IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 11, November 2016
ISSN (Online) 2348 – 7968 | Impact Factor (2015) - 4.332
www.ijiset.com

Impact of Post-Weld Heat Treatment (PWHT) on the Hardness and Microstructure of Low Carbon Steel

Adewuyi, Reuben Adebare [1] and Elegbeleye, Kayode Edward[2]

[1]Olusegun Obasanjo Centre for Engineering Innovation (OOCEI), The Federal Polytechnic, Ado Ekiti, Nigeria. [2]Department of Agricultural and Bioenvironmental Engineering, The Federal Polytechnic, Ado Ekiti, Nigeria.

ABSRACT

The impact of Post-Weld Heat-Treatment (PWHT) on the hardness and microstructure of of 0.165% carbon steel was determined in this study after welding operation. Autodesk Inventor Simulation CFD 2015 Application Software for Visual Style –Wire Frame and Visual Style –Shaded Mesh was used to simulate the Heat Affected Zone (HAZ) and welded pool on three planes (YZ, XZ, XY). The welded samples were subjected to normalizing, annealing and quench hardening in different media (water, palm oil, Quartz 5000 Total Engine oil, and Groundnut oil). The prepared samples (PWHTs and as-welds) were subjected to hardness and microstructure tests and were compared with non-heat treated as-weld to determine their hardness and observed microstructure. The results obtained showed significant differences in the microstructure and mechanical properties of the different PWHT samples. Results also showed that specimens annealed and quenched in water and palm oil had lowest Brinnel Hardness Numbers (BHN) at welded pool, that is 62.105BHN, 84.06BHN and 69.835BHN, while the specimens normalized, annealed and quenched in palm had the lowest hardness values at HAZ , that is 82.25,73.365 and 88.13BHN. Hardness values of 100.77BHN for welded pool and 133.735BHN for HAZ were highest for samples quenched in Quatz 5000 Engine oil . The normalized and annealed samples had values of 89.695 and 62.105BHN at welded pool, and 82.25BHN and 73.365BHN at HAZ compared with untreated as-weld low carbon steel samples with 106.855BHN at welded pool and 100.97BHN at HAZ. Normalizing PWHT sample yielded a microstructure of better quality than annealing and quench hardening in the different media used. It was deduced that the reduction in hardness values was a consequence of an increase in ductility and toughness in normalized and annealed samples. This improved the properties of the low carbon steel and reduced mechanical hazard. It was concluded that improved mechanical behaviour of welded low carbon steel is achieved by post-weld normalizing and annealing operations.

Key words: PWHT,HAZ, BHN, Microstructure, Hardness, Quenching media.

1. INTRODUCTION

It is *sine qua non that* low carbon steel (NST 44-2) do fail at welded joints while in service. Welding is a fabrication process used to join two or more materials, usually metals together. During welding, the work pieces to be joined 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 fabrication and construction of a variety of structures in buildings, bridges, ships, offshore structures, boilers, storage tanks, pressure vessels, pipelines, automobiles and rolling stock [1, 2]. Automobile and structural engineering materials are subjected to a wide range of operating conditions. As a result of the quest for materials that can perform such task at optimum efficiency, Metallurgists, Designers and Engineers have been in the vanguard of looking into the ways of developing materials that will be able to suite specific engineering applications [3,4]. Heat treatment is the term used to alter or improve some properties of materials by heating to certain temperature, holding at that temperature and coolling appropriately to ambient temperature [5,6]. By this, residual stresses are greatly reduced and the materials are best suited for service conditions. Microstructure of the Heat affected zone (HAZ) is responsible for the property deterioration of weld and cold cracking susceptibility and these are preventable by pre and post weld heat treatment [7,8]. Post weld heat treatment (PWHT), is a procedure that is used to influence the structure and properties obtained in the previous weld pool and in the heat affected zone (HAZ). Heat treatment is an important operation in the fabrication process of many engineering components. Effective post weld heat treatment is the primary means by which welded pool, heat affected zone properties and minimum potential for hydrogen induced cracking are corrected .Only by heat treatment is it possible to impart high mechanical properties on steel parts and tools for sophisticated applications [9,10].

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this study include : 0.165% carbon steel, gauge 10 Oelikon welding electrode (E6013), vertical drilling machine, arc welding machine, platinum rhodium thermocouple (+30-1370^{0}C), electric furnace, Brinell hardness tester, quenching tank, optical microscope, optical emission spectrometer, tap water, palm oil, quartz 5000 Total engine oil, groundnut oil, synthetic velvet polishing cloth, micron alumna paste, abrasive papers and 2% nital for etching.

