mm) will have any negative impact on the strength properties of the executed welded joints as well as description of influence of the heat input of submerged arc welding of duplex stainless steel UNS S31803 on welded joint microstructure, particularly average value of ferrite volume fraction, mechanical properties and corrosion resistance. The exceeded heat inputs used were 3.0kJ/mm,3.5kJ/MM,4.0kJ/mm, 4.5kJ/mm and 5.0kJ/mm. Their findings were based on the performed tests and their conclusion is that according to DNV Rules the welding heat input exceeding the recommended values has no negative impact on the strength properties and corrosion resistance of the executed joints. It also showed that submerged arc welding of duplex stainless steel with heat input from 2.5kJ/mm up to 5.0kJ/mm has no negative influence on the properties of the joints.

With all their afore-mentioned favorable properties, they still fail mostly at the weld points which can be as a result of the welding process, process variables used and the welding environmental contamination. Hence, this research work is targeted to verify the effect of welding process and heat treatment on the mechanical properties of duplex stainless steels. The mechanical properties that are to be investigated are; tensile strength, impact strength and hardness, as we already know that the durability of a welded structure directly depends on the resulting mechanical properties after welding. This work will also look at the effect of stress relief, quenching and hardening heat treatment methods on the mechanical properties of duplex stainless steel.

## MATERIALS AND METHODS

### MATERIALS.

Duplex stainless steel was the major material used for this research work which was sourced locally at building materials market Jos, Nigeria, while its chemical composition (see table 2) was determined at National Metallurgical Center Jos using the XFR test. Other materials that were used are: lubricating oil 85W90, neem oil, electrode E308L-16 and Nertalic 50 wire electrode which has higher nickel content than the base metal, and etchant.

### METHODOLOGY

#### 2.2.1 PRE-WELDING SAMPLE PREPARATION.

The duplex stainless steel of 10mm diameter was cut into equal pieces (samples) of length 100.2mm; the samples from welding were further cut into two equal parts each chamfered to produce 30° half groove angle on one side with the aid of a milling machine, leaving a root face of 2mm each. The butt joint welding method was implemented as illustrated in fig. 1

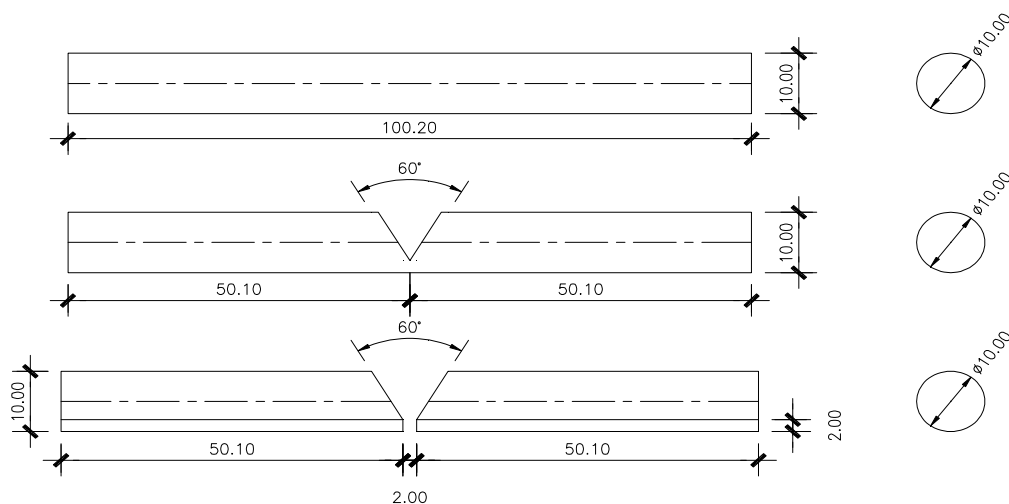


Fig. 1 joint preparation for V-groove welding [1]

Samples were cleaned of dirt and oil and a grinding machine was used to grind the surfaces of samples prior to welding in order to have smooth and uniform surfaces according to Dauda [23].

### 2.2.2 Welding procedure.

The shield metal arc welding processes were used to weld over one hundred samples. They were laid on an angle bar with their beveled edges parallel and facing each other, leaving a root face and root opening of 2mm with an included angle of 60° then an arc was struck. The first bead was laid down at the root of the joint to ensure equal fusion in both rods, before the second bead was laid the first bead was allow to cool down to about 150°C. Any slag noticed was removed before an additional bead was laid. The welding parameters are shown in table 1. The number of passes used was two on each of the sample; the second pass was to fill the groove and to produce a crown.

Both welded samples were cleaned of dirt and oil. The grinding machine was used to grind the surfaces of samples after welding in order to have smooth and uniform surfaces.

