Studying the Post Weld Microstructural Evolution of Conventionally Heat Treated Medium Carbon Steel.

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ABSTRACT

The characteristics of various forms of heat treatment operations on medium carbon steel subjected to submerged arc welding (SAW) in order to reduce structural failure that results from welding has been of utmost importance. Thus in this work, the microstructural evaluation of locally sourced medium carbon low alloy steel have been extensively studied. The as-received steel was firstly machined and welded using SAW technique before subjecting it to conventional heat treatment (i.e., annealing, normalizing, quenching (water & oil), and tempering). The microstructural evolution was studied with the aid of an optical microscope. The resulting micrographs show that there were considerable reductions in the heterogeneity of the microstructures when subjected to heat treatments (annealing, normalizing, and tempering) after welding. The micrographs obtained during quenching in both oil and water still exhibited the heterogeneity observed in the control sample.

(Keywords: Post Weld Heat Treatment (PWHT); microstructure; low alloy steel; HAZ; fusion zone)

INTRODUCTION

Used in ships, pressure vessels, industrial machinery, agricultural machinery, bridges, and many other fields, welding has remained an important fabrication process. But it also remains, a big concern to engineers due to its complexity in welded structures, varying from heterogeneity of microstructure to the built up residual stresses between the base metal and the weld metal. Weldability of a material is its ability to produce a sound and reliable welded joint, comprising also, is its tendency to produce hard and brittle areas in the heat affected zone (HAZ) or the fusion zone. Steel of poor weldability may require either restrictions in the welding process or special measures to avoid defects of such materials *[1]*. The applications of carbon steel include: ship's hull, pressure vessels, industrial machinery, agricultural machinery, bridges, automotive castings and many others. And in almost all this applications we find a need to introduce welding to join pieces of the carbon steel together.

During welding, steel is heated and the resulting structures are divided into the weldment or fusion zone (FZ), heat affected zone (HAZ) and the base (heat unaffected zone) *[10]*. Differential heating and cooling caused by the thermal cycles produced during welding's rapid heating and cooling results in changes in the microstructural properties and causes detrimental residual stresses *[4]*. Thus, post weld heat treatment is generally carried out on weldments to relieve the thermal residual stresses and reduces the level of heterogeneity of the microstructures at the fusion Zone, the heat affected zone (HAZ) and the base of the metal. The change in the microstructural properties causes heterogeneity of the microstructures at the fusion Zone, the HAZ and the base of the metal. That serves as an impetus to this research to determine and minimize this effect when welded medium carbon steel of 0.33% carbon content is subjected to conventional heat treatment

RESEARCH METHODOLOGY

Sample Preparation

A structural steel was sourced locally in ribbed form. The specimen was received in ribbed form and thus was firstly machined to face off the rib in order to enhance a uniform smooth surface. A part of the specimen was cut for spectrometry analysis (in Universal Steel Company, Lagos) and was found to contain 0.33% carbon and other alloy elements as depicted in Table 1.

Table 1: Spectrometric Analysis of Locally Sourced Medium Carbon Low Alloy Steel (Composition in wt. %).

Elements	Composition
C	0.3300
Si	0.1740
S	0.0499
P	0.0341
Mn	0.8225
Ni	0.0911
Cr	0.0585
Mo	0.0018
V	0.0029
Cu	0.3031
W	0.0003
As	0.0060
Sn	0.0230
Co	0.0094
Al	0.0019
Ca	0.0002
Zn	0.0037
Fe	Bal.

Welding Procedure

The machined specimen was cut into pieces. After setting apart two samples to serve as the control, the other pieces were cut with the aid of hacksaw and a bench vice to a V-shape configuration and filled with electrode by adopting the Submerged Arc Welding (SAW) technique. The schematic setup of a typical SAW is as shown in Figure 1.

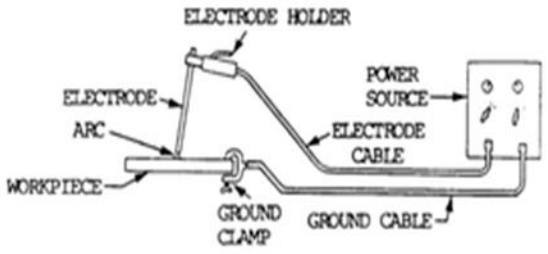

Figure 1: Diagram for Welding Setup [5].

