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THE EFFECT OF ANNEALING ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF WELDED CARBON STEEL

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ABSTRACT

This paper is focused on the investigation of the effect of annealing on the microstructure and mechanical properties of welded carbon steel. The properties put into consideration were strength, hardness, ductility, and microstructure examination of the sample with optical microscopy. Samples of the same grades of steel plates of 10mm diameters were used in this research work. The carbon content of the steel plates was 0.16 %wt. From each grade of steel materials, groove specimens of 250mm were prepared. The groove was filled to create welds using arc welding. The resulting welds were then subjected to annealing heat treatment. The strength values and ductility of the weld were determined. The microstructural analyses of the weld were carried out as well. The results show that ultimate tensile strength for the heat-treated specimen was 9355MN/m^2 and that of the untreated specimen was 10,327.27MN/m^2. The percentage ductility for heat treated specimen was 16% while the un treated specimen was 12%. There was also significant microstructural modification due to heat treatment. Therefore, for improvement in mechanical properties of carbon steel, annealing heat treatment is required.

1. INTRODUCTION

Carbon steel is generally used in engineering applications accounts for 85% of the yearly steel production worldwide (Oyejide et al., 2017; Orhorhoro et al., 2017). In general, metallic materials are classified as ferrous and nonferrous (Rajput, 2004). Ferrous materials consist of steels and cast irons, while nonferrous materials consist of the rest of the metals and alloys (Rajput, 2004). Ferrous metals and alloys are basically irons with carbon added to them. As the carbon content rises, the metal becomes harder and stronger but less ductile and more difficult to weld (Al-Quran et al., 2012). Alloys with less than 2% carbon are classified as steels, while those with more than 2% carbon are called cast iron (Rajput, 2004). As the name implies, cast iron is predominantly produced by casting whereas steels are predominantly produced as wrought products, which needs to be deformed and shaped after casting.

Steels are grouped according to some common characteristics. The most common classification is by their composition and then by their yield or tensile strength. According to their composition, the classification is made regarding to their carbon content and the alloy content, which can be classified as low carbon, medium carbon and high carbon. Low carbon consists of less than 0.25% carbon content, while medium carbon consists of 0.25-0.55% carbon content and high carbon consists of more than 0.55% carbon content. In this research work, 0.16% weight carbon was used. Alloys such as manganese, nickel and molybdenum are added to increase the strength. If the alloying elements are less than 5%, they are called low-alloy steels while more than 5% alloy content are classified as high-alloy steels. For better workability, carbon steel required heat treatment in order to improve its mechanical properties such as toughness and ductility (Oluwole, et al., 2008; Singh, et al., 2010).

Heat treatment involved heating and cooling of a metal or alloy in its solid state with the objectives of changing the characteristics of the material. Heat treatment processes include: normalizing, hardening (age hardening, surface hardening, case hardening, flame hardening induction hardening etc.), tempering, annealing, etc. Annealing is a heat treatment process that alters the physical and sometimes chemical properties of a material to increase its ductility and soften it, make the material more workable. It involves heating a material to above its recrystallization temperature, maintaining a suitable temperature, and then cooling (Ismail et al., 2016). In annealing, atoms migrate in the crystal lattice and the number of dislocations decreases, leading to the change in ductility (Fadare, et al., 2011). Annealing is very important commercially because it restores the ductility to a metal that has been server strain-free hardened. By interposing annealing operations after server deformation, it is possible to deform most metals to a very great extent. Annealing is carried out to soften the metal, improve machinability, refine grain size due to phase recrystallization, increase ductility of metal, prepare steel for subsequent treatment, modify electrical and magnetic properties, relieve internal stresses, remove gases, and produce a definite microstructure.

Most metals are usually very difficult to work upon during various machining process, hence the need for annealing to soften the metal so that various machining operation can be carried out. During service condition most materials often fail as a result of poor mechanical properties (Rajput, 2004). In this research work, the effect of annealing on the microstructure and mechanical properties of welded carbon steel was investigated.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this research includes; carbon steel, muffle furnace, lathe machine, charpy impact testing machine, and sand paper. The carbon steel was purchase in Warri, Delta State, Nigeria. The machining and annealing operation were carried out at Petroleum Training Institute (PTI), Effurun, Delta State, Nigeria. The properly machined carbon steel was divided into two samples namely sample A (untreated), and sample B (annealing heat treated).

2.2. Methods

The following methods were adopted in this research work.