Table 1: welding parameter

Electrode type	Electrode diameter	polarity	Current	Voltage
E308L-16	3.2mm	DCEP	60A	400V

### 2.2.3. Post-Welding Thermal Treatment.

Two post thermal heat treatments were adopted viz:

- i) Stress relieve annealing
- ii)Hardening by quenching.

#### 2.3.3.1 Stress-Relieve annealing

This treatment was done by heating the samples from ambient temperature up to 600°C, and then soaked at this temperature for 30 minutes. After which they were removed from the furnace and air cooled back to ambient temperature.

#### 2.2.3.2 Quenching and tempering.

Samples, that had been previously stress relieved were again heated to the temperature of 900°C and remained at this temperature for 30 minutes, they were then quickly removed and plunged into a can of engine oil or Neem oil at room temperature. The quenched samples were tempered slowly by reheating them to 300°C and allowed to soak for 30 minutes, after which they were removed from the furnace and allowed to cool to room temperature in air.

### 2.2.4.Mechanical test procedure

#### 2.2.4.1. Tensile strength test.

Tensile strength indicates the ability of a composite material to withstand forces that pull it apart as well as the capability of the material to stretch prior to failure. Tensile tests were carried out using a Hounsfield Tensiometer, with maximum load of 250KN. 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 using an extensometer. Samples were prepared as shown in fig. 2 according to BS18 standard.

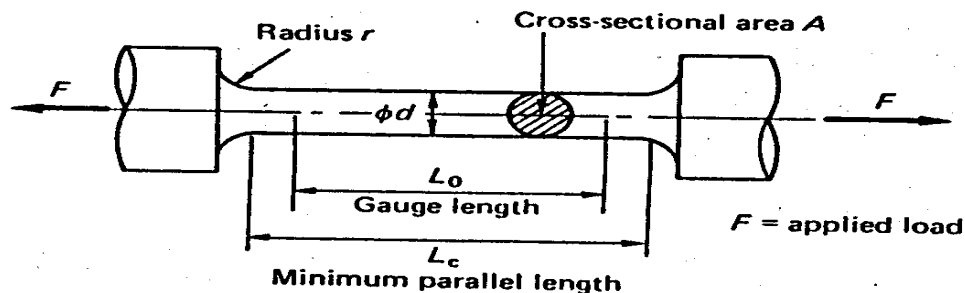


Fig. 2 Standard sample for tensile test

Proportional sample (BS18) are given by the relationship

$$L_0 = 5.56\sqrt{A}. \text{ Since } A = \pi d^2/4, \text{ then } \sqrt{A} = d\sqrt{\pi}/2 = 0.88d. \text{ Thus } L_0 = 5.65 \times 0.88d \approx 5d \text{ [24]}$$

#### 2.2.4.2. Charpy Impact Test

Charpy Impact tests were conducted in accordance with ASTM A370 “Standard Methods and Definitions for Mechanical Testing of Steel Products”, and ASTM E23, “Standard Method for Notched Bar Impact Testing of Metallic Materials”. The Charpy V-notch samples, used in this evaluation, were machined according to the specification in ASTM E23 as shown in figure below.

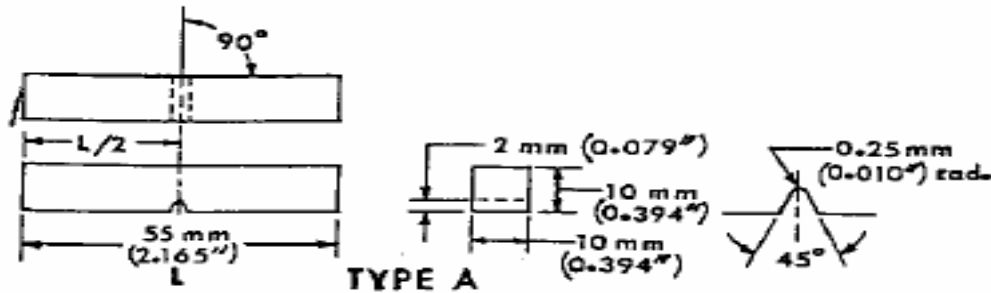


Fig 3 standard sample for charpy impact test

#### 2.2.4.3. Hardness Test.

The hardness values of the samples were determined according to the provisions in ASTM E18-79 using the Rockwell hardness tester with a 1.56mm steel ball indenter, minor load of 10Kg, and major load of 150Kg and hardness value of 56.4HRC as a standard block. Before the test, the mating surface of the indenter, plunger rod and the test samples were thoroughly cleaned by removing the dirt, scratches and oil.

