Comparative Analysis of Neem and Lubricating (85W90) Oils as quenchants on the Mechanical Properties of Shield Metal Arc welded Duplex Stainless Steel.

T. K. Ibrahim, I.U. Leva, I. Iliyasu and D.S. Yawas.

Abstract-The study has compared the effects of neem and lubricating (85w90) oils as quenchants on some mechanical properties of shield metal arc welded duplex stainless steel. The results of the studies show that quenching in neem and lubricating (85w90) oils improved some mechanical properties of the alloy after welding like toughness and ductility. The research also shows that the stress relief heat treatment gives better strength compared to those that were quenched in lubricating oil (85W90) and neem oil but the reverse is the case in terms of toughness and ductility. Finally the results indicated that quenching in lubricating oil gives better mechanical properties compare to the neem oil.

Key Words: -, Ductility, Duplex stainless steels, Hardness Number, heat treatment, Impact Energy, Neem oil, Quenchants, , and Tensile Strength, and Ductility Toughness,

1 INTRODUCTION

Ever since the discovery of stainless steels in 1913, several groups of these steels have emerged. Among these groups are martensitic, ferritic and austenitic stainless steels (ASS). This classification is based on their chemical composition, metallurgical structure and mechanical properties [1]. However, the search for improved material to meet the challenges of ever dynamic technological world has led to recent discovery of duplex stainless steel (DSS) [1]. The corrosion behavior of these steels in a particular medium is determined by their passive nature [2,3], alloy composition [4,5] and precipitation morphology [6]. The intactness of passive film on these metals is dependent on its stability in the medium of exposure.

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. [7]

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. [7]

Duplex stainless steels are ferromagnetic, a property that can easily differentiate them from common austenitic grades of stainless steels. Generally the ratio of ferrite to austenite in duplex stainless steels depends mainly on the chemical composition. The presence of ferrite with austenite provides better intergranular corrosion (IGC) resistance, other advantages offered by these alloys over convection 300 series stainless steels are strength, chloride stress-corrosion cracking resistance, and pitting corrosion resistance. [7]

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.

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 to compare the effect of two quenchant on the mechanical properties of welded 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.

2. MATERIAL AND METHOD

2.1 MATERIALS.

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

2.2 METHODOLOGY

2.2.1 PRE-WELDING SAMPLE PREPARATION.

The duplex stainless steel rod was cut into equal pieces (samples) of length 100.2mm; they were further cut into two equal parts. All the samples for welding were prepared as shown in fig.1 below

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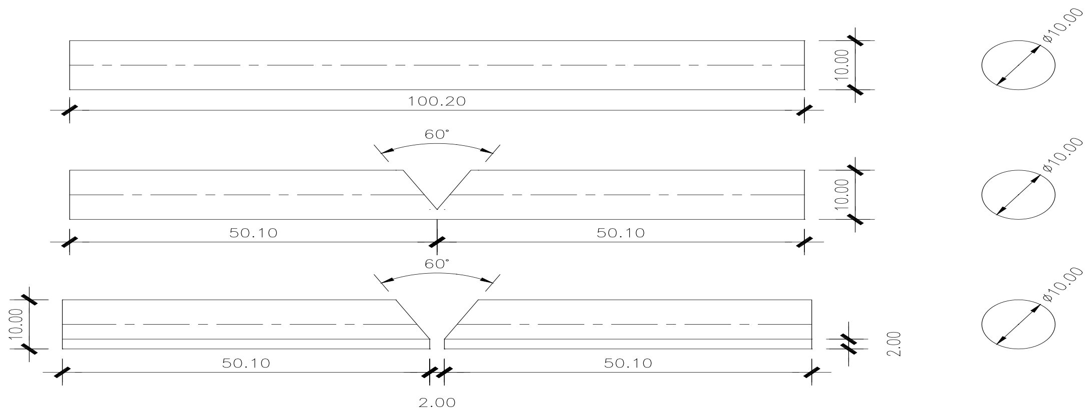

Fig 1 joint preparation for V-groove welding (7)

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].

2.2.1.1 Welding Procedure

The shield metal arc welding process was used to weld over one hundred samples respectively. 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 grove and to produce a crown.

Table 1: welding parameter

Welding process	Electrode type	Electrode diameter	Curren t	Voltag e	Polarity
SMAW	E308L-16	3.2mm	60A	400V	DCEP

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.