2.2 Methods

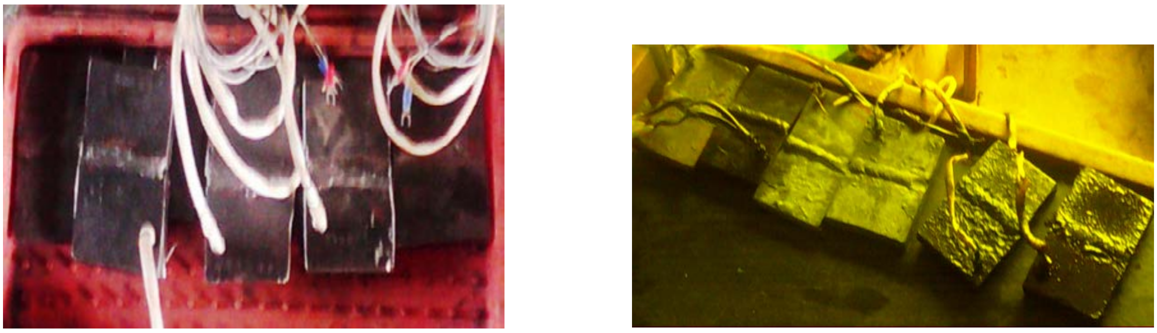
2.2.1. Determination of Chemical Composition

The chemical composition of low carbon steel specimen used was obtained using an optical emission spectrometer. This process also revealed the presence of other alloy elements in the specimen (Table 1).

2.2.2. Welding Operation

The low carbon steel was cut into 40 pieces of dimensions 100mm x 50mm x 14mm thick. An edge of each specimen was chamfered so that when placed for welding they formed a Double-V shape (classified as double-V-butt welded joint configuration). Each pair of the workpiece was melted and filled at the joining interface by the use of filler material (gauge 10 Oelikon Electrode E6013). A welding speed of 15mm/s was employed to form a pool of molten material at one pass on each side and this solidified to form a strong joint. They were welded into 20 pieces with dimension 100mm x100mm. Plate 1a and b shows the welded specimens before and after thermal treatments respectively. A hole of diameter 5.0mm was drilled and tapped close to the upper edge of the samples for thermocouple placement and temperature measurement during welding. 3-D Model of the test specimen generated from Autodesk Inventor Professional Modeling Software was used in simulating HAZ and welded pool along three planes (YZ, XZ, XY) (Figs. 1 and 2).

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 11, November 2016
ISSN (Online) 2348 – 7968 | Impact Factor (2015) - 4.332
www.ijiset.com



(a) (b)

Plate 1: Welded specimens (a) before thermal treatment (b) after thermal treatment

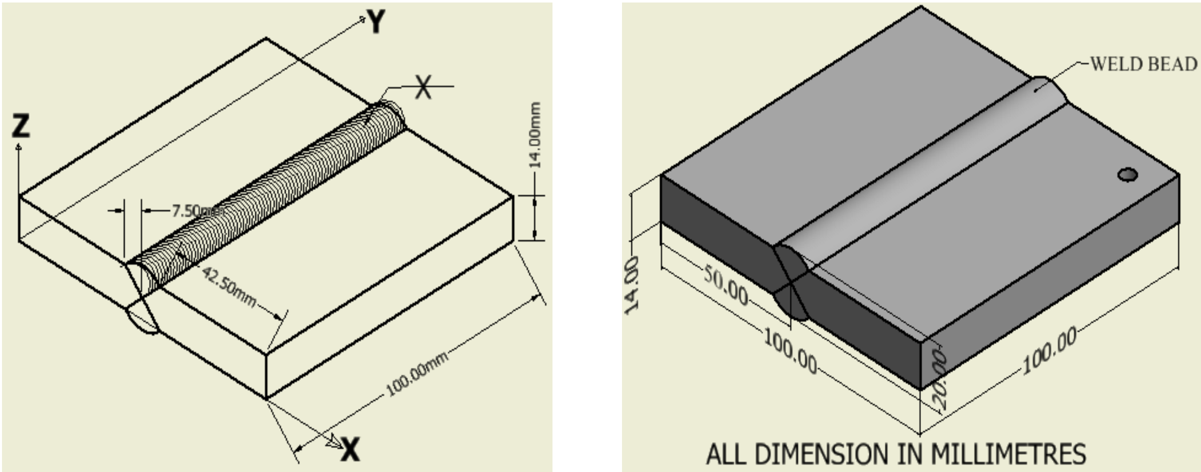


Fig. 1: 3-D Model of the test specimen generated from Autodesk Inventor Professional Modeling Software,(a) Double-V-butt welded joint and (b) 5.0mm hole drilled and taped.