### 2.2.5. Microstructural Analysis

#### 2.2.5.1. Surface preparation

The surfaces of samples for metallographic examination were ground and polished. The grinding process was performed using silicon carbide papers of varying grits starting with the coarsest grit size of 120. Subsequently grit size of 240, 320, 400 and 600 were used. The grinding was done wet with the aid of a lubricant. The lubricant were applied intermittently to prevent overheating of the sample and to provide a rinsing action to flush away the particles being removed from the surface.

Polishing was carried out using a silicon abrasive in form of a very fine powder (1000 grit). The powder was applied to a wet polishing wheel rotating in the clockwise direction. The samples were polished by rotating them in the direction opposite to the direction of rotation of the wheel. This resulted into a shiny, scratch free surface ready for etching and microscopy.

#### 2.2.5.2. Etching

Etching was done to expose and make visible the grains of the samples structural characteristics under the different conditions of heat treatment, as received and as welded. The etching was done using 10cc of HCl, 3cc HNO<sub>3</sub> and 100cc distilled water.

#### 2.2.5.3. Scanning Electron Microscope Analysis

Samples after preparation (grinding, polishing and Etching) were attached to multi-stub sample holder with the use of double sided conductive aluminum tape, after which, they were mounted onto the sample chamber, while the column was put at vacuum. After reaching the vacuum target, the electron gun was switched on which passed an accelerating voltage of 20kV and probe current of 227pA through the samples at a working distance of 7.0mm and 6.0mm.

Micrographs of the Samples were taken at two different positions viz; the fusion Zone (FZ) and the heat affected Zone (HAZ). The scanning electron microscope (SEM) EVO MA-10 manufactured by Carl, was used for the analysis at Sheda Science and Technology Complex, Abuja Nigeria.

### 2.3. Samples Labeling

The samples after preparation were labeled as follows before testing them; this is also referred to in the discussion of results.

**Table 2: Samples Labeling**

Sample B	Sample that was welded with SMAW method
Sample B <sub>1</sub>	Sample that was welded with SMAW and Quenched in NEEM oil (heat treated)
Sample B <sub>2</sub>	Sample was welded with SMAW and Quenched in Engine oil(heat treated)
Sample B <sub>3</sub>	Sample that was welded with SMAW and undergo Stress Relief heat treatment
Sample C	As received or Control

## RESULTS AND DISCUSSION

### 3.1. Chemical Composition of Research Material

X-ray florescence test was used to determine the actual chemical composition of the research material. Table below shows the results of XRF test carried out on the material as received from the manufacturing company.

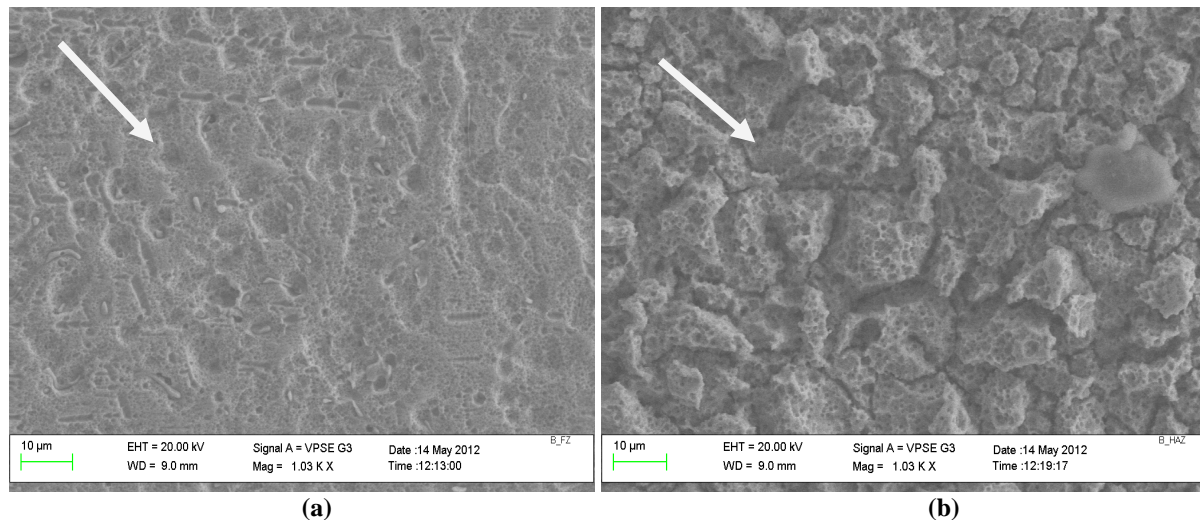
**Table 3: Research Material Chemical Composition**