2.2.2 Post-Welding Thermal Treatment.

Two post thermal heat treatments were adopted viz:

i. Stress relieve annealing
ii. Hardening by quenching.

2.2.2.1Stress-Relieve Annealing

This treatment was done by heating the samples from ambient temperature up to 600°C, and then soaked at

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this temperature for 30 minutes. After which they were removed from the furnace and air cooled back to ambient temperature.

2.2.2.2 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.

2.2.3 Mechanical test procedure

2.2.3.1 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 the fig 2 below according to BS18 standard.

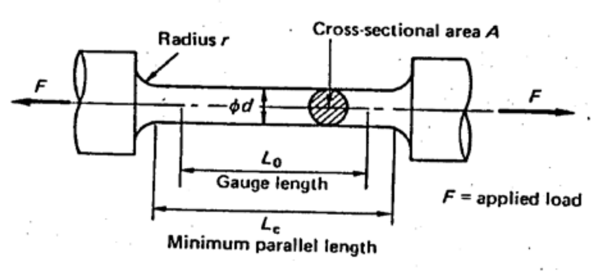

Fig 2 Standard sample for tensile test [29]

Proportional sample (BS18) are given by the relationship
LO=5.56√A. Since A=πd2/4, then √A=d√π/2=0.88d. Thus LO=5.65X0.88d≈5d [29]

2.2.3.2 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.

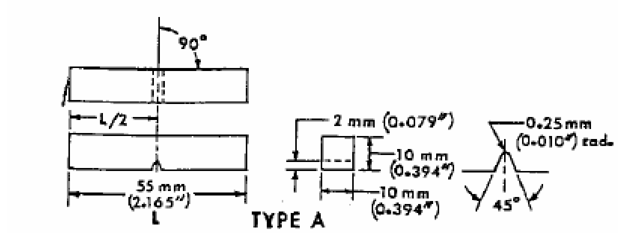

Fig 3 standard sample for charpy impact test

2.2.3.3 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 harness 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.

2.2.4 Microstructural Analysis

2.2.4.1 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.

2.2.4.2 Etching

Etching was done to expose and make visible the grains of the samples structural characteristics of the sample under the different conditions of heat treatment, as received and as welded. The etching was done using 10cc of HCl, 3cc HNO_3 and 100cc distilled water.

Scanning Electron Microscope Analysis

Samples after preparation 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.

2.2.5 Samples Labeling

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

3 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.

The results of the research material chemical composition as shown on table 4.1, 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) 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)

3.2 Scanning Electron Micrograph of the Samples

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

TABLE 2: SAMPLES LABELING

Sample B	Sample that was welded without heat treatment
Sample B1	Sample that was welded and Quenched in NEEM oil (heat treated)
Sample B2	Sample that was welded and Quenched in Engine oil (heat treated)
Sample B3	Sample that was welded and undergo Stress Relief heat treatment
Sample C	As received

