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Research Article

Influence of Vibration and Heat Treatment on Hardness and Impact Toughness of Low Carbon Steel Butt-Welded Joints

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Abstract

Effect of vibration and heat treatment on hardness and impact toughness of butt-welded joints of mild steel treated to vibration during welding and annealed after welding were investigated with a view to establishing vibration regimes and the resultant microstructures that may improve service performance and increase life extension programs of welded joints. Commercially available mild steel plates were butt-welded employing vibration and non-vibration welding conditions. Vibration frequencies were varied from 0 to 14.32Hz in three different steps. Hardness and impact toughness tests were conducted on test specimens produced from both vibratory and non-vibratory welding conditions. Similarly, tests specimens of both conditions were annealed at temperatures 350^{0}C, 450^{0}C, 550^{0}C, 650^{0}C and 750^{0}C. There was no remarkable difference in hardness values of heat treated and non-heat treated specimens. The same scenario repeats itself for annealed specimens. In the same vein, hardness values obtained at the weld zones were higher than those of base metal and heat affected zones (HAZ). Consequently, the higher the annealing temperature the lower the hardness. Impact toughness of joints produced with 7.96 Hz and 14.32 Hz vibration frequencies were inferior in comparison with the stationary condition. The mechanical performance of the weldment with reference to strength and toughness depend upon the type of microstructure of weld metal and heat affected zone. The post weld heat treatment of annealing and stress relieving tend to significantly reduce the incidences of the conditions highlighted above.

Keywords: annealing; steel; heat treatment; Impact toughness

1.0 Introduction

Mechanical vibration has been used to improve mechanical properties of castings and weldments by way of grain refinement, and this practice has been used by researchers. Several researches describing the benefits of vibration during welding and casting on microstructure, internal micro-stresses and mechanical properties had been carried out [1, 2, 3, 4]. Grain refinement and improvements in mechanical properties in castings due to the application of vibration during casting had also been achieved [1, 3]. A weldment is usually formed by fusion welding which results in the formation of monolithic structure owing to recrystallization and grain growth (Parmar, 1997). Such welded joints vary in metallurgical structure from point to point with consequential variation in mechanical properties. This is so because welding results in the development of a temperature gradient which varies from the higher temperature encountered in the centre of the weld pool to the ambient temperature along the transverse direction to the weld axis. In vibrated weldments, two major factors contribute to the changes in grain size and harness; these include dendritic fragmentation and detachment and total cooling rate [5] .Vibration enhances the total cooling rate of the weld pool by causing a positive effect on the effective value of thermal conductivity of the liquid pool. The stirring effect increase the heat transfer rate within the weld pool and thereby accelerated the rate of dendrite fragmentation and grain detachment with reduced dendrite spacing. Faster cooling weld pool due to vibration produces harder phases with reduction in percent elongation of the welded joint [2] .According to [2], a high hardness value indicates quite severe cooling conditions in the heat affected zone in low carbon steel weldments. There is strong evidence to show that harness also has a strong influence on the strength and toughness of welded joints. Impact toughness drops in areas of maximum hardness and rises in the field of declined hardness or coarsening of carbides [2]. Many methods exist for improving quantity and performance of welded structures [6]. Mechanically vibrated welded joints of low carbon steel have been produced and shown to improve quality of joints significantly [7, 8,9] Parmar, 1997). In other previous works [9, 2, 10, 11] impact toughness, yield strength and tensile strengths also increased significantly at moderate vibration of the weld pool. As the use of welded steel structures of both low and high carbon steel continues to increase, incidences of fracture and cracking has become an important issue. From the point of view of design, impact toughness and hardness properties of mechanically vibrated welded structures at optimum vibration frequencies at which improved performances is achieved should be determined accurately so that the life of these welded structures can correctly be evaluated.

The present study examines the effect of low frequency vibration during welding on hardness and impact toughness of butt-welded joints of low carbon steel with a view to investigating the interaction between these two strength parameters as a result of vibration. Knowledge of this phenomenon is very useful for design and life extension programs in structures produced from these welding techniques. Also in weld failure assessment, a profound knowledge of these weld characteristics is required to determine the mechanisms of the weld failure and what can be done to prevent it.

2.0 Materials and Methods

2.1 Materials and Equipment

Commercially available mild steel bars were obtained from a metal scrap market at high level Makurdi in Benue State, Nigeria. Chemical composition of the steel material and welding electrodes were confirmed and are presented on Tables 1-2. Mild steel plates treated at three different frequencies of 0Hz, 7.96Hz, 14.32Hz and measuring 10mm thick, 8mm wide and 75mm long were used. The equipment used for this work include hacksaw, hand file, heat treatment furnace, impact testing machine, Rockwell hardness tester, grinder, mounting press, metallurgical microscope and polishing wheel.