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al
%by wt	0.02-0.05	0.238	1.57	0.036	0.032	>9.96	>6.60	0.342	0.011
Element	V	W	Pb	B	Sn	Zn	As	Bi	Ca
%by wt	0.106	0.036	>0.003	<0.0005	0.012	0.029	<0.001	0.009	0.0015
Element	Cu	Co	Ti	Nb	Ce	Zr	La	Fe	
%by wt	0.302	0.132	0.011	0.046	0.031	0.0015	0.0043	69.6	

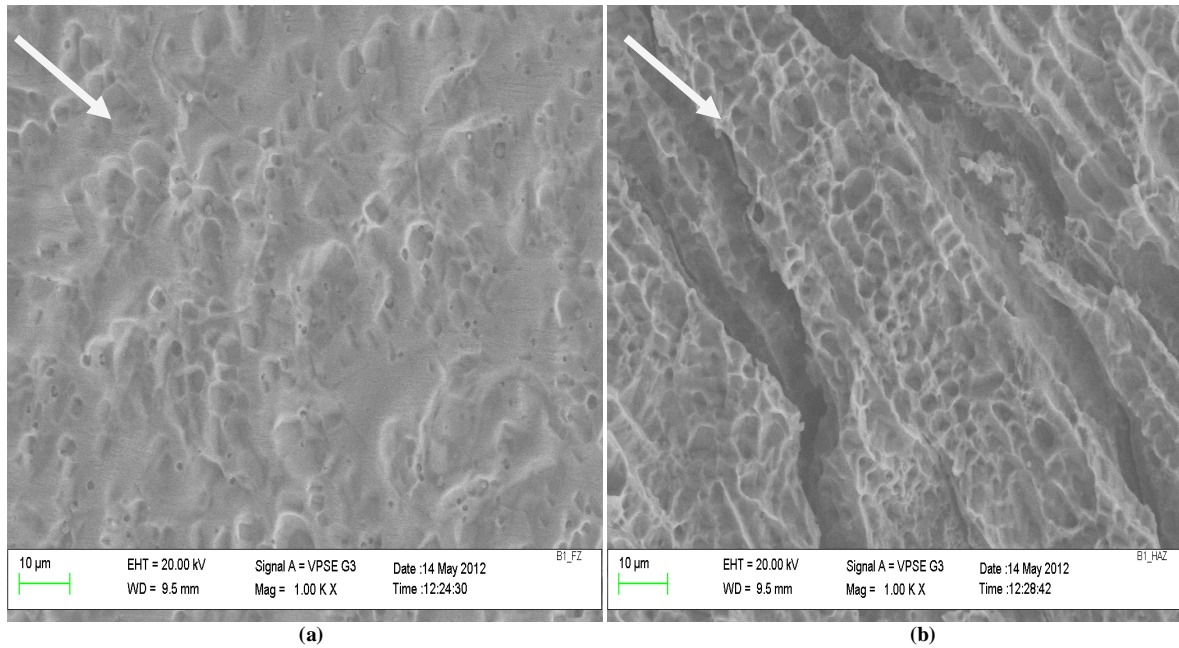
The results of the research material chemical composition as shown on table 3, prove that the material is actually a duplex stainless steel. This is due to the presence of high percentage composition of iron (Fe) as the base material, chromium (Cr), Nickle (Ni) and manganese (Mn) as major alloying elements, low percentage of Carbon (C) and other trace elements. This is in close agreement with the chemical composition of Duplex stainless steel grade ([www.azom.com](http://www.azom.com))