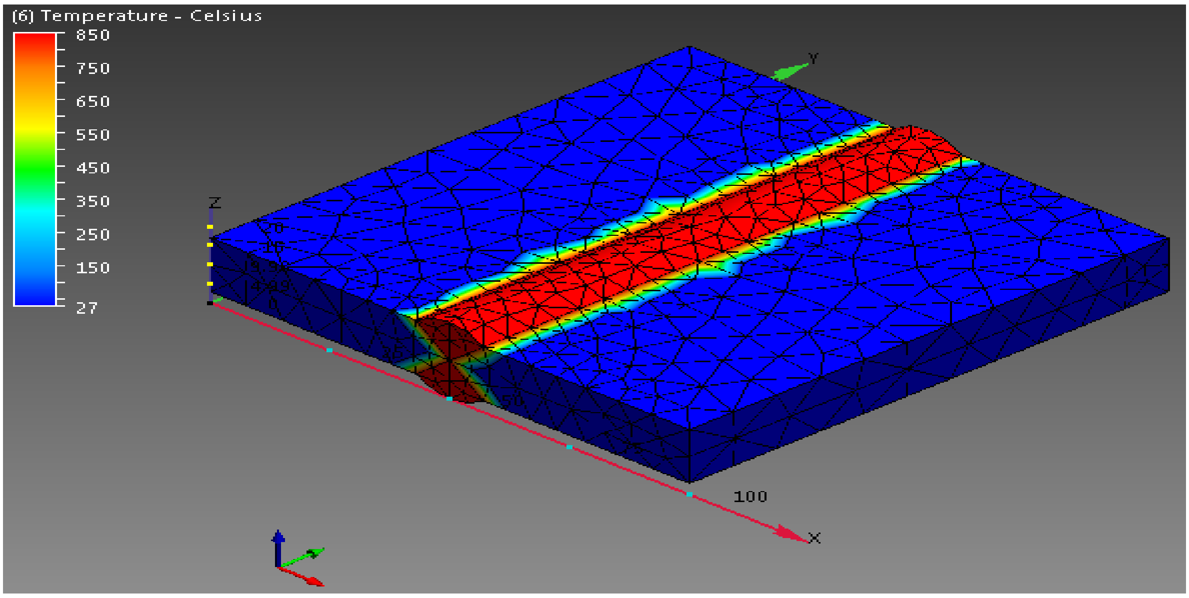


Fig. 2 : Simulated model of low carbon steel showing Heat Affected Zone and Welded pool on the three Planes (YZ, XZ, XY) (Visual style –Shaded mesh), Using; Autodesk Inventor Simulation CFD 2015 Application Software;.

2.2.3. Post Weld Heat Treatment (PWHT)

A two pass welding was conducted on the low carbon steel under room temperature. After welding operation, the specimens were prepared for post weld heat treatment. Platinum rhodium thermocouple of K-Type (-30 to +1370°C) were inserted into each of the holes drilled at the edge of the welded specimen to be connected for temperature measurement of the specimen while inside the furnace.

Five standard specimens were annealed by heating to a temperature of 920℃ in a furnace and cooled in the furnace environment to room temperature. Another five specimens were normalized by heating to a temperature of 920℃ and held for about 20 minutes and allowed to cool naturally in air. A set of two standard specimens at a time were heated to a temperature of 920^0C and were allowed to homogenize at that temperature for 20 minutes and this was repeated four times. After 20 minutes, the specimen was taken out of the furnace and directly quenched in different media; tap water, palm oil, quartz 5000 Total Engine oil and ground nut oil maintained at room temperature in the quenching tank for 30 minutes. The specimens were taken out of the quenching tank and cleaned. The remaining two as-weld specimens served as control.

2.2.4. Mechanical Tests

Hardness Test

The hardness of samples was measured by Brinell hardness tester under a static load of 490.3MN with a diamond ball indenter of 10mm diameter maintained for 10 to 15 seconds. The diameter of the resulting impression was then measured with the aid of a calibrated microscope according to BS240 and ASTME 10-84 standard.

