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Study of effects of Heat treatment on the Hardness and Microstructure of Welded Low Carbon Steel Pipes

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ABSTRACT
This paper reports investigations made on the effects of annealing heat treatment on the micro-structural and mechanical property behavior of 0.078wt % C steel weld. Welding operation was carried out on the low carbon steel of 0.078wt % carbon content in pair; followed by heat treating (annealing), the specimen was heat treated at the weld zone to a temperature of 850°C using digital heat treatment furnace. For effective study of the effect of annealing on the welded joint, mechanical test (hardness) was carried out and micrographs were obtained to reveal the microstructures of the heat treated (annealed) and un-heat treated samples. From the micro-structural analysis, the micrographs shows that the heat treated sample had a more predominant pearlite structure which is the reason larger areas of the structure is darker and less ferrite structure due to recrystallization and carbon diffusion; hence a significant improvement in ductility, toughness and grain refinement accompanied with decrease in hardness and brittleness.
Keywords: Annealing, Ductility, Hardness, Heat treatment, Microstructure, Welding

1. Introduction

One of the most important methods of permanent fastening and versatile means of fabrication available to industry is welding. This is because it is one of the most important tools available to engineers in his efforts to reduce production, fabrication and maintenance costs (Adedayo *et al.*, 2010).
Welding is simply an art of joining metals by heating and then pressing together which simply requires a heat source to produce a high temperature zone to melt the material (though it is possible to weld two metal pieces without much increase in temperature), its application includes: used in ships building, bridges, pressure vessels, industrial machinery, automobile, rolling stock and many other fields. Hence the optimization of the welding process is of the essence in fabrication as its importance cannot be overemphasized but it requires a good understanding of the microstructures generated by the rapid temperature rise in the heat-affected zone (Bipin et al., 2010; Kumaar, 2010 and Maamar, 2008).
However with its importance, problems associated with welding are common issues in these fields, as a complex mixture of two or more constituents is formed when steel or any metal is welded altering its microstructure (International Institute of Welding Guidelines, 1988) .This complex microstructure mixture can lead to highly varied properties of the weld or defects (since the properties of steels or metals are related to its structural make-up (Rajan, 1988). Weld defects may include: cracking, hardness reduction, reduction in strength, distortion, wear properties, corrosion characteristics, internal stresses and etcetera. These defects cannot be overlooked, as a means to control them is of essence to an effective design (Khan and Haasen, 1996).
These defects can however be reduced through various types of heat treatment to obtain the desired properties, simply because a way to unify the structure of the welds is by heat treatment. The science of heat treatment deals with the control of the constituents in metal by heating and cooling, it also deals with the relationship between these constituents and the properties of the metal which can be monitored by microscopic examination known as metallographic. Engineering materials, mostly steel, are heat treated under controlled sequence of heating and cooling to alter their physical and mechanical properties to meet desired engineering applications (Fadare *et al.*, 2011).
Previous research on annealing heat treatment effects on steel welds, were carried on samples of varying carbon content; the results show that hardness and toughness were dependent on the carbon content of the steel (Adedayo *et al.*, 2010). In this project, special attention was focused on the effect of annealing on the mechanical and micro-structural properties of welded low steel pipe of 0.078%wt C in other to appropriately adapt it for better utilization in the aforementioned area of applications of welding.

2. Materials and Method

The specimen used is a low carbon steel pipe (Φ32mm, 2mm thick and 600mm long), which was obtained from a local market known as “Owode Onirin” market, Lagos state, Nigeria. Chemical composition analysis was carried out at Universal Steel Rolling Mill, Ogba-Ikeja, Lagos state, Nigeria using the mass analyzer.

2.1 Equipment
The equipment used for this research are; mass analyzer, digital heat treatment furnace, metallurgical microscope with in-built camera, electrical arc welding machine, Grinding and polishing machine, hack saw, TECO micro-hardness tester and welding electrodes.
2.2 Welding Procedure
The specimen was cut into four pieces of equal sizes (150mm long) and welded together in pair. The specimen (low carbon steel) was welded using electric arc welding at Federal Industrial Institute of Research, Oshodi, Lagos state, with procedural steps as follows:

i. Clamping of the specimen firmly on the vice.
ii. Welding operation parameters; welding current= 140A; welding voltage=80V; Electrode specification= 2.5mm (gauge 10)
iii. Welding was carried out at a slow speed.

2.3 Heat Treatment
The heat treatment process (annealing) was carried out at Federal Industrial Institute of Research (FIIRO), Oshodi, Lagos state Nigeria. A Digital heat treatment furnace with a maximum temperature of 1200°C was used for the heat treating processes. The specimen was heated at the weld centre line gradually to a temperature of about 850°C, and then was held for about two hours at this temperature before allowed to cool in the furnace for 24hrs.
2.4 Hardness test
Hardness values of the treated and untreated weld sample was determined using LECO micro-hardness tester; model: LM-700AT with test load of 490.3MN and a dwell time of 10secs. The LECO micro-hardness tester automatically calculates the hardness values in Vickers hardness number (VHN). This test was carried out at Engineering Material and Development Institute (EMDI), Akure, Ondo state Nigeria.
The hardness of the heat treated and untreated welded steel were evaluated at two points: (i) the weld pool region (ii) the heat affected zone (HAZ).
2.5 Micro-structural Test
The micro-structural examination was carried out as follows; sectioning, grinding, polishing, etching and microscopic viewing at the Metallurgical department of the University of Lagos, using a metallurgical microscope.