### 3.2. Scanning Electron Micrograph of the Samples

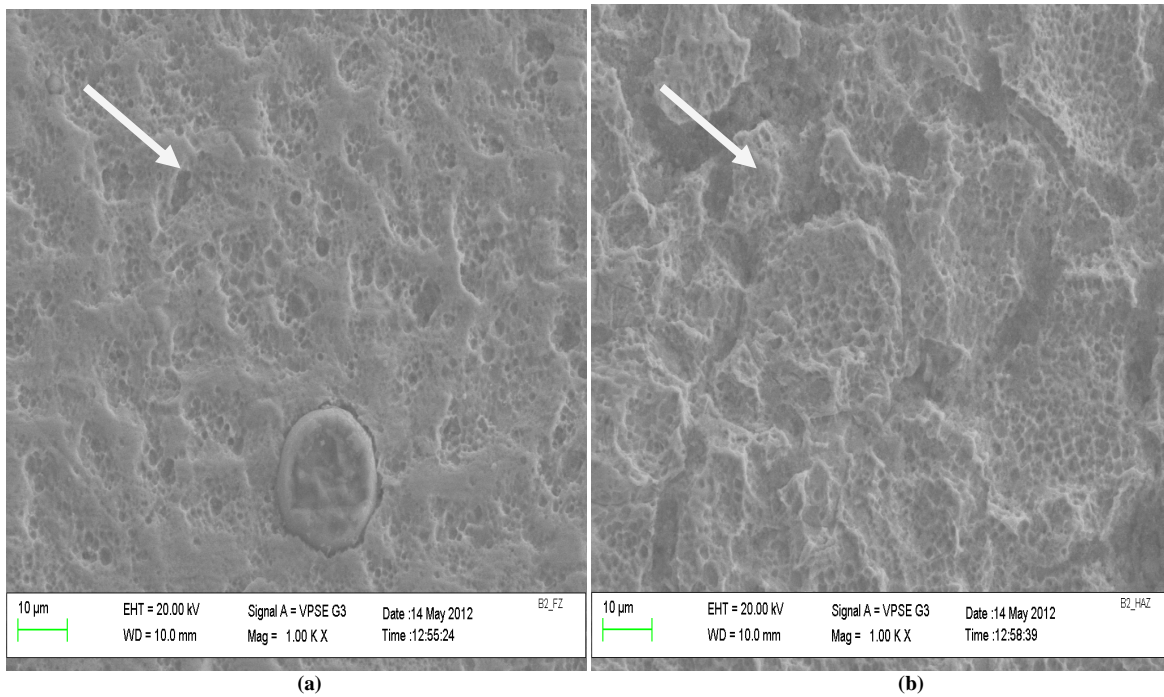
The micrographs of the samples, as taken by scanning electron microscope, are presented in plates 1-5;



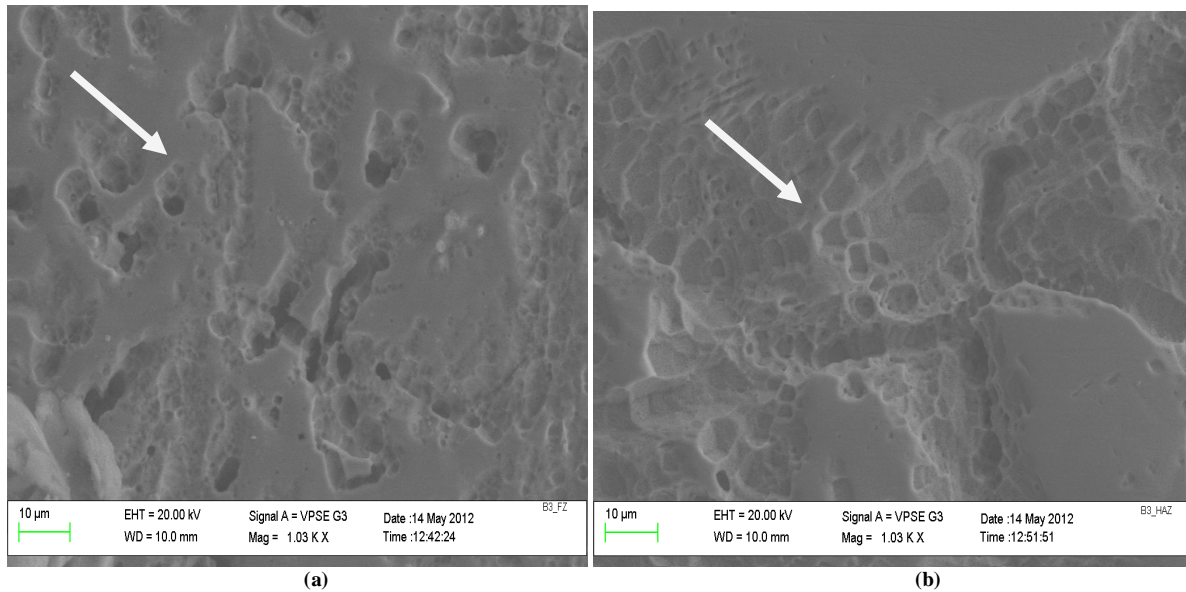
**Fig.4 (a) Micrograph of the Fusion Zone for Sample B (b) Micrograph of the Heat Affected Zone for Sample B**