Microstructure Examination

The microstructure of the PWHT and non heat treated samples were observed under optical microscope. The specimens were mounted in hot phenolic powder and were ground on a water lubricated hand grinding set-up of abrasive papers, from the coarsest to the finest grit sizes. Polishing was carried out on a rotating disc of a synthetic velvet polishing cloth impregnated with micron alumna paste. Final polishing was carried out with diamond paste. The specimens were then etched with standard 2% nital so as to reveal the ferrite grain boundaries. The optical microscopic examinations were carried out with a metallurgical microscope with magnification 40*16. Low carbon steel has several structures such as ferrite, pearlite, and martensite depending on how the carbon is distributed in the material. Differences in microstructure are important because they can help to determine if a metal has been subjected to corrosive chemicals, is softer or harder at the surface, has been deformed, was welded properly, or has been over-heated. Microstructural results were typically reported as pictures of the microstructure along with a paragraph interpreting the meaning of the structure.

3. RESULTS AND DISCUSSION

Chemical Composition

The result of chemical composition of the low carbon steel is presented in Table 1.

Table 1. Chemical composition of the low carbon steel

Grade	Colour code	%wt Carbon	%wt Silicon	%wt Manganese
Standard	Yellow	0.135 – 0.33	0.18 – 0.28	0.40 – 0.60
NST 44-2	Yellow	0.165	0.19	0.50

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 11, November 2016
ISSN (Online) 2348 – 7968 | Impact Factor (2015) - 4.332
www.ijiset.com

Simulated result of Heat Affected Zone (HAZ) on the three planes YZ, XZ and XY using Autodesk Inventor Simulation CFD 2015 Application Software

YZ-plane HAZ across the welded area:

Fig. 3 shows HAZ on different coordinate points determined from the base metal to the welded metal on the yz -plane. The temperature profile of the center of heat-affected zone (reddish area), is completely different from the HAZ (yellowish, greenish and bluish areas) to the edges of the plate. The effect of HAZ decreases to the edges of the plate, the reddish area was greatly affected.

XZ-plane HAZ along the welded area:

Fig. 4 shows HAZ on different coordinate points determined from the base metal to the weld metal on the xz-plane. The temperature profile of the center of weld zone (reddish area), is completely different from the heat-affected zone (reddish, yellowish, greenish and bluish areas) to the edges of the plate. The effect of the heat-affected zone decreases towards the edges of the plate.

XY-Plane Heat Affected Zone on the Welded area:

Fig. 5 shows HAZ on different coordinate points determined from the base metal to the weld metal on the xy-plane (100 x 100 mm). The temperature profile of the center of weld zone (reddish area) is completely different from the heat-affected zone (reddish, yellowish, greenish and bluish area). The effect of heat-affected zone decreases towards the edges of the plate.

In general, the HAZ decreases as the colour of the affected area changes from reddish-yellowish-greenish-bluish area.

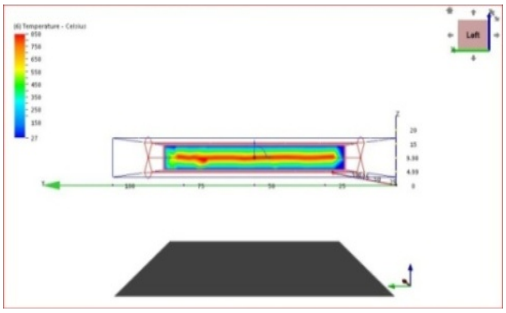


Fig. 3: HAZ across the welded YZ plane 61.00, 66.30, 7.00

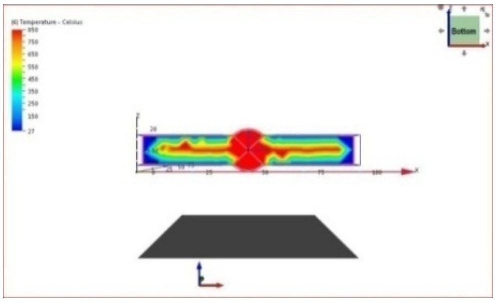


Fig. 4: HAZ along the welded area XZ-plane 61.00, 66.3, 7.00 .

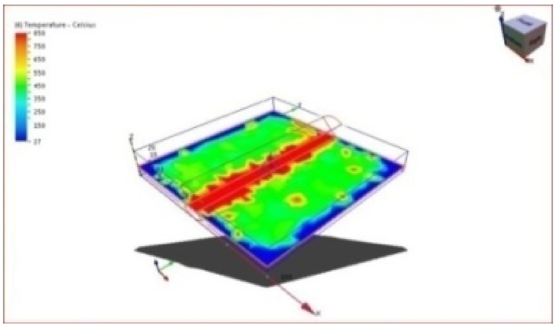


Fig. 5: HAZ on the welded area XY-plane 61.00, 66.3, 7.00.

Temperature profile:

The temperature profile from CFD model for the first and second passes are shown in Figs. 6 and 7.