2.2 Methods

Commercially available mild steel bars were obtained from a metal scrap market at high level Makurdi in Benue State, Nigeria. Chemical composition of the steel material and welding electrodes were confirmed and are presented on Tables 1-2 Element	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**
(%)	0.15	0.26	0.18	0.005	0.001	0.058	0.016	0.318

Table 1: Chemical composition of Steel Material

Element	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**
(%)	0.11	0.18	0.37	0.02	0.02	0.04	0.47	0.40

Table 2: Chemical composition OF Welding ElectrodesSome mechanical properties of the steel namely, yield strength (Qy); tensile strength (Qts) and elongation (E) were also confirmed (Qy=450Mpa, Qts = 629Mpa and E= 25%). The steel bars were cut into 18 pieces measuring 10 x 8 x 75mm using the hacksaw. Three pieces were selected representing the three different frequencies of 0Hz, 7.96Hz and 14.32Hz whereas the remaining 15 pieces of the samples were heat treated (annealed).

2.2.1 WELDING

The steel bars were cut into several plates measuring 14mm thick, 50mm wide and 90mm long using an electrically driven power saw. Each cut pieces was paired together with another to give six pairs. From each pair and each piece, a welding groove was marked out and milled to give a full butt type edge with a bevel angle of 30^0 to ensure penetration of filler metal. The steel pieces with smooth and uniform bevels were cleaned of oxides grease, rust and paints by sand grinding and degreasing using methanol. The cleaned pieces were swabbed in water and dried in hot air. Thereafter, the paired pieces were tack-welded together with a roof gap of 3mm, the tack-welded pairs were marked as A, B, C, D, E and F to be welded machine. Welding current of 100A and guage 10 (SAW E6013) filler rod were selected. The vibrator was calibrated into five different frequencies using a vibration meter [model – VB-8201 HA] along with vibration pick up. The five frequencies were recorded as 1.59Hz, 7.96Hz, 14,32Hz, 20.69Hz and 27.06Hz a pair of tack-welded plate (marked A) was welded without vibration while the remaining pairs (B-F) were welded applying vibration at the five different frequencies. Due to the thickness of the plates, four passes in all were deposited. At the end of each pass, excess slag was removed from the weld metal by use of an electric grinding stone followed by cleaning with a wire brush.

2.2.2 Heat Treatment

Heat treatment process of annealing was carried out on non-vibratory specimen at 0Hz frequency and others at 7.96Hz and 14.32Hz respectively. 15 pieces of the specimens were heat treated at different temperatures of 350^0C, 450^0C, 550^0C, 650^0C and 750^0C. The specimens were packed into a refractory-linked box, inserted in the heat treatment furnace [model -2804L] and heating was carried out at 20^0C above the upper critical temperature. At each temperature, the specimens were held in the furnace for 1 ½ hours followed by slow cooling in the furnace from the desired temperature. The entire mass of the furnace was allowed to cool down along with the specimens. The specimens were then taken for hardness measurement and impact test.

2.2.3 Hardness Measurement

Harness test samples (10 x 8 x 75mm) were prepared using a hacksaw. All samples were obtained in the same direction from the flat position of each welded plate such that the welded zone was in the middle of each sample. Hardness values were obtained on the non-heat treated and annealed samples. Three samples were not heat-treated and represent the three different vibratory conditions while the annealed specimens were also subjected to the same conditions. The hardness values were as well subjected to the same conditions. In all, hardness values were determined across the cross-section of each specimen. Rockwell hardness tester (model – WELL TEST - 38506) was used and indentations were made on the specimens at intervals of 1mm using the conical diamond indenter and Rockwell scale of C with a load of 1471N. Six different readings were taken in each zone of the joint including the welded portion and the average values recorded. The hardness tester used a direct reading instrument based on the principle of differential measurement. The test was carried out by slowly raising the specimen against the indenter until a fixed minor load was applied through a loaded lever system. When the major load was removed and with the minor load still acting, the Rockwell hardness number was read on the dial gauge using the outer scale

2.2.4 Impact test

Impact toughness was determined on all the samples which include the annealed and non-heat treated. The test was conducted on an Avery

Denison Impact testing machine (model-300/150J) after a notch of 2.5mm was milled into each of the samples at midpoints, in order words at the weld zones. The notch was done in a manner that crack would propagate through the weld metal upon application of impact load application the amount of energy absorbed defined as the impact toughness of the sample was recorded for every sample.

3.0 Result and Discussion

The results obtained in this work are presented below: the hardness values for the non-heat treated and heat treated are presented in tables 3 and 4 respectively while the corresponding impact toughness value is presented in table 5.