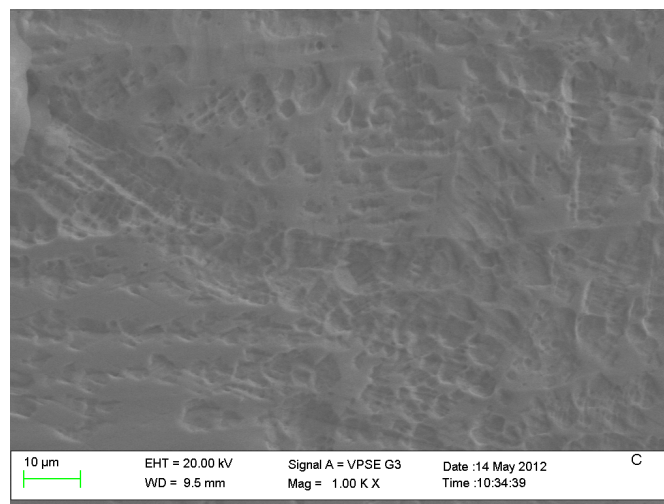
**Fig. 5: (a) Micrograph of the Fusion Zone for Sample B1 (b) Micrograph of the Heat Affected Zone for Sample B1**



**Fig. 6: (a) Micrograph of the Fusion Zone for Sample B2 (b) Micrograph of the Heat Affected Zone for Sample B2**



**Fig. 7: (a) Micrograph of the Fusion Zone for Sample B3 (b) Micrograph of the Heat Affected Zone for Sample B3**



**Fig. 8: Micrograph for Sample C**

SEM was used to study the morphology of all the welded and as received samples. Fig. 8 shows the SEM micrograph of as received sample. Fig. 4-7 shows the SEM micrograph of the Welded and heat treated samples,

Morphological analysis using SEM clearly shows difference in the morphology of the heat affected zone and the fusion zone, showing the grains of the heat affected zone to be coarser than that of the fusion zone (see fig. 4a and 4b). The microstructure clearly shows that there will be great influence of this change in morphology to the properties of the welded samples.

The microstructure of the as received sample shows a fine grain boundary and an indication of a better blending of the parent material and the alloying elements (see fig. 8). From the SEM micrograph, there exist a great variation in morphology of the fusion zone and heat affected zone for same sample. This is due to the difference in the cooling rate of the two zones. (Compare Plate 4a & b, 5a & b etc).

Finally, the grains sizes of the heat affected zone for samples B2 are shown to be finer as compared to other samples in the group. This is expected to give them better properties in their group. The basic information obtained from the

SEM micrograph is in agreement with observations raised by other researchers [4-6, 27], while the relationship between the microstructure and the properties of the developed composite agrees with conclusions of other researchers [7-10, 27]

### 3.3. Mechanical Properties of the Samples

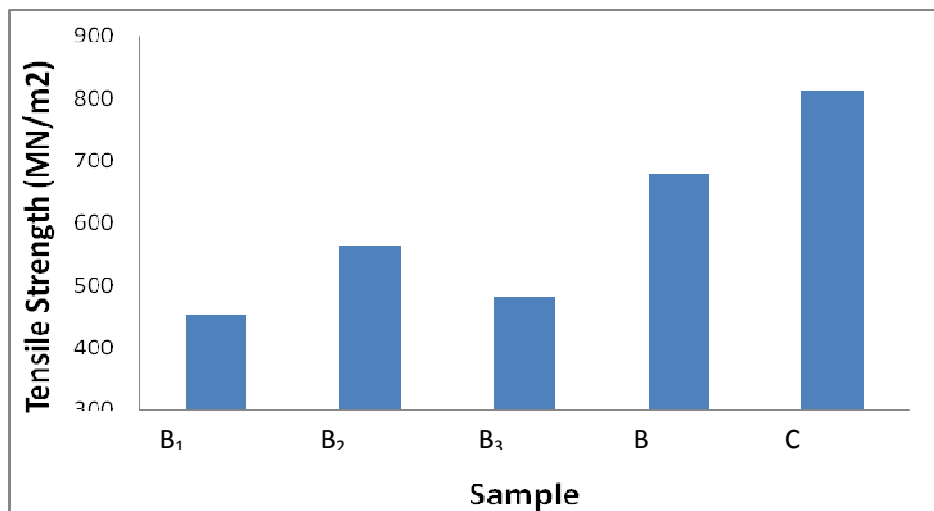
#### 3.3.1. Tensile Properties of the samples

The results of the tensile tests carried out on the samples are recorded in table 4 and fig 4 and 7.

**Table 4: The Tensile Tests Results for Samples**

Sample	Area $A_0 = 7.85 \times 10^{-5}$		Gauge Length $l_0 = 50\text{mm}$	
	Maximum Load (KN)	Tensile Strength (MN/m <sup>2</sup> )	Elongation (mm)	Strain (%)
B	66.6	848	19.65	39.3
B1	44.4	566	31.75	45.36
B2	47.2	601	34.80	69.6
B3	52.2	665	18.10	36.2
C	79.6	1010	35.00	70

The comparison of the tensile strength of samples with the as received one is shown in Figure 8.