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	

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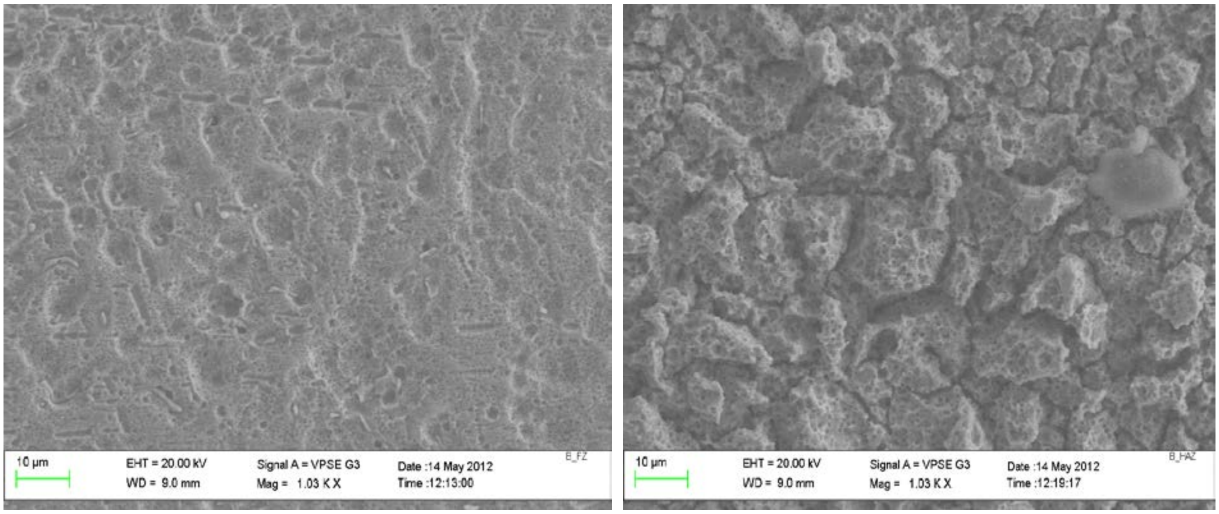
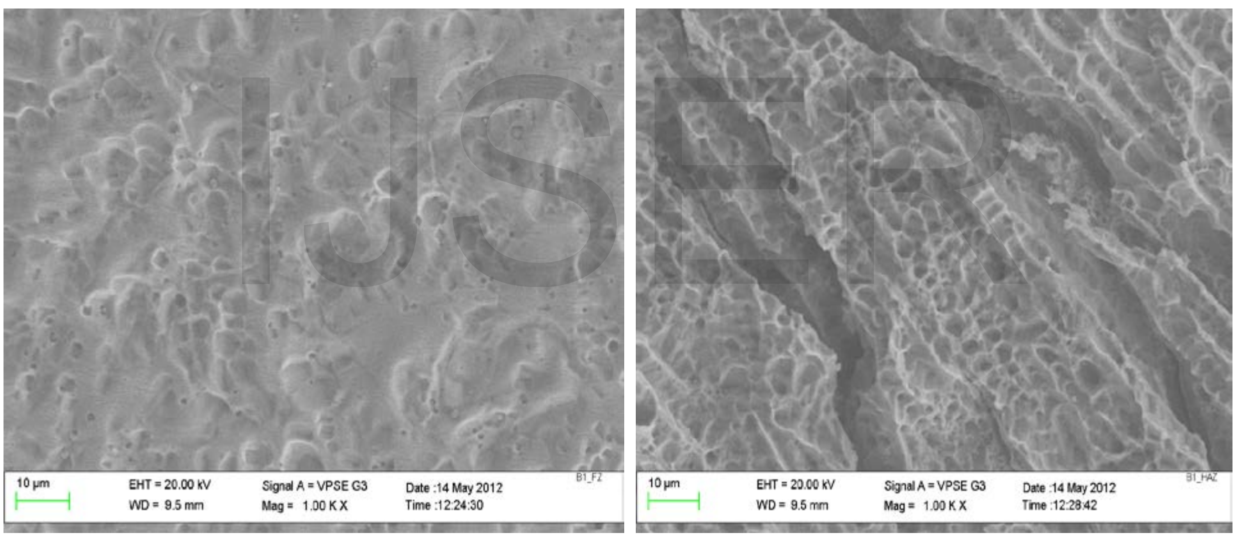


(a) (b)

Plate 1: (a) Micrograph of the Fusion Zone for Sample B

(b) Micrograph of the Heat Affected Zone for Sample B



(a) (b)