Heat Treatment

The samples, after machining and welding, were divided into five (5) groups, each group for each heat treatment process. The first group was heated to 950^{o}C – a temperature in the region of 30^{o}C – 50^{o}C above the A_1 line of the Fe – Fe$_3$C phase diagram. At 950^{o}C the samples were held for 1 hour to ensure thorough homogeneity .The furnace was switched-off so that the samples temperature will gradually decrease to room temperature. This process is called *annealing*. The specimens were taken out of the furnace after 48 hours of gradual cooling when the furnace temperature would have attained the nominal room temperature.

Normalizing process was also carried out on the second group of samples by heating the welded samples to 950^{o}C – a temperature in the region of 30^{o}C – 50^{o}C above the A_1 line of the Fe – Fe$_3$C phase diagram, were held for 1 hour to ensure thorough homogeneity. These samples were then allowed to cool in the air at a controlled rate.

The third, fourth, and fifth group of samples were subjected to quenching by heating the samples to 950^{o}C – a temperature in the region of 30^{o}C – 50^{o}C above the A_1 line of the Fe – Fe$_3$C phase diagram, and were held for 1 hour to ensure uniform homogeneity. In order to enhance hardness, the red hot steel samples were directly and rapidly cooled in two different quenching media – the third and fifth group in water (that have been heated to a temperature above room temperature to avoid possible quench crack) and the fourth group in 'used engine oil'.

Tempering is another very important form of heat treatment that introduces toughness into ferrous metals *[11]*. After quenching the fifth group of samples from red hot condition to a temperature above room temperature (as explained above), the samples were subsequently re-heated in the muffle furnace to 250^{o}C, held for 30 minutes and then air-cooled in order to toughened it and improve on the ductility as compared to the quenched specimens.

Microstructural Examination

The microstructural investigation was performed using Daheng software – driven AP2000 MTI metallurgical microscope. The samples for the microscopy were mounted to enhance its tangibility for grinding, grinded using a series of emery paper of grits sizes ranging from the roughest to the smoothest (i.e. 60µm – 2400µm respectively). They were further polished using an ultrafine polishing cloth, and its effectiveness enhanced using polycrystalline diamond suspension of particle size 3µm. The samples were chemically etched by swabbing following an international standard information guide before microstructural examination was performed using optical microscope.

RESULTS AND DISCUSSION

The microstructures of steel is agreed to be related and thus determined the mechanical properties [2, 11]. The bases of all the conventionally treated samples (including the untreated) exhibited already established micrographs. The samples were etched (by swabbing) with 2% nital solution. Each micrograph was captured at a consistence magnification of x200 prior to analysis.

Plate 1 shows, (a) the micrograph of medium carbon low alloy steel consisting of a uniformly distributed pearlite colonies (dark phase) and ferrite grains (grey phase). Both ferrite and pearlite grains were nearly equiaxed. This corresponds to the findings of Ma and co-researchers *[7]*. A micrograph of the heat affected zone of the control sample after welding showing more of ferritic (grey phase) and sparsely distributed pearlite (dark phase) as shown in Plate 1 (b). And a fine and alternate layer of ferrite and cementite was formed at the fusion zone of the untreated sample [Plate 1 (c)].

A fine structure of ferrite and cementite was, however, formed after subjecting the samples to post weld annealing treatment as shown in Plate 2(a) and a lamella structure of ferrite and cementite in Plate 2(b) was formed at the heat affected zone. The interface that serves as a transition between the HAZ and the FZ is significantly shown in Plate 2(c). Similar structure orientation was also formed when the sample was normalized (i.e. allowed to cool in air) heat treatment, but with ferrite and pearlite phase as shown in Plates 3 (a) – (c).