**Fig. 8: Tensile Strength for Group B as compared to Control C**

The comparison of the percentage elongation (Strain) of the samples with the as received one is shown in Figure 9.

The results of the tensile test carried out on the samples, as recorded in the table 3 above shows that, carrying out of post welding treatment increases the ductility of the samples, thereby making the materials to be tougher and decrease their tensile strength. The results also show that, treating the samples in engine oil after welding highly increases their ductility, making them to have highest elongation in their group. This can be associated to the fine grain size as revealed by the micrograph, compared to that of other samples in the group (see Plate 3a and 3b)

The results also shows that samples that underwent stress relief treatment after welding had higher tensile strength, next to those treated in engine oil, while those treated in neem oil had the lowest in their group. The results obtained from the tensile test of the material are in agreement with those obtained by other researchers [11-15, 28-30]



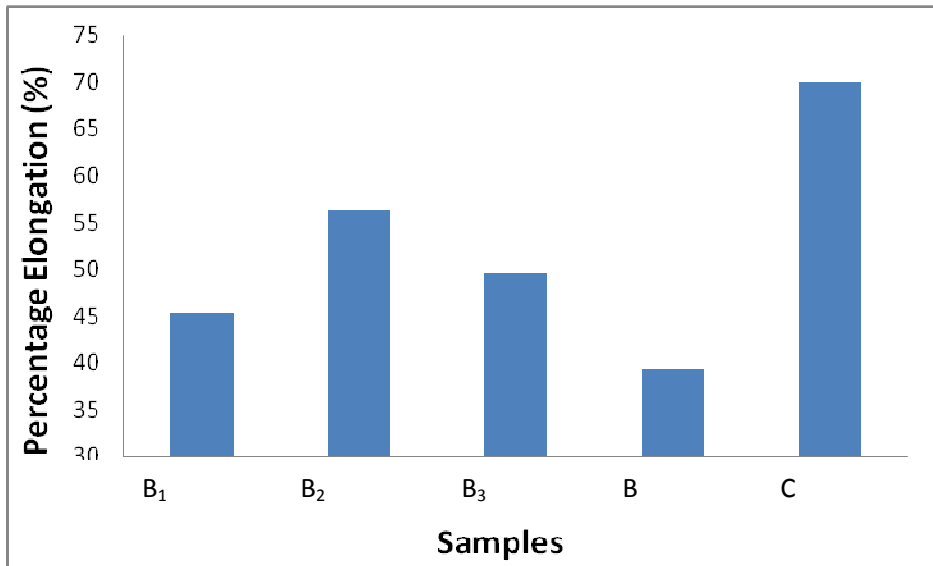


Fig. 9: Percentage Elongation for Group B as compared to Control

**3.3.2. Impact Properties of the samples**

The results of the impact test carried out on the samples are summarized in table 4.

Table 4: The Impact Tests Results for Samples

Sample	Average Energy (ft pound)	Average Energy Joules (J)
B	109.66	148.70
B <sub>1</sub>	110.81	150.26
B <sub>2</sub>	115.06	156.02
B <sub>3</sub>	109.99	149.14
C	120.00	162.70

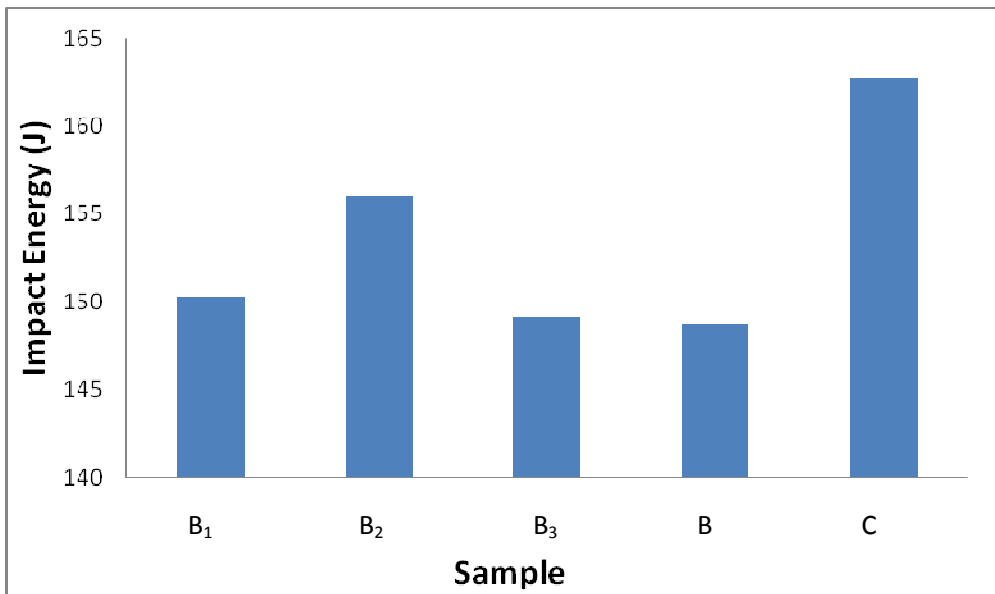


Fig. 10: Impact Energy for Group B as compared to Control

The comparison of the impact energy for group B samples with the as received one is shown in Figure 10.