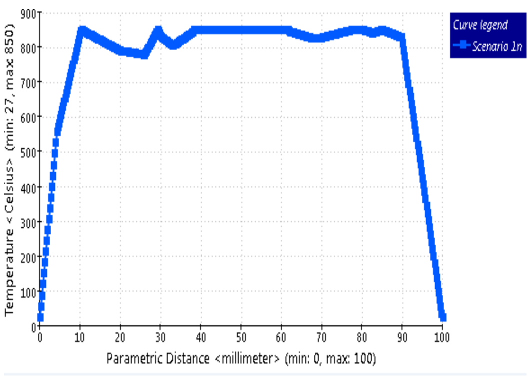


Fig. 6 : Temperature profile from CFD model for the first pass

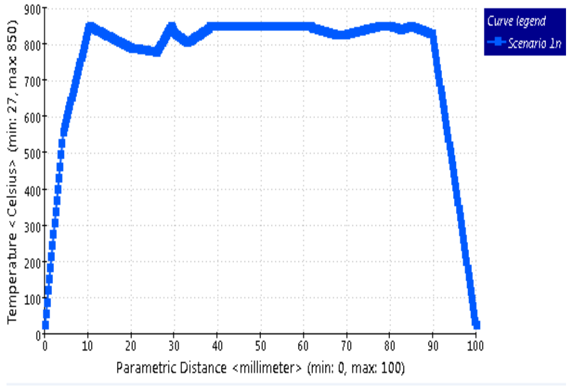
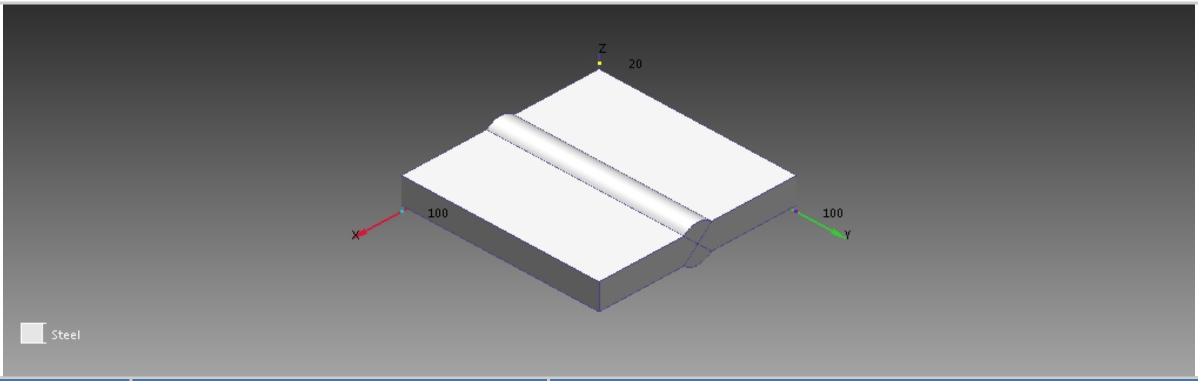


Fig. 7 : Temperature profile from CFD model for the second pass

Table 2. shows the Autodesk Simulation CFD 2015 sheet

Table 2.0: Autodesk Simulation CFD 2015 sheet

Materials



NAME	ASSIGNED TO	PROPERTIES	
Steel	BAR:2@BARS1:1 welding beads:1@BARS1:1 welding beads:1@BARS1:1 BAR:6@BARS1:1	X-Direction	Piecewise Linear
		Y-Direction	Same as X-dir.
		Z-Direction	Same as X-dir.
		Density	7833.0 kg/m3
		Specific heat	465.0 J/kg-K
		Emissivity	0.3
		Transmissivity	0.0
		Electrical resistivity	1.7e-07 ohm-m
		Wall roughness	0.0 meter

TYPE	ASSIGNED TO
Total Heat Generation (850 W)	welding beads:1@BARS1:1 welding beads:1@BARS1:1

Boundary conditions

Initial Conditions

TYPE	ASSIGNED TO
Total Heat Generation (27 W)	BARS1:1@ welding beads:1 BARS1:1@ welding beads:1

Hardness properties:

Figs. 8 and 9 show variations of hardness values at welded pool and heat affected zone (HAZ) respectively for welded specimens. As expected, the hardened specimens (martensite) have the average hardness values of (133.73 BHN, 125.64 BHN, 88.13 BHN ,123.99 BHN) at heat affected zone hardened in (Quatz 5000 Engine oil,Ground nut oil,Palm oil and Water) media respectively , compared with average hardness value of 100.97BHN at heat affected zone for untreated as-weld specimen. This signifies that at heat affected zone quench hardening improves the strength of low carbon steel by increase in hardness value except for palm oil quench hardening medium.