2.2.1. Experimental procedure

Low carbon steel plate was use for this study. During material selection we considered low carbon steel as the parent metal which has the required properties that are suitable for this experiment. The chemical composition of the carbon steel was determined in PTI, Effurun, Nigeria. Table 1 shows the chemical composition of carbon steel used in this research work.

Table 1: Chemical composition of low carbon steel used in this research work

Component	Composition (%)
C	0.16
S	0.14
Mn	0.52
P	0.25
Cr	0.11
Nb	0.40
Ni	0.01
Cu	0.02
V	0.03
Mo	0.03
Fe	98.12

The annealing heat treatment was carried out at Petroleum Training Institute Effurun, Delta State. A digital furnace with a maximum temperature of 1500^{o}C was use for the process. The specimen was heated at weld zone (i.e., heat affected zone- HAZ). Annealing heat treatment was carried out at 1200^{o}C for duration of two hours and allowed to cool in the furnace for 24 hours.

2.2. Metallographic Examination

For metallographic observation, the specimens were etched with 90ml of methanol, 10ml of HNO_3 for 20 seconds. Etching was carried by swab method of test piece in etchants, and the specimens, each was place under a microscope with magnification of 800 and consequently the internal structure of the heat treated and untreated specimens was revealed accordingly (Atanda et al., 2012). This metallographic examination was carried out at Standard Organization of Nigeria (SON), Enugu.

2.3. Tensile Test

The tensile strength of the material of both heat treated and untreated weld sample was determined using tensile tester. This test was carried out in Welding Department, Petroleum Training Institute, Effurun, Nigeria. For each specimen, tensile test was attached to jaws of the testing machine and subjected to a progressively increasing tensile pull till it fractures. Before testing, the gauge length were mark out and measured using vernier caliper. The weld sample were gripped and loaded till yield point reached and also the loading (tension pull) continues till break point.

2.4. Welding Procedure Specification

The welding procedure and specification is shown in Table 2. Shield arc welding was adopted, and this was carried out manually. The welding was done to material specification of A36-ASTM. Other welding procedures are summarized in the table.

Table 2: Welding procedure and specification

Materials specification	A36- ASTM
Welding process	Shield metals Arc welding (SMAW)
Manual or machine	Manual
Position of welding	1G
Filler metal specification	E7018 & E6011
Filler metal classification	Fleet and low hydrogen
Flux	Cellulose/Fe_2O_3
Weld metal grate	Mild steel
Single or multiple pass	Multiple
Welding current	(50 – 120) Ampere
Polarity	(21 – 37) V
Welding progression	Down hill
Root treatment	N/A
Preheat treatment	N/A

3. RESULTS AND DISCUSSION

The tensile specimen, specimen for metallography, specimen before tensile test, specimen after tensile test, specimen for metallographic examination, specimen for untreated are shown in Figure 1 to Figure 6.

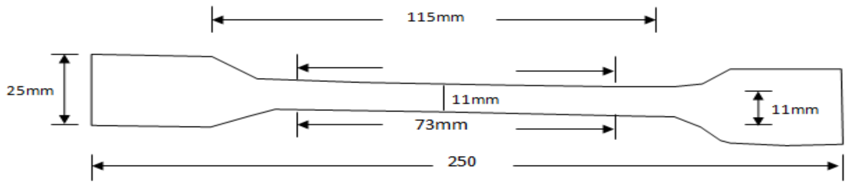


Figure 1: Heat treated specimen (Dimension)

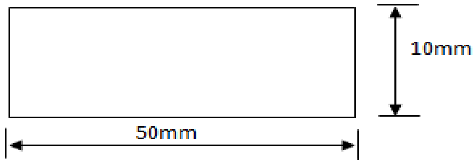
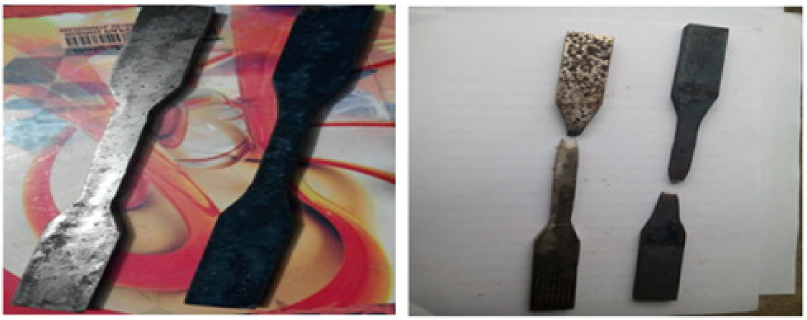