Plates 4 and 5 show the post weld micrographs at various points of medium carbon steel when quenched in automobile engine oil and water. The microstructures at the base consist of a duplex ferrite martensite; the strong deformable second phase consists of predominantly of martensite but may contain bainite and retained austenite.

The strong second phase is dispersed in a soft ductile ferrite matrix, where the martensite provides the strength in the composite and the ferrite provides the ductility. These results correspond and support the findings of *Daramola et al [3]*. These structures are subsequently refined at the HAZ thereby increasing the mechanical properties – hardness and ultimate tensile strength of the material *[8]*, a coarse duplex structure with no definite interface / boundary is formed at the FZ. This is as a result of the deposits of the consumable electrode used during the joining process.

The tempered microstructures [Plates 6(a) - (c)] however, indicate an elongated alternate layers of transition carbide (ε-carbide) and low-C martensite. Kemar and Xervier have discussed this in their earlier work *[6]*. Due to incomplete dissolution of martensite and fine ε-carbides, needle-like cementite may cause overlapping. Solidified electrode deposits were observed at the FZ and by extension HAZ region as a result of the inconsistencies in the welding speed used during joining of the samples to tables and figures should precede their inclusion in the text.

CONCLUSION

In this work, the microstructural evaluation of medium carbon low alloy steel was studied. The as-received steel was firstly machined and welded using SAW technique before subjecting it to conventional heat treatment (i.e., annealing, normalizing, quenching (water & oil), and tempering). The microstructural evolution was studied with the aid of an optical microscope. The resulting micrographs show that there were considerable reductions in the heterogeneity of the microstructures when subjected to heat treatments (annealing, normalizing, and tempering) after welding. The micrographs obtained during quenching in both oil and water still exhibited the heterogeneity observed in the control sample.