Also, the hardened specimens (martensite) have the average hardness values of (100.77 BHN, 99.26 BHN, 84.06 BHN, 69.83BHN) at welded pool hardened in (Quatz 5000 Engine oil, Ground nut oil, Water and Palm oil) media respectively, compared with average hardness value of 106.855BHN at welded pool for untreated as-weld specimen. This signifies that at welded pool quench hardening has not improved the strength of low carbon steel by decrease in hardness value.

Normalizing and annealing post-weld heat treatments resulted into lower strengths of the low carbon steel at heat affected zone with hardness values 82.25BHN and 73.365 BHN and at welded pool with hardness values 89.2BHN and 61.96 BHN respectively, compared with average hardness value of 100.97BHN at heat affected zone and average hardness value of 106.855BHN at welded pool for untreated as-weld specimen. The decrease in hardness value when compared with the control was expected for normalizing and annealing thermal treatment processes.

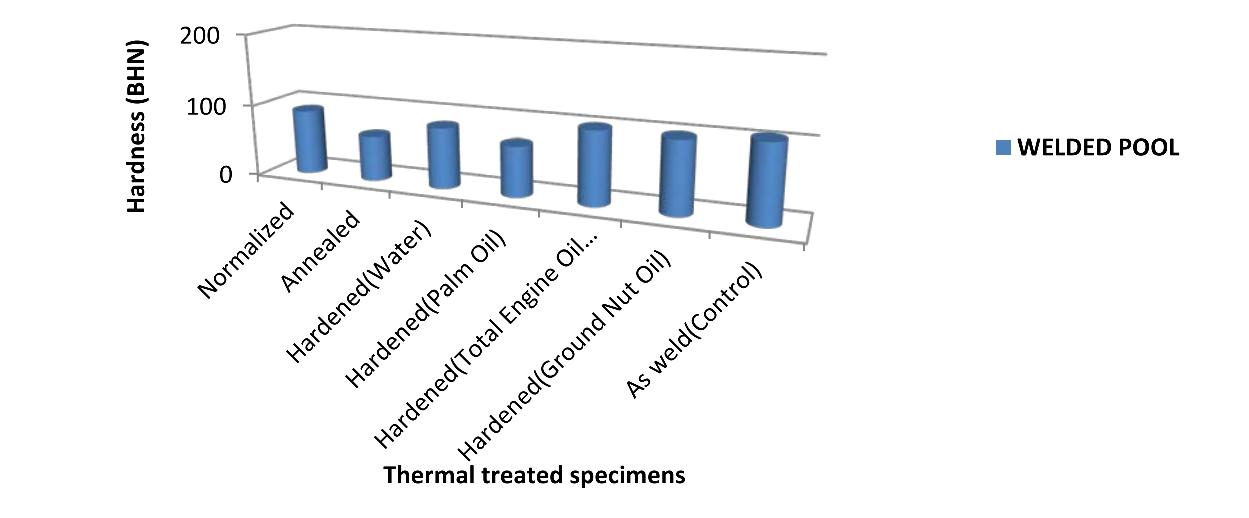


Fig. 8: Brinell Hardness test result for welded pool

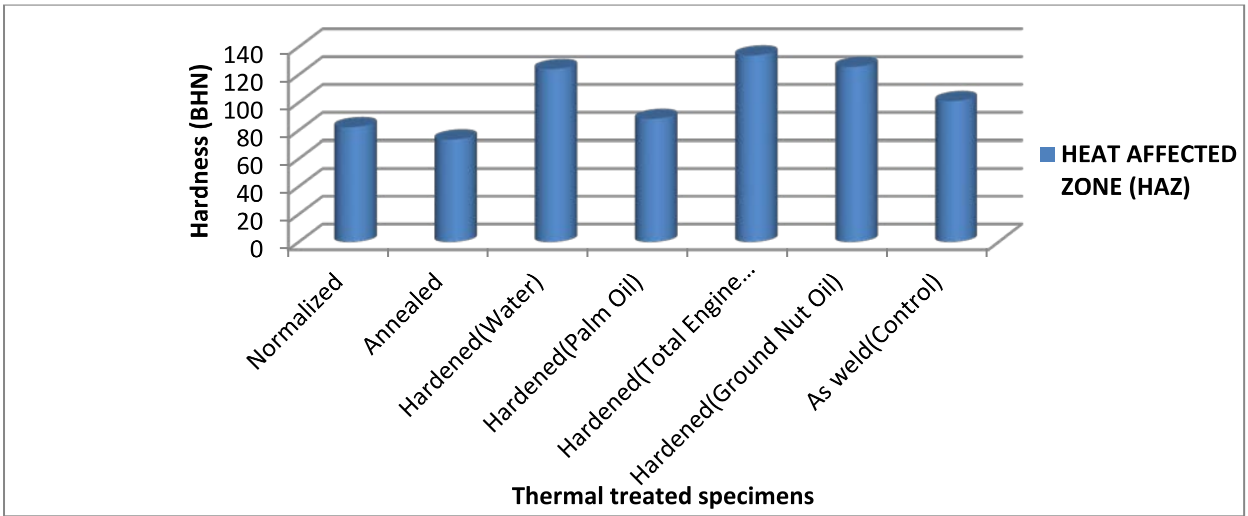


Fig. 9 : Brinell Hardness test result for HAZ 15mm away from weld pool

Microstructure analysis:

The microstructures of as-weld and PWHT low carbon steel are presented in Plates 2 to 8. The microstructure of the as-weld low carbon steel sample showed ferrite in the grain boundaries of the acicular pearlite grains. For this reason, the microstructure of the untreated low carbon steel can be described as having a ferrite-austenite duplex phase (Plate 2 (a) and (b)). Subjecting the low carbon steel to annealing PWHT at 920^{0}C affected the spatial distribution of ferrite at the grain boundaries, and scales were observed to be present in ferrite (Plate 3 and (b)). This may be due to oxidation at the metal surface. On the other hand, normalizing PWHT gave a uniform large grained structure of ferrite and pearlite with fine grained (Plate 4 (a) and (b)). The quench-hardened PWHT in media, water (Plate 5), Palm oil (Plate 6), Engine oil quatz 5000 (Plate 7) and Ground nut oil (Plate 8) revealed the presence of scales more widely distributed on the metal surface and highly dispersed ferrite.

40x16

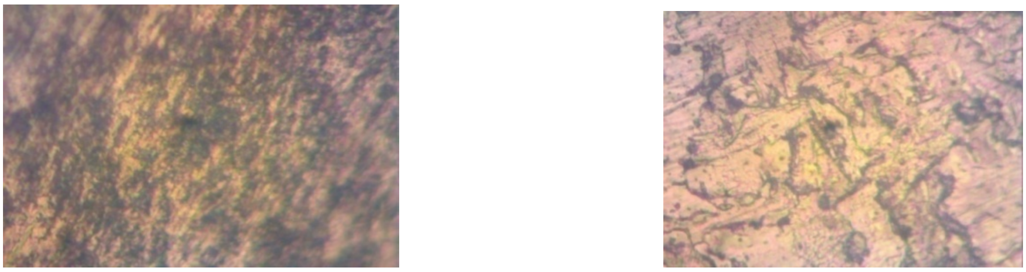
(a) (b)

Plate 2: Microstructure of as-weld specimens, (a) welded pool, (b) HAZ.

40x16

(a) (b)

Plate 3: Microstructure of annealed specimens, (a) welded pool, (b) HAZ.



40x16

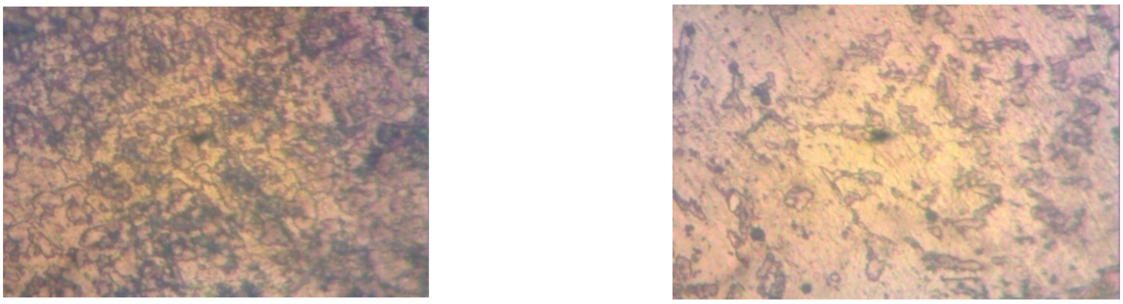
(a) (b)

Plate 4: Microstructure of normalized specimens, (a) welded pool, (b) HAZ

40x16

(a) (b)

Plate 5: Microstructure of water quenched specimens, (a) welded pool, (b) HAZ.