The results of the impact test carried out on the samples as recorded in Table 4 and as shown in fig.10 shows the impact energy absorbed by B2 samples that were heat treated in lubricating oil are close to that of the as received sample which absorb 162.70J before it fails next are those that were heat treated in neem oil.

Also, the results show that samples that are welded without heat treatment absorb less impact energy than those welded and heat treated. The variation in the impact test results is in agreement with variation of their elongation at failure during tensile test and the hardness test carryout. The result obtained from this test is in agreement with those obtained by these researchers, [2, 25-26, 31].

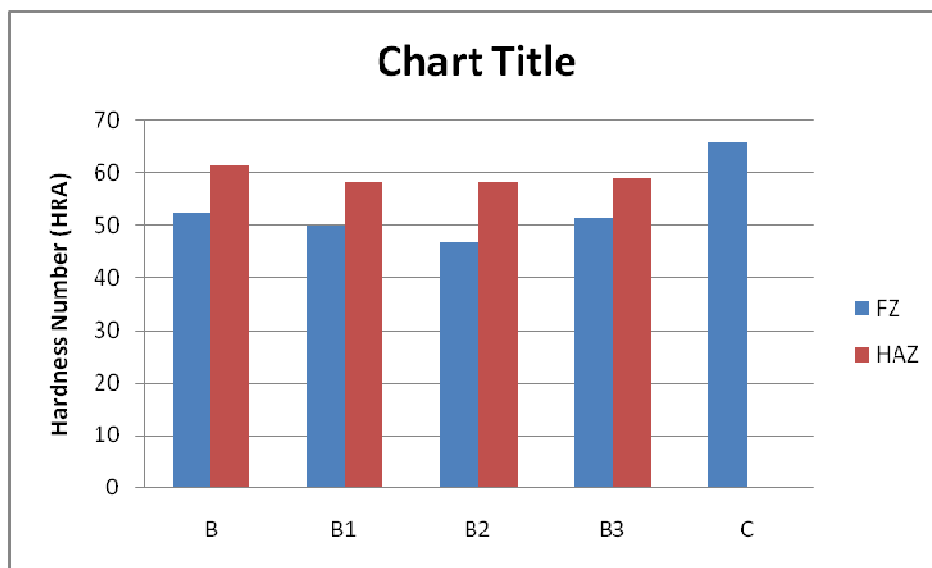
**3.3.3.Hardness Number for the samples**

The results of the hardness test carried out on the samples are summarized in table 5.

**Table 5: Hardness Number for the samples**

Sample	Hardness value (HRA)	
	FZ	HAZ
B	52.3	61.3
B1	50	58.2
B2	46.9	58.3
B3	51.3	58.9
C	65.8	

The comparison of the hardness number for group B samples with the as received one is shown in Figure 11.



**Fig. 11: Hardness Number for Group B as compared to Control C**

The results obtained from the hardness test show that the hardness numbers of the treated samples differ from those obtained from samples that are not treated, depending on the kind of treatment carried out on them (see Fig. 11), those that were heat treated oil are softer compared to those that were not heat treated. The hardness number of samples that are treated in lubricating oil is lower as compared to other treated samples in the group. This is expected since the softer a material the higher its ductility thus its toughness. The result also implies that treating the welded samples in lubricating oil increases their ductility and decreases their hardness.

The variation in the hardness number of the samples also agrees with observations made by other researcher [16-19].

### CONCLUSION

From the analyses carried out on the samples and the discussions, following conclusions were drawn:

- [1] The tensile test, impact test and the hardness test shows that welding has a negative effect on the mechanical properties of this alloy while the heat treatment improved some of the mechanical properties like ductility and impact energy.
- [2] The duplex stainless steel can be welded successfully using shielded metal arc depending on the application or service life which the material will be subjected to.
- [3] Both engine oil and neem oil can serve as quenching medium for post weld treatment of duplex stainless steel. But engine oil gives better results compared to neem oil in terms of toughness, elongation, and tensile strength.
- [4] Tempering after quenching improved the mechanical properties of the alloy.

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