Frequency (Hz)	Parent Metal	HAZ	Weld Zone
0Hz	26.1	30.1	34.3
7.96Hz	25.4	32.9	32.6
14.32Hz	30.1	30.1	32.2

Table 3: Hardness Test Results for Non-heat Treated Samples

Frequency	Temperature(^{0}C)	Parent Metal	HeataffectedZone	Weld Zone
0	350	29.4	33.3	39.3
7.96	350	28.6	32.5	34.9
14.32	350	30.4	37.3	41.8
0	450	28.5	32.5	35.7
7.96	450	27.3	31.6	37.7
14.32	550	28.8	31.3	33.4
0	550	29.9	36.0	37.7
7.96	550	28.9	31.7	35.1
14.32	550	25.6	29.8	32.8
0	650	28.2	30.1	33.7
7.96	650	26.0	30.8	35.0
14.32	650	27.4	32.4	37.4
0	750	26.3	28.4	30.7
7.96	750	25.7	30.5	33.5
14.32	750	26.7	29.7	31.7

Table 4: Hardness Test Results for Annealed (Heat Treated Samples)

Non heat-treated samples	0Hz 41.5J	7.96Hz 28J	14.32Hz 20J
350^{0}C	0Hz 42.5J	7.96Hz 24.0J	14.32Hz 32.0J
450^{0}C	0Hz 42.0J	7.96Hz 28.0J	14.32Hz 38.0J
550^{0}C	0Hz 43.0J	7.96Hz 28.0J	14.32Hz 14.0J
650^{0}C	0Hz 45.0J	7.96Hz 32,0J	14.32Hz 38.0J
750^{0}C	0Hz 36.0J	7.96Hz 44.5J	14.32Hz 31.0J

Table 5: Impact Test Results (Notch Bar)**3.1 Hardness**

Measured values of harness cross –section of the welded joints of steel welded at the different vibration frequencies are presented in Tables 3 and 4. The hardness values are basically mean values of six measurements taken from each zone of the welded joints. It is worthy of note that irrespective of the welding conditions, vibration frequencies and heat treatment, hardness of the weld zone was consistently higher than that of the parent metal while heat affected zone was consistently higher than that of the parent metal and heat affected zones in all the specimens studied. Highest value of 41.8 HRC for all the samples studied at 14.32Hz and annealed at 350^{0}C as against the least hardness value of 30.7 in the same zone but at normal welding condition and annealed at 750^{0}C. Similarly, at the heat affected zone hardness value of 37.3 HRC was recorded at 14.32Hz vibration frequency and annealing temperature of 350^{0}C when compared with the least of 28.4 HRC at normal welding condition annealed at 750^{0}C. Hardness value of 30.4HRC was recorded as the highest at 14.32Hz annealed at 350^{0}C in comparison with 25.4 HRC recorded at 7,96Hz but not annealed or heat treated. In all low hardness numbers recorded especially at the weld zones for all the samples were attributed to welding defects (Parmar, 1997). The defects that were visible were blowholes and metal penetration. These defects might be due to faulty welding technique employed during the welding process (Parmar, 1997).

As evident in the results of the hardness, low hardness values were recorded in the parent metal and heat affected zone presumably due to coarse grains. These zones were also established to be prone to corrosion and stress corrosion cracking [9]. Due to the vibration treatment, the residual stresses introduced in the weld zone and high temperature gradient experienced during the welding process and subsequent grain growth was reduced by about 70%. Welding defects such as porosity, cracking, inclusions and gas entrapment also accounted for the seemingly low hardness values especially at the weld zone. The hardness numbers were consistently higher at the weld zones than at the parent metal zones and the heat affected zones in spite of the welding conditions and vibration frequencies for all the sampled studied. It was also established that at the moderately vibration frequency of 14.32Hz, hardness values are consistently higher especially at the weld zones when heat treated than in non-heat treated samples.

3.2 Impact Toughness

The notch-bar impact test does not yield the true toughness of the welded joints, but rather its behavior with a particular notch especially the welded at the different vibration frequencies as presented in Table 5. However, the outcome may be useful for comparative purposes as it could be used by aircraft and automotive industries where high impact strength will generally give satisfactory service where shock loads are often encountered [8]. In spite of the welding condition or vibration frequency, the result of the impact at stationary welding condition that is 0Hz was consistently higher than vibrated samples**.** Unlike in earlier cases, vibration does not seem to improve the impact toughness of the butt-welded joints. Test result from table 5 shows that the low carbon steel material can be used for comparison purposes rather than in industrial applications. From the date and information obtain in this work, impact toughness recorded at the normal welding condition (that is 0Hz) were consistently higher than those recorded at 7.96Hz and 14.32 Hz vibration frequencies. It follows the same pattern even with the non-heat treated samples. Impact strength is highest at 0Hz (41.5J); 7.96Hz (38.0J) and 14.32Hz (20.0J). Impact toughness at the different heat treatment temperatures are consistently increasing as the temperature increases for non-vibratory condition. The same phenomenon was also recorded for vibration frequency of 7.96Hz. However, the same scenario did not manifest with the raising in temperature from 350^0C -750^0C for 14.32Hz. In all, moderate toughness was recorded for samples vibrated at 14.32Hz.