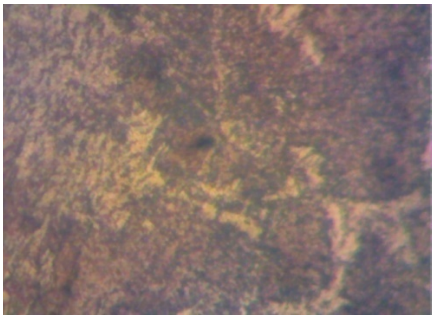


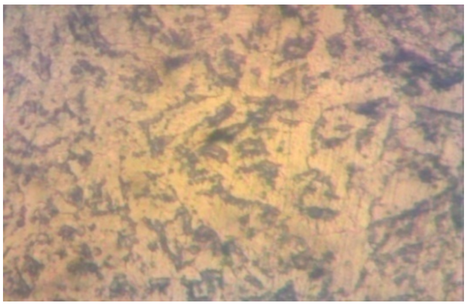
40x16

(a) (b)

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 11, November 2016
ISSN (Online) 2348 – 7968 | Impact Factor (2015) - 4.332
www.ijiset.com

Plate 6: Microstructural of palm oil quenched specimens, (a) welded pool, (b) HAZ.

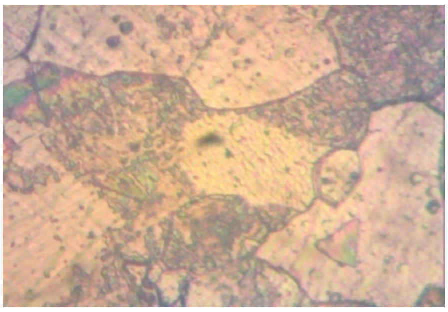


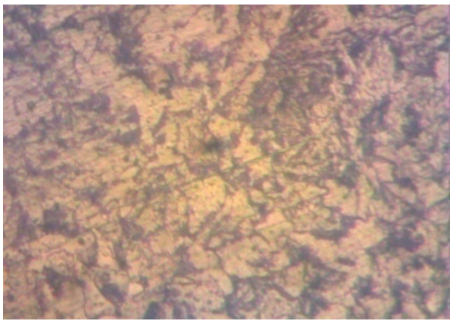


40x16

(a) (b)

Plate 7: Microstructure of quartz 5000 Total Engine oil quenched specimens, (a) welded pool, (b) HAZ.





40x16

(a) (b)

Plate 8: Microstructure of ground nut oil quenched specimens, (a) welded pool, (b) HAZ.

.

4. CONCLUSION

From the results of the mechanical tests it could be concluded that butt-welded annealed and normalized low carbon steel specimens heat treated at 920^{0}C tend to be more resilient to failures at welded joints while improved fatigue strength was obtained with annealing heat treatment. This may be because of their highest impact average values and higher fatigue strength. Hence, PWHT techniques significantly improved the mechanical property of butt-welded, annealed, normalized low carbon steel.

5. REFERENCES

[1] 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 (1-2).

[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,Vol. 9, No.8, Journal of Minerals & Materials Characterization & Engineering, pp.693-708, USA.

[3] Davies A.C., (1996): Welding, New york, 10th Edition,Cambridge University Pres, pp.343-377.

[4] Devinder,P.S., Mithlesh,S. and Jaspal,S.G., (2013): Effect of Post Weld Heat Treatment on the Impact Toughness and Microstructural Property of P-91 Steel Weldment, Vol. 3, Issue 2, International Journal of Research in Mechanical Engineering & Technology,India.
www.ijrmet.com.

[5] Ejilah, R. I., Onuh, E.I., and Datau, S., (2009): A Study of the Effect of Post Weld Heat Treatment (PWHT) on the Torsional Behavoir of Low Carbon Steel, NIMechE 22nd International conference, pp.13.

[6] Joseph, O.O. and F.I. 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 ISSN 2224-6096 (Paper) ISSN 2225-0581.

[7] Merchant, S. Y, (2015):A review of effect of welding and post weld heat treatment on microstructure and mechanical properties of grade 91 steel, Vol.04, Issue03 ISSN: 2321-7308, International Journal of Research in Engineering and Technology, India

[8] 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.

[9] Senthilkumar, T., and Ajiboye, T.K. (2012): Effect of heat treatment processes on the mechanical properties of medium carbon steel, Journal of Minerals and Materials Characterization and Engineering 11(2) pp. 143-52.

[10] 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.

[11] The New International Webster's Comprehensive Dictionary of the English Language. (2010) : Deluxe Encyclopedic Edition, Typhoon Media Corporation ,USA, pp.583.