Quenching Heat Treatment Effects on Steel Welds.

A.V. Adedayo, M.Sc.[1,2*]; S.A. Ibitoye Ph.D.[1]; and K.M. Oluwasegun, Ph.D.[1]

[1]Materials Science and Engineering Department, Obafemi Awolowo University, Ile-Ife, Nigeria.
[2]Metallurgical Engineering Department, Kwara State Polytechnic, PMB 1375, Ilorin, Nigeria.

E-mail: adelekeadedayo58@yahoo