4.0 Conclusion

The deterioration in strength of a welded joint has been attributed to increase in amount of impurities, flaws and discontinuities present in the welded section. There is therefore need to improve the quality and performance of welded structures. Consequently, mechanically vibrated welded joints of low and medium carbon steels have been produced and shown to improve quality of joints significantly. The heating and cooling cycles of welding result in the development of residual stresses. The residual stresses developed due to welding being a combination of tensile and compressive stresses. Different welding processes result in different rates of cooling with consequential effect on microstructure, grain size and residual stresses. All these factors can individually and collectively affect the fracture toughness of a welded joint. A high cooling rate process like EAW results in fine-grained weld zone of high hardness and strength, but with low impact strength, i. e. low toughness. The post weld heat treatment of annealing and stress-relieving tend to significantly reduce the incidences of the conditions highlighted above. On the other hand, a low cooling rate process like submerged arc welding results in comparatively coarser-grained weld zone of medium hardness and strength with high fracture toughness. As the weld zone and HAZ have different hardness so is their tendency to brittle fracture which is a major function of the composition of the microstructure that influences the mechanical properties of the weld metal.

Reference

1. Shajan,Nikhil; Arora, Kanwer Singh; Asati, Brajesh; Sharma, Vikram; Shome, Mahadev (2018) Effects of Post-Weld Heat Treatment on the Microstructure and Toughness of Flash Butt Welded High-Strength Low-AlloySteel. Metallurgical and Materials Transactions A, Volume 49, Issue pp.1276-1286.
2. Xi C, Sun D, Xuan Z, Wang J, Song G (2016) Microstructures and mechanical properties of flash butt welded high strength steel joints- Materials & Design, 2016 –Elsevier
3. Xu Z, Lu P, Shu Y (2016) Microstructure and fracture mechanism of a flash butt welded 380CL steel – Engineering Failure Analysis, 2016 – Elsevier
4. Yin N, Meng XT, Li F, Cui Y, Zhou ZW (2014) Cracking analysis of automobile rim flash butt welding- Advanced Materials, 2014 - Trans Tech Publ
5. Räsänen A.N, Martikainen J. (2011) Experimental review of metallurgical flash weld defects in welded joints: essence of flat spots, penetrators and oxide inclusions- Science and Technology of Welding, 2011 - Taylor & Francis
6. Raveendra, J. and Parmar, R. S. (2000); Mathematical Models to predict Weld bead geometry from Flux Cored Arc Welding. Metal Construction. Vol. 19.
7. Mandal S, Tewary NK, Ghosh SK, Chakrabarti D (2016) Thermo-mechanically controlled processed ultrahigh strength steel: microstructure, texture and mechanical properties- Materials Science and Engineering, - Elsevier
8. Polakowski, N. H. and Ripling, F. J. (1999) Strenght and structure of Engineering Materials, Prentice –Hall, Inc. Englewood Cliffs, N. J.
9. Parmar, R. S. (2007); welding Engineering and Technology. KHANNA Publishers, India.Show, B.K.; Veerababu, R.; Balamuralikrishnan, R.; Malakondiah, G. (2010) Effect of vanadium and titanium modification on the microstructure and mechanical properties of microalloyed HSLA steel. Material Science andEngineering A 2010, 527, 1595–160
10. Oladele, Isiaka Oluwole, Adewuyi, Benjamin Omotayo(2019) Performance Evaluation of the Effects of Post Weld Heat Treatment on the Microstructure, Mechanical and Corrosion Potentials of Low Carbon Steel-Advanced Technologies & Materials 2019.
11. Tawfik D, Mutton PJ, Chiu WK (2008)Experimentaland numerical investigations: Alleviating tensile residual stresses in flash-butt welds by localised rapid post-weld heat treatment - Journal of materials processing technology, 2008 – Elsevier
12. Ichiyama Y, Saito T (2004) Factors affecting flash weldability in high strength steel–a study on toughness improvement of flash welded joints in high strength steel - Welding international, 2004 - Taylor &Francis.
13. Garcia, C.I.; Al-Hajeri, K.; Hua, M., (2009). Particle stimulated nucleation of ferrite in micro-alloyed steel.IMaterials Science and Technology (MST&TO9), Steel Processing, Pro- duct and Applications Symposium, Pittsburgh, PA, October 25–29