Plate 2: (a) Micrograph of the Fusion Zone for Sample B1

(b) Micrograph of the Heat Affected Zone for Sample B1

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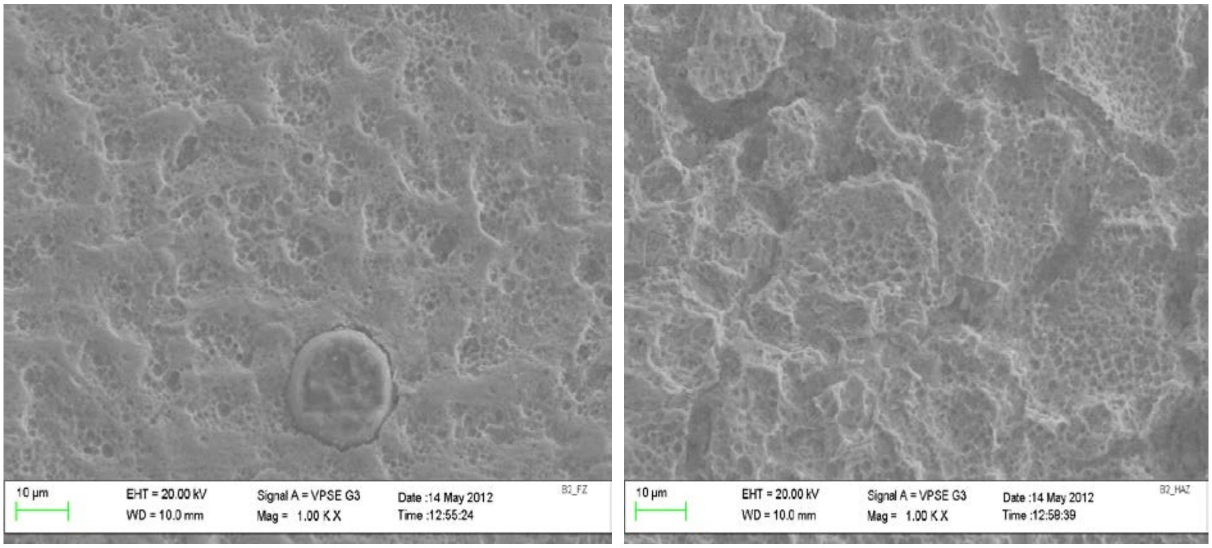
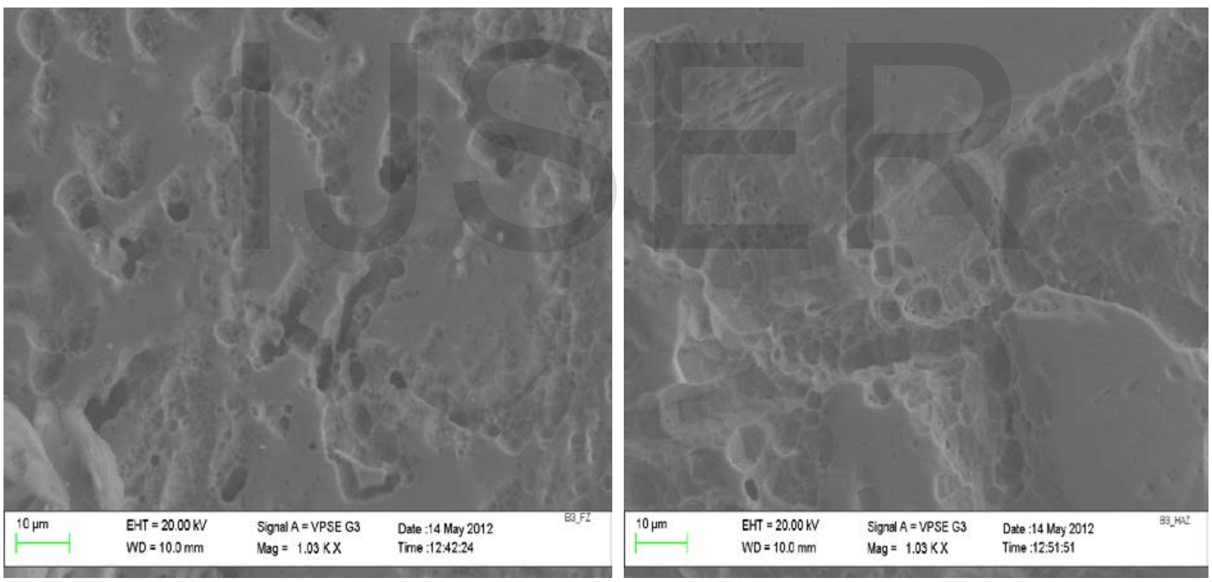


(a) (b)

Plate 3: (a) Micrograph of the Fusion Zone for Sample B2

(b) Micrograph of the Heat Affected Zone for Sample B2



(a) (b)