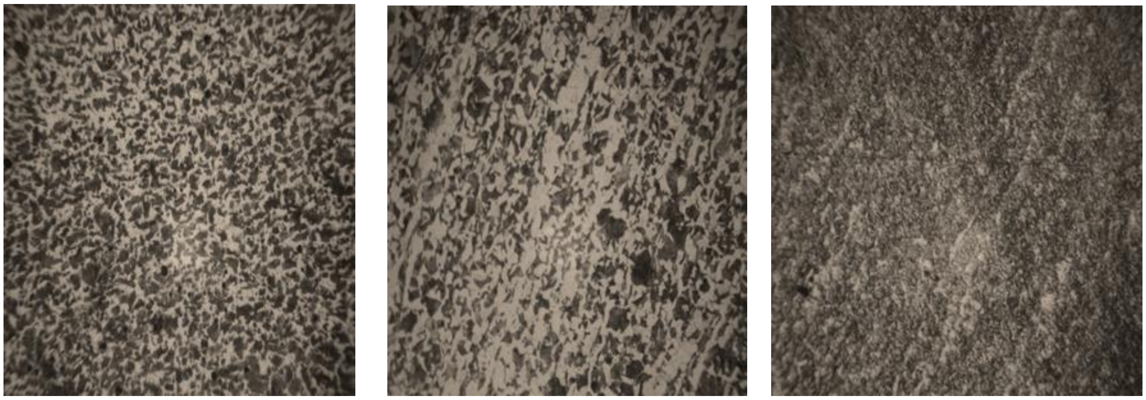

Plate 1: Control
(a) Base (b) HAZ (c) Weld

Plate 2: Annealing
(a) Base (b) HAZ (c) Weld

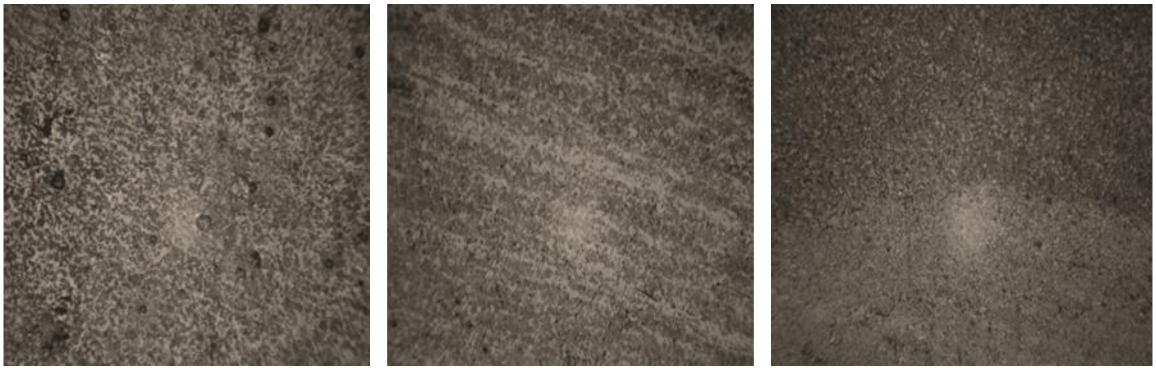

Plate 3: Normalized
(a) Base (b) HAZ (c) Weld

Plate 4: Quenched (in oil)
(a) Base (b) HAZ (c) Weld

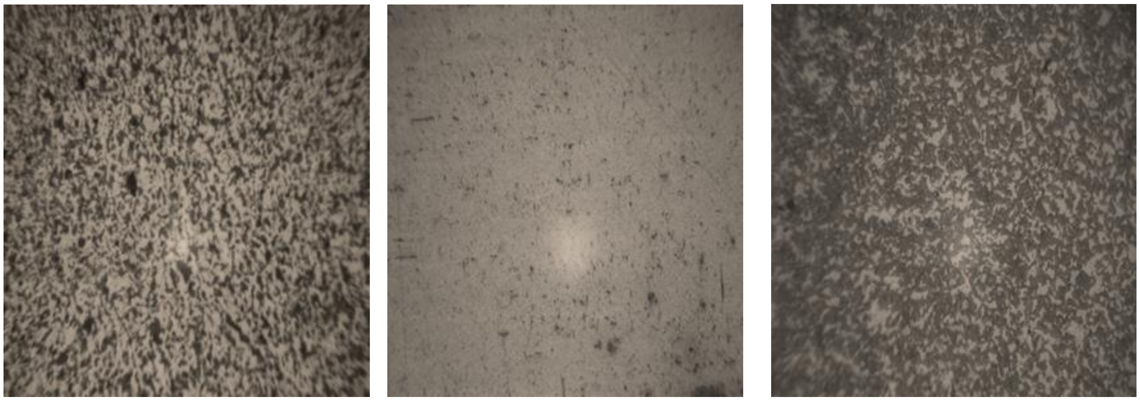

Plate 5: Quenched (in water)
(a) Base (b) HAZ (c) Weld

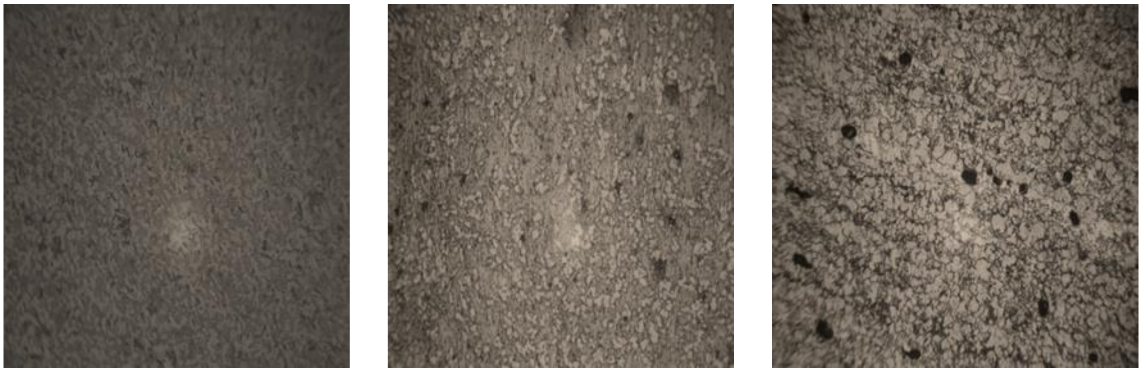

Plate 6: Tempered
(a) Base (b) HAZ (c) Weld

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