- **Preparation (Sectioning)**

Sectioning was carried out by sawing at the weld bead, but care was taken to ensure that the original condition of the material is not altered.

- **Grinding**

A silicon carbide paper was used. This strip of paper was laid flat on the heat-treated pipe and the specimen is robbed to and fro on the strips. Starting with the roughest cloth (240 grit), rub continued until all traces of cuts/roughness are removed. Turning through 90° and rubbing on the next (finer) paper (320 grit) until the previous scratches was removed.

- **Mechanical Polishing**

This was done in two stages with a coarse abrasive agent and fine polishing agent respectively. The specimen was held against a horizontal rotating wheel covered with a short - pile cloth fed with a suspension cream of the polishing agent.

- **Etching**

In this, the specimen was submerged in and swabbed with a chemical reagent (mixture of acid and alcohol) that removes the surface layer produced on polishing.

- **Microscopic Viewing**

The sample was illuminated by a reflected light which was mounted on the microscope; the specimen was viewed through the eyepiece of the microscope so as to determine the micro-structure which was subsequently by snapped by the attached camera to obtain the micrograph.

3. Results and Discussion
3.1 Spectrometry Result
The result of the chemical composition analysis carried on the low carbon steel sample is shown in table 1.

Table 1: Chemical composition of low alloy steel specimen

Element	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Cu**	**Al**	**Fe**
Weight %	**0.078**	**0.025**	**0.304**	**0.0049**	**0.021**	**0.017**	**0.031**	**0.008**	**0.015**	**99.4**

3.2 Hardness Result
The hardness result obtained from the tests carried out on the heat treated specimen and un-treated specimen of the low carbon steel pipe were recorded in table 2.

Table 2: Vickers Hardness test values for annealed and untreated samples

	Weld Pool	**Heat Affected Zone**
Annealed	319.7	191.9
Untreated	358.0	202.3

3.3 Micro-structural analysis results

Plate 1 shows the untreated specimen at the weld pool while Plate 2 shows the treated specimen at the weld pool.

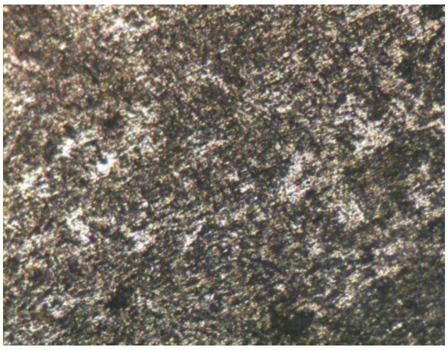

Plate 1: Micrograph of untreated specimen weld pool X200

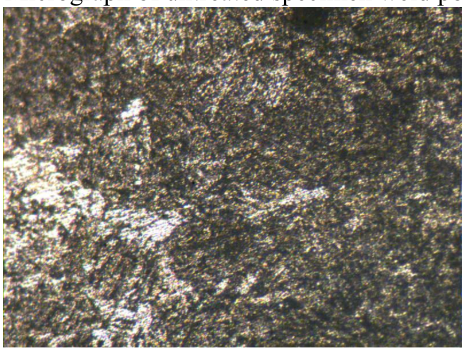

Plate **2:** Micrograph of treated specimen weld pool X200

3.4 Discussion of hardness results

From the hardness test results tabulated above, it can be deducted that the annealed specimen hardness is less than the un-treated specimen and this is due to the recrystallization of the ferrite structure thereby leading to a reduction in carbon (due to diffusion) content hence increasing the ductility and reducing the hardness.

It is obvious from Table 2 that the hardness values have increased from the heat affected zone (HAZ) to the weld pool where the hardness is higher; this is due to the carbon content of the electrode which is added during welding and solid state diffusion of carbon from the base metal; the higher the carbon diluted or diffused into the weld pool, the higher the hardness values.

3.5 Discussion of micro-structural results

(i) Untreated Specimen

The value for the untreated weld sample is maximum for hardness; this is due to a more predominant ferrite structure which is the reason considerable area of the structure is white (the higher the carbon diluted and/or diffused into the weld zone, the higher the hardness values.) as seen in Plate 1.

The arc welding process also induces residual stresses in the weld during the course of welding; the electrodes have low carbon content which also adds to the original carbon content of the material thereby increasing hardness and reducing ductility.

(ii) Annealed Specimen

Annealing the specimen, results in the transformation of austenite grains into ferrite and pearlite. The microstructure observed, shows a coarse grain of ferrite and a coarse structure of pearlite as a result of the furnace cooling which imparts ductility on the material.

The value for the annealed sample is minimal for hardness and maximum for toughness. This is due to the softening effects of the ferrite matrix which arise from liberation of trapped carbon atoms in the saturated ferrite during annealing as depicted in microstructure of the annealed samples in Plate 2. Leading to a more predominant pearlite structure which is the reason larger areas of the structure is darker hence reducing hardness and increasing toughness and ductility.

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; the electrodes have low carbon content. The higher the carbon diluted and/or diffused into the weld zone, the higher the hardness values. The weld structure having a low carbon content due to recrystallization have changed from a harder to a more ability to machine the material by improving the ductility of the material hence reducing the internal stresses.

4. Conclusion

Mechanical property of ductility and toughness in the annealed weld was found to be higher than the un-annealed weld specimen due to carbon diffusion and re-crystallization from the weld zone during annealing accompanied with a refined grain structure. This treatment is recommended as final treatment after welding of low carbon steel when high ductility is required at the expense of hardness as a pointer to the material performing creditably well in service.

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