Figure 2: Metallography (Dimension)



i. Specimen before Tensile Test ii. Specimen after Tensile Test

Figure 3: Tensile Test

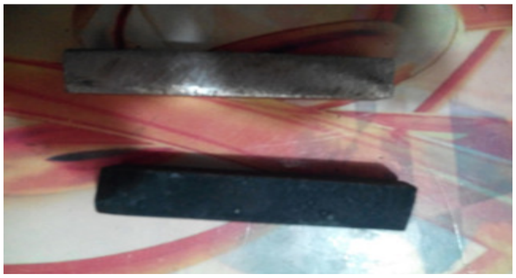


Figure 4: Metallographic examination

Figure 5: Heat treated (Metallographic examination)

Figure 6: Unreated (Tensile test)

The microscopic images in Figure 7 and Figure 8 indicate the micro structure of heat treated annealed sample (specimen B) and untreated sample (specimen A). In an attempt to have a lucid understanding of the effects of annealing on the welded steel sheets, the microstructure of the welded material was analyzed using optical microscopy. The images for specimen A shows direction of heat flow on elongation of both ferrite and pearlite grains. The grain stretched was due to heat resulting from welding operation. The allotropy of the metal is in Body Cubic Centre (BCC) state. It appears that these films contain mainly ferrite and some colonies of pearlite and that the microstructure is in homogeneity. On the other hand, for specimen B, the upper critical temperature is 890°C and 30°C was added thereby increasing the temperature to 920^{0}C (annealing temperature). The effect of annealing temperature (920^{0}C) transformed the specimen from Body Cubic Centre (BCC) to Face Cubic Centre (FCC) [Calister, 2007], which is now in austenite state. From the image in specimen B, the microstructure of the grains is homogeneous, the grains size is larger, and the material is ductile and magnetic.

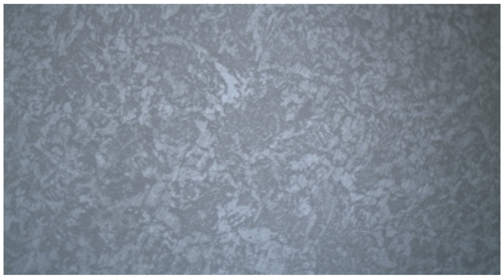


Figure 7: Microscopic Structure of Specimen A

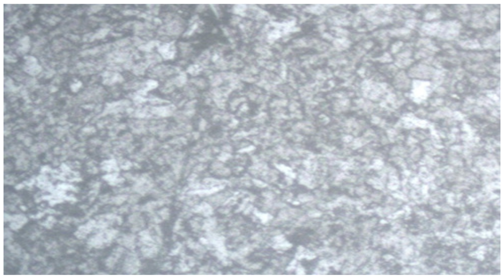


Figure 8: Microscopic Structure Specimen B

By comparing the values obtained in the tensile test results. It is quite obvious that the trend is decreasing (i.e., ultimate tensile stress values decrease), while it is high in the untreated sample. Generally, the values for the annealed sample are minimal for strength and maximum for ductility. This is due to the softening effects of the ferrite matrix which arise from liberation of trapped carbon atoms in the super saturated ferrite during annealing as depicted in the microstructure of the annealed sample. The microscopic photography of specimen B in Figure 8 clearly identifies ferrite and pearlite. Also, apart from straining due to saturation by carbon atoms which are relieved, residual stresses in the welds are also relieved during annealing. Normally arc welding process can induce residual stresses in the weld during the course of welding. Also, it is obvious that the ultimate tensile strength (UTS) values increased from the weld pool through the heat affected zone (HAZ), the ductility however decreased.

The dimension of the heat-treated sample is shown in Table 3. The initial; thickness (T_0), width (W_0), area (A_0), and initial length are all tabulated as shown.

Table 3: Heat treated sample

	Original Dimensions			Final Dimensions	
	mm	Inches		mm	Inches
T_o	10	0.3937	T_F	5.207	0.205
W_o	12.44	0.4898	W_F	7.5184	0.296
A_o	124.4	0.1928	A_F	39.1483	0.0607
L_o	80	3.149	GL_F	93	3.6614

For heat treated sample, the ultimate tensile strength, yield strength, percentage ductility and reduction were obtained as follow.

Ram Load = 2600 psi = 179, 263MN

Ram Factor = 6.492

Maximum Load = 179263 X 6.492 = 1163775. 4MN

$$Ultimate\ Tensile\ Strength\ (UTS) = \frac{Maximum\ Load}{A_0} = \frac{1163775.4}{124.4} = 9355.1MN/m^2$$

$$Percentage\ Ductility = \frac{GL_F - GL_0}{GL_0} \times 100 = \frac{(93-80)}{80} \times 100 = 16.25\%$$

$$Percentage\ Reduction = \frac{A_0 - A_F}{A_0} \times 100 = \frac{(124.4-39.1483)}{124.4} \times 100 = 68.53\%\%$$

Where:
L_F = Final length
L_0 = Initial length
A_F = Final area
A_0 = Initial area

Table 4: Untreated Sample (Sample A)

	Original Dimensions			Final Dimensions	
	mm	Inches		mm	Inches
T_o	10	0.3937	T_F	8.636	0.340
W_o	13	0.5118	W_F	7.8994	0.311
A_o	130	0.2015	A_F	68.2192	
GL_o	80	3.1496	GL_F	90	3.5433

For heat treated sample, the ultimate tensile strength, yield strength, percentage ductility and reduction were obtained as follow.

Ram Load = 3000 PSI = 206800MN
Ram Factor = 6.492

Maximum Load = 206800 x 6.492 = 1342545.6MN

$$Ultimate\ Tensile\ Strength\ (UTS) = \frac{Maximum\ Load}{A_0} = \frac{1342545.6}{130} = 10327.27MN/m^2$$

$$Percentage\ Enlongation = \frac{GL_F - GL_0}{GL_0} \times 100 = \frac{(90-80)}{80} \times 100 = 12.5\%$$

$$Percentage\ Reduction = \frac{A_0 - A_F}{A_0} \times 100 = \frac{(130-68.2192)}{130} \times 100 = 47.5\%$$

4. CONCLUSION

The result of this research work shows that the ultimate tensile strength (UTS) and ductility values of the specimen vary with untreated and treated specimen. Generally, there was a higher value of ultimate tensile strength of the untreated specimen to the treatment specimen. It was equally found out that the ductility value of the treated specimen is higher than the untreated specimen. Annealing significantly affects microstructure and thus the mechanical properties of the welded steel product.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Al-Quran, F.M.F and Al-Itawi, H.I. (2012). Effects of the heat treatment on corrosion resistance and micro hardness of alloy steel, *European Journal of Scientific Research*, 39(2), pp. 213-222

Atanda, P.O., Olorunniwo, O.E., Alabi, O.D., and Oluwole, O.O. (2012). Effect of Iso-Thermal Treatment on the Corrosion Behaviour of Low Carbon Steel (Nigerian C2R grade) in a Buffered Solution containing Chloride and Carbonate Ions*, International Journal of Materials and Chemistry,* 2(2), pp. 65-71

Fadare, D.A., Fadara, T.G., and Akanbi, O.Y. (2011). Effect of heat treatment on mechanical properties and microstructure of NST 37-2 Steel, *Journal of Minerals & Materials Characterization & Engineering*, 10(3), pp.299-308

Ismail, N.M., Khatif, N.A.A., Kecik, M.A.K.A, and Shaharudin, M.A.H (2016). The effect of heat treatment on the hardness and impact properties of medium carbon steel IOP Conf. Series, *Materials Science and Engineering* 114, pp. 1-9

Oluwole, O.O., Oloruntoba, D.T., and Awheme, O. (2008). Effect of zinc plating of low carbon steel on corrosion resistance in cassava fluid environment, *Corrosion Engineering Science and Technology, Institute of Materials, Minerals and Mining, UK.,* 43(4), pp. 320-323

Orhorhoro, E.K., Oyiboruona, P.E., and Ikpe, A.E. (2017). Investigation and Evaluation of the Corrosion Inhibition Properties of Water Hyacinth Extract on Low Carbon Steel, *International Journal of Emerging Engineering Research and Technology*, 5(12), pp.45-50

Oyejide, J.O., Orhorhoro, E.K., Ogie, N.A. and Idi, U.S**.** (2017). Investigation of the Effect of Annealing on the Corrosion Resistance of Medium Carbon Steel in Sea Water, *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)*, 8(5), pp. 219-224

Rajput, R.K. (2004). Material Science Engineering, 3rd Edition, Kataria Public, NaiSarak, Delhi, India

Singh, A., Singh, V.K. and Quraishi, M. (2010). Effect of fruit extracts of some environmentally green corrosion inhibitors on corrosion of mild steel in hydrochloric acid solution, *Journal of Materials and Environmental Science,* 1(3), pp.162–174.