Plate 4: (a) Micrograph of the Fusion Zone for Sample B3

(b) Micrograph of the Heat Affected Zone for Sample B3

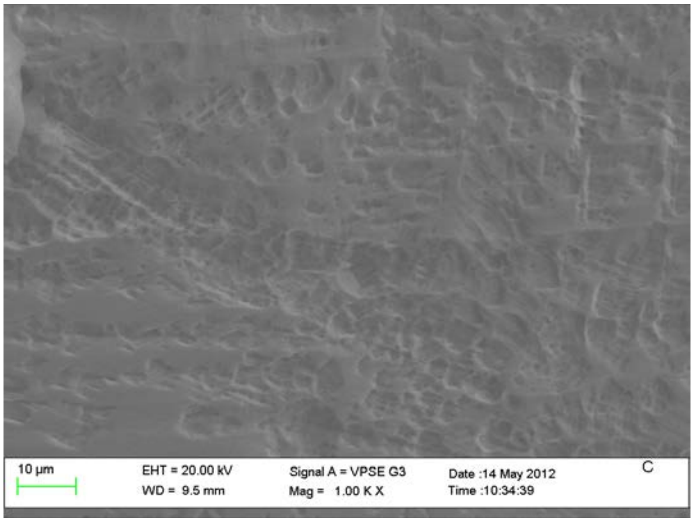


Plate 5: Micrograph for Sample C

SEM was used to study the morphology of all the welded and as received samples. Plate 5 shows the SEM micrograph of as received sample, Plate 1-4 shows the SEM micrograph of the welded samples.

Morphological analysis using SEM clearly show difference in the morphology of the heat affected zone and the parts that are not affected, causing the grains of the heat affected zone to be more coarse than that of the unaffected zone (see Plate 1b and plate 5). 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 Plates 5). From the SEM micrograph, there was 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 1a & b, 2a & b etc).

Finally, the grains sizes of the heat affected zone for samples B2 is 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 [9-11], while the relationship between the microstructure and the properties of the developed composite agrees with conclusions of other researchers [12-15]

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 below.

TABLE 4: THE TENSILE TESTS RESULTS FOR SAMPLES (AREA A_0 = 7.85 X10^5, GAUGE LENGTH L_0 = 50MM)

Sample	Maximum Load (KN)	Tensile Strength (MN/m 2)	Extension (mm)	Elongation (%)
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 for group B samples with the as received one is shown in Fig 4.

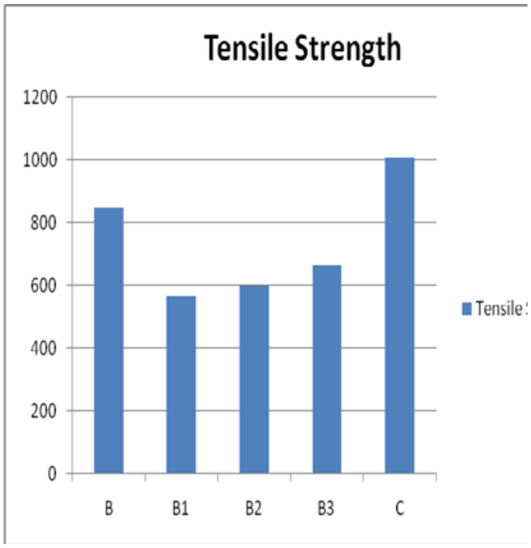


Fig. 4: Tensile Strength for Group B as compared to Control

The comparison of the percentage elongation (Strain) B samples with the as received one is shown in Figures below.

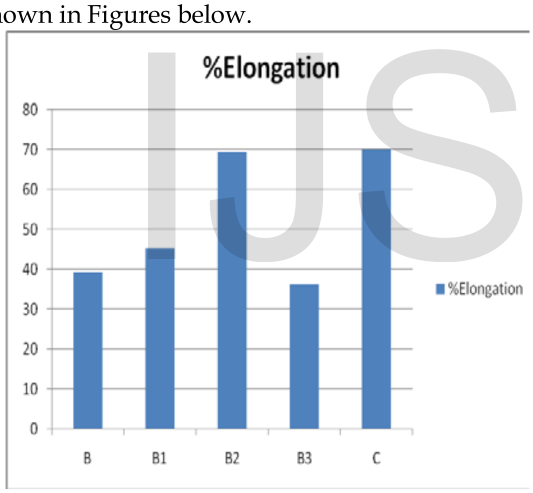


Fig.5: Percentage Elongation for Group B as compared to Control

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 increase 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 lubricating 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 4.3b and 4.7b)

The results also showed that heat treated samples that undergo stress relief treatment after welding posses' better properties in terms of strength, next those that were treated in engine oil, followed by those treated in neem oil as shown in fig 4. The results obtained from the tensile test of the welded duplex stainless steel are in agreement with those obtained by other researchers [11-15]

3.3.2 Impact Properties of the samples

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

TABLE 5: THE IMPACT TESTS RESULTS FOR SAMPLES

Sample	Average Energy Joules (J)
B	148.70
B1	150.26
B2	156.02
B3	149.14
C	162.70

The comparison of the impact energy for group B samples with the as received one is shown in Fig. 6.

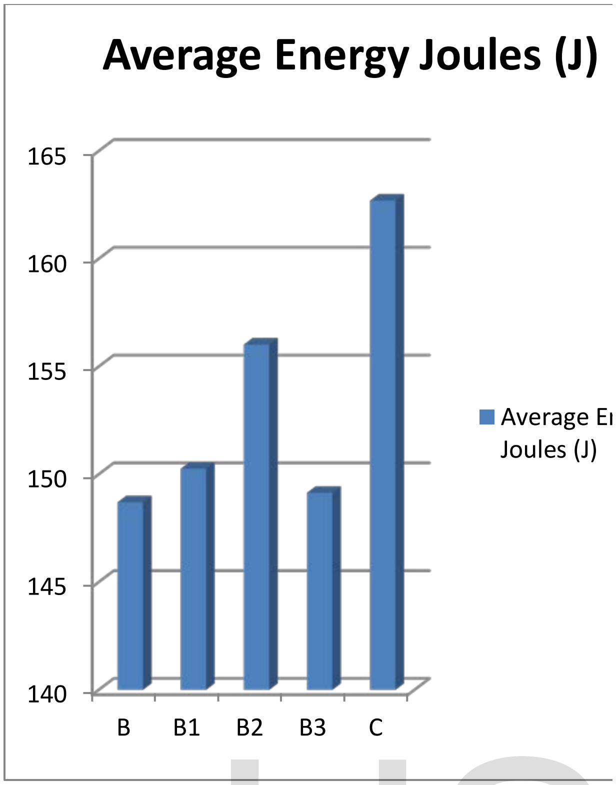


Fig 6. Impact energy for the samples.

The results of the impact test carried out on the samples as recorded in Table 5 shows that the impact energy of the material rises from 148.7J obtained in the non treated sample, to 156.26J obtained in sample B2, which is the highest in the group, then fall to 149.14J in sample B3. The samples that were heat treated in lubricating oil gives better result compare with those that where heat treated in neem oil.

These variations can be related to the morphology of the microstructures in plate 3, B2 have the finest microstructure in the HAZ in the group. The basic information obtained from the impact test is in agreement with observations raised by other researchers [20-27],

3.3.3 Hardness Number for the samples

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

TABLE 6: HARDNESS NUMBER FOR THE SAMPLES

Sample	Hardness value (HRA) FZ	Hardness value (HRA) 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 Fig. 7

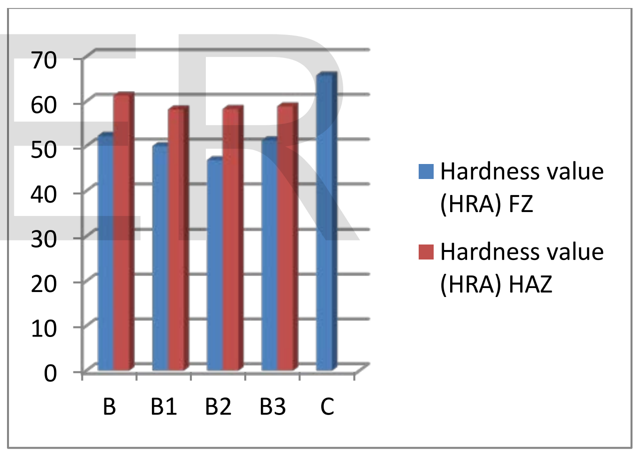


Fig. 7 Hardness Number for FZ and HAZ as compared to Control

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. 7). The hardness number of samples that are treated in engine oil is lower as compared to other treated in neem oil. 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 engine 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 [16-25].

4 CONCLUSIONS

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

Both lubricating oil (85W90) and neem oil can serve as quenching medium for post weld treatment of duplex stainless steel. But lubricating oil (85W90) gives better results compared to neem oil in terms of elongation, and tensile strength.

1. The duplex stainless steel can be welded successfully using either shielded metal arc process depending on the application or service life which the material will be subjected to.

Tempering after quenching improved the mechanical properties of the alloy in both neem oil and lubricating oil (85W90).

The tensile test, impact test and the hardness test shows that the two quenching media improved the mechanical properties (toughness and ductility) of this alloy after welding.

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