## Effects of Thermal Treatment Processes (TTP) on the Tensile Properties of 0.165% Carbon Steel

<sup>1</sup>Yusuf Lanre Shuaib-Babata, <sup>2</sup>Reuben Adebare Adewuyi,

<sup>1</sup>Department of Materials & Metallurgical Engineering, University of Ilorin, Ilorin <sup>2</sup>Obasanjo Centre for Engineering Innovation, The Federal Polytechnic, Ado Ekiti sylbabata@gmail.com

Abstract— In practice, welded low carbon steels do fail at the welded joints in use, thus leading to structural defects, material wastages, structural failure, and at times loss of lives, among others. This has been a great concern to practicing Engineers and Researchers. This study tends to proffer solution to this problem of concern through application of post welded thermal treatments. The welded samples were subjected to some post-weld thermal-treatment (TTP) operations such as normalizing, annealing and quench-hardening using different quenching media (Water, Palm oil, Quartz 5000 Total Engine oil, and Ground nut oil). The Tensile properties of the steel (such as tensile stress, tensile strain, and toughness) were determined before and after welding operations. At yield points, the thermal treatment processes adversely affected the strength of the welded steel. Meanwhile, normalizing and annealing processes enhanced the steel's ductility and toughness, while quench-hardening process, irrespective of medium of quenching used reduced the steel toughness value. The toughness of the welded steel at the fracture point was also reduced through all the adopted thermal processes, except for normalizing process. The steel ultimate tensile stress and strain and its toughness values were equally reduced after TTP. Improvement of the properties of welded low carbon steel was elicited by post-weld normalizing and annealing operations. Hence, butt-welded annealed and normalized low carbon steel specimens tend to be more resilient to failures at welded joints.

\_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_

Keywords— Failure, Heat affected zone, Quench hardening, Tensile properties, Welding

---- - - - - •

#### **1** INTRODUCTION

Velding is a fabrication process used to join materials, usually metals or thermoplastics, together. During welding, the pieces to be joined (the work pieces) are melted at the joining interface and usually a filler material is added to form a pool of molten material (the weld pool) that solidifies to become a strong joint. Welding is currently used for the fabrication and construction of a variety of structures such as buildings, bridges, ships, offshore structures, boilers, storage tanks, pressure vessels, pipelines, automobiles and rolling stock (Elijah, Onuh & Datau, 2009). Categories of welding processes commonly used include Arc welding [Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Gas Tungsten Arc Welding (GTAW)], Gas Resistance Welding (Spot-welding, Welding, Seamwelding), Energy Beam Welding, and Solid-State Welding.Automobile and structural engineering materials are subjected to a wide range of operating conditions, which include welding operation. As a result of the quest for materials that can perform such task at optimum efficiency, Metallurgists, Designers and Engineers have been forced to look into ways of developing materials that would be able to suit specific engineering applications (Oloabi & Hashmi, 1995).

Out of 90% of all steels available in the world market, low carbon steel, such as mild steel is mostly used for structural engineering works, such as reinforcement in concrete used in construction of buildings, bridges, construction of ship, vehicles, boilers, building roof, truss conveyors, tanks and other storage facilities (Shuaib-Babata, 2006). Apparently, this is because of its excellent mechanical properties such as strength, high ductility, toughness, ease of fabrication, and availability. According to Piccard, Lefebure and Tremillion, "low carbon steels are preferred as the container, tubing material for heat transfer and storage processes below 600oC, partly due to the ease with which they are fabricated" (Shuaib-Babata, 2004). The steel is available commercially as plate or rod which needs to be welded after cutting operation to achieve desirable shapes required in structural development. It is common phenomenon that low carbon steel does fail at welded joints while in service, which needs to be addressed to avoid its consequences, such as loss of lives, material wastages, and structural defects (Shuaib-Babata & Adewuyi, 2015).

Heat treatment is a common practice to improve broad combinations of mechanical properties in materials, especially low carbon steel (Rollason, 1985). It involves heating of the material to certain temperature, holding at that temperature and cooling appropriately to ambient temperature (Devinder, Mithlesh & Jaspal, 2013). Heat treatment has been found to be the easiest process of improving material properties (Shuaib-Babata, 2008). The thermal process is described as an important operation in the final fabrication process of many engineering components (Daramola, Adewuyi & Oladele, 2010). Thermal treatment processes (TTP) is also described as a procedure that is used to influence the structure and the properties obtained in the weld zone and in the heat affected zone (HAZ) (Chen, 2012). Effective thermal treatment processes is the primary means by which welded zone, heat affected zone properties and minimum potential for hydrogen induced cracking are corrected (Davies, 1996). Only by heat treatment is it possible to impact high mechanical properties on steel parts and tools for sophisticated applications (The New International Webster's Comprehensive Dictionary of the English Language, 2010).

<sup>\*</sup> Corresponding Author

In attempt to find solution to the structural problems originated as a result of failure at welded joints, Engineers and other users of welded steels thermal treatment processes (TTP) are being applied.

Through mechanical testing, such as tensile test, hardness test and microstructure analysis, properties of the steel that contribute to the welded joints failure are revealed. Study also showed that dimensions, joint design, welding parameters and the likely mechanism of failure as other factors that influence the need for TTP (Senthilkumar & Ajiboye, 2012). More so, Hard microstructure of the heat affected zone (HAZ) is said to be responsible for the property deterioration of weld and cold cracking susceptibility, which are preventable by thermal treatment processes (Joseph & Alo, 2014).

#### **2 MATERIALS AND METHODS**

#### 2.1 Chemical Composition of the Test Specimens

To classify the studied steel, the chemical composition of 14 mm thick commercial steel plate was obtained using an Optical Emission Spectrometer (OES), MODEL JEOL JEM2100.

#### 2.2 Preparation and Simulation of the Test Specimens

The low carbon steel was cut into 40 pieces with dimension 100 mm by 50 mm, 14mm thick and welded into 20 pieces with dimension 100 mm by 100 mm, 14 mm samples shown in Plate 1. The 3D drawing (model) of the specimen is has shown in Figure 1a. For ease thermocouple placement on samples, 5.0 mm diameter hole was drilled and taped close to the upper edge of each of the samples, prior to welding operation, as shown in Plates 1. A 3-D Model of the test specimen was generated from Autodesk Inventor Professional Modeling Software shown in Figure (1b) to show the heat distribution across the weld bead, fully described in Shuaib-Babata & Adewuyi (2015).

#### 2.3 Thermal Treatment and Quenching

Sequel to welding operation, the specimens were prepared for post weld heat treatment. Thermocouple of K-Type (Platinum Rhodium) (-30 to +13700C) were inserted into each of the holes drilled on upper edge of the welded specimen to be connected to the temperature controller to read the core temperature of the specimen while inside the furnace, as shown in Plates 1.

Five standard specimens were annealed by heating to a temperature of 920°C in a furnace for 30 minutes and cooled in the furnace environment to room temperature. The next set of five specimens were normalized by heating to a temperature of 920°C and held for 30 minutes and allowed to cool in still air. A set of two standard specimens at a time was heated to temperature of 9200C and was allowed to homogenize at that temperature for 30 minutes. This procedure was repeated for four different periods. After 30 minutes, the specimen was taken out of the furnace, directly quenched in different media (Tap Water, Palm Oil, Quartz 5000 Total Engine Oil and Ground Nut Oil) and maintained at room temperature in each of the quenching tanks. After 30 minutes, the specimens were taken out of the quenching tank and cleaned properly. While, the remaining two asweld specimens served as control. Plates1 show welded specimens before thermal treatment and after thermal treatment.





Fig. 1. 3-D model of the test specimen generated from Autodesk Inventor Professional Modeling Software, (a) Double-V-butt welded joint and (b) Heat Affecting Zone (HAZ) after being simulated respectively.



(a) before thermal treatment (b) after thermal treatment

#### 2.4 Tensile test

The tensile specimens (heat treated and non-heat treated) as shown in Figure 2 were prepared and individually subjected to tensile forces on Computerized Universal Testing Machine (UTS) (a Testometric Materials product) shown in Figure 3. The values of the tensile stress, tensile strain and energy (toughness) at various points (yield, peak, and fracture), E-Modulus for each specimen were obtained and documented from the system.



Fig.2. Tensile and Hardness test specimens

## **3** RESULTS AND DISCUSSION

#### 3.1 Chemical Composition

The results of the specimen's elemental chemical composition and that of standard low carbon steel obtained in the literature are presented in Tables 1a and 1b respectively.

Table 1a: Chemical composition of low carbon steel sample as obtained using optical Emission spectrometer

Grade	Colour	%Weight	% Weight	%Weight
	Code	Carbon	Silicon	Manganese
NST 44- 2	Yellow	0.165	0.190	0.500
Table1b: Chemical composition of standard low carbon steel sample				
Grade	Colour	%Weight	% Weight	%Weight
	Code	Carbon	Silicon	Manganese
NST 44-	Yellow	0.135-	0.18-0.28	0.40-0.60
2		033		

The result revealed that the specimen possessed 0.165% of carbon, 0.19% of Silicon and 0.50% Manganese. All these elemental chemical values fell within the standard values for low carbon steel as shown in Table 1b.

# 3.2 Simulated Result of Heat Affected Zone on the three Planes (YZ, XZ, XY) using Autodesk Inventor Simulation CFD 2015 Application Software.

The thermal simulation of heat affected zone and welded pool on low carbon steel showing the three Planes (YZ, XZ, XY) using Autodesk Inventor Simulation Computational fluid dynamics (CFD) 2015 Application Software in Figure 1 above helps to understand how the temperature distribution changes with time. This sort of information is useful for assessing thermal stresses which may lead to failure. The simulated results are also shown in Figure 4. Detailed information about the application and distribution of heat were presented by Shuaib-Babata & Adewuyi (2015).





Fig. 4: Heat affected zone (i) on the welded area (ii) across the welded area

#### 3.3 Tensile result

The results of the tensile tests are presented graphically using stress- strain curve in Figure 5. The Figure 5 shows the variation of Tensile Stress (MPa) against Tensile Strain (mm/mm) for different conditions of quenching media. Figure 5 depicts three different regions: Elastic, Non-uniform plastic and Necking regions, with each region showing the uniqueness of the engineering materials behaviour. For better illustration, the results are presented in Figures 6 to 14.



Fig. 5: Stress/Strain curves for thermal treated samples (quenchedhardened) and untreated sampleof welded 0.165% low carbon steel

The ability of the studied steel to absorb shocking load (toughness) at yield is apparently shown in Figure 8 with the energy values at yield in descending order of normalized (231.3 J), annealed (215.8 J), untreated specimen (202.5 J), quench-hardened specimen with water (170.3 J), quenchhardened specimen with palm oil (15.9 J), quench-hardened specimen with total quartz 5000 (14.7 J) and quenchhardened specimen with ground nut oil (13.7 J) ...



Normalized welded steel Quench-hardened with water welded steel

Quench-hardened with palm oil welded steel

Quench-hardened with ground nut oil welded steel

#### Fig. 6: Tensile stress at yield for the welded 0.165% carbon steel



#### Fig. 7. Enlogation at yield for the welded 0.165% carbon steel



Fig. 8. Energy at yield for the welded 0.165% carbon steel



Fig. 9. Stress at peak values for the welded 0.165% carbon steel

For maintenance and inspection of materials, consideration was given to the steel properties, such as strength, toughness and ductility, at the points of peak and failure (breaking point). The stress values possessed by the steel at peak (Ultimate tensile strength) decreased in order of shown in Figure 9: untreated specimen (965.1 MPa), quench-hardened specimen with total oil quartz 5000 (919.2 MPa), quench-hardened specimen with ground nut oil (898.2 MPa), normalized (847.3 MPa), quench-



hardened specimen with water (755.5 MPa), annealed (714.1

MPa) and lastly quench-hardened specimen with palm oil

(669.9 MPa).



Fig. 14. Young Modulus values for the welded 0.165% carbon steel

The strain values at peak displayed by the steel in Figure 10 were: untreated specimen (106.4), quench-hardened specimen with total oil quartz (83.8), quench-hardened specimen with ground nut oil (73.8), annealed 61.9), quench-hardened specimen with palm oil (58.5), normalized (56.2) and quenchhardened specimen with water (53.4).

#### REFERENCES

- The exhibited values of steel stress at break points presented in Figure 11 were in descending order of: untreated specimen (965.1 MPa), quench-hardened specimen with total oil quartz 5000 (919.2 MPa), quench-hardened specimen with ground nut oil (818.2 MPa), normalized (622.7 MPa), quench-hardened specimen with water (588.3MPa), quenchhardened specimen with palm oil (583.9 MPa), and annealed specimen (533.5 MPa).
- Meanwhile, the elongation at break as exhibited by the steel (shown in Figure 12) were: annealed (17.3 mm), normalized (15.4 mm), quench-hardened specimen with water (14.8 mm), quench-hardened specimen with total oil quartz 5000 (14.0 mm), quench-hardened specimen with ground nut oil (13.7 mm), quench-hardened specimen with palm oil (13.4 mm) and untreated specimen (12.2 mm).
- The steel energy at break in Figure 13 reveals toughness values to be in reducing order of: normalized (356.9 J), untreated (326.8 J), annealed (302.6 J), quench-hardened specimen with ground nut oil (285.2 J), quench-hardened specimen with water (263.2 J), quench-hardened specimen with palm oil (259.0 J) and quench-hardened specimen with total oil quartz (248.1 J).

Figure 14 shows that the exhibited young modulus values for various thermal treated and untreated specimens as: untreated specimen (9327. 4 MPa), annealed (8943.8 MPa), quench-hardened specimen with palm oil (8480.5 MPa), quench-hardened specimen with total oil quartz 5000 (8480.5 MPa), quench-hardened specimen with water (7213.0 MPa), quench-hardened specimen with ground nut oil (7087.7 MPa) and normalized (6291.8 MPa)

The analysis of the experimental results revealed that the thermal treatment processes reduced the stress of the low carbon steel at yield point. Thus, any accumulated gas in resulted blow- hole as result of welding process and stresses in the steel material during welding process were reduced significantly. Normalizing and annealing processes increased the ductility and toughness of the welded low carbon steel, while quenchhardening processes reduced the properties. At peak, the ultimate tensile strength and the ductility of the welded steel were also reduced. Meanwhile, at the fracture point, the thermal treatment processes reduced the welded low carbon steel's strength and increased its ductility. The toughness of the welded low carbon steel was reduced through the thermal treatment processes, except for normalizing process. Interestingly, the welded low carbon steel's young modulus was also reduced through thermal treatment processes.

### 4 CONCLUSION

From the study it could be concluded that butt-welded annealed and normalized low carbon steel specimens tend to be more resilient to failures at welded joints. This is because of their higher toughness values and ductility (tensile strain) at yield point. Hence, TTP techniques significantly improve the mechanical properties of butt-welded annealed, normalized low carbon steels.

- Chen Liang (2012), Effect of PWHT temperature on mechanical properties of high-Cr ferritic heat-resistant steel weld metal. *Welding in the World*, Vol.56 (January-February), pp.1-2.
- Daramola, O.O., Adewuyi, B.O. and Oladele, I.O. (2010), Effects of heat treatment on the mechanical properties of rolled medium carbon steel, *Journal of Minerals & Materials Characterization & Engineering*, Vol. 9, No.8, pp.693-708.
- Davies A.C. (1996), *Welding*, 10th Edition, New York, United State of American: Cambridge University Press, pp.343-377.
- Devinder, Pal S., Mithlesh, Sharma and Jaspal, Singh G. (2013), Effect of post weld heat treatment on the impact toughness and microstructural property of P-91 steel weldment, *International Journal* of *Research in Mechanical Engineering & Technology*, Vol. 3, Issue 2, pp. 216 – 219. Retrieved from http://www.ijrmet.com.
- Ejilah, R. I., Onuh, E.I., and Datau, S. (2009), A Study of the effect of post weld heat treatment on the torsional behavoir of low larbon Steel, *Proceedings of the 22nd international conference of Nigerian Institution of Mechanical Engineers (NIMechE)*, pp.13.
- Joseph, O.O. and Alo, F. I. (2014), An assessment of the microstructure and mechanical properties of 0.26% low carbon steel under different cooling media: Analysis by one-way ANOVA, *Industrial Engineering Letters*, Vol.4, No.7, pp 39 – 45, Retrieved from http://www.iiste.org/Journals/index.php/IEL/article/view/14180/14488
- Oloabi, A.G. and Hashmi, M.S.J. (1995), The effect of post weld teat treatment on mechanical properties and residual stresses mapping in welded structural steel , *Journal of Material Processing Technology*, Vol.55, issue 2, pp.117-122.
- Rollason, E. C. (1985), Metallurgy for Engineers, 4th ed., London: Arnold Edward / English Language Book Society, pp.71-211
- Senthilkumar, T. and Ajiboye, Tajudeen K. (2012), Effect of post weld heat treatment on the mechanical properties of medium carbon steel, *Journal of Minerals and Materials Characterization and Engineering*, Vol. 11, No. 2, pp. 143-52.
- Shuaib-Babata, Yusuf L. (2004), Effects of heat treatment on the corrosion and mechanical properties of locally available mild steel (Unpublished M. Eng. Mechanical Engineering Thesis), Ilorin, Nigeria: University of Ilorin.
- Shuaib-Babata, Yusuf L. (2006), Effect of heat treatment on corrosivity of commercial mildsteel in sulphuric acid, *Journal of Environmental Monitor*, pp.73-82.
- Shuaib-Babata, Yusuf L. (2008), Evaluation/ assessment of tensile properties of some commercially available steels in Ilorin metropolis, *Nigerian Journal of Research in Engineering*, Vol. 5, No. 3, pp 76 – 82
- Shuaib-Babata, Yusuf L. & Adewuyi, Reuben, A. (2015), Simulation of heat affected zone(HAZ) in multi-pass welds in low carbon steel, *Proceedings of School of Engineering 10th Engineering Forum*, The Federal Polytechnic, Ado-Ekiti, Vol. 2, pp. 77 – 83.
- The New International Webster's Comprehensive Dictionary of the English Language (2010), *Deluxe Encyclopedic Edition*, USA: Typhoon Media Corporation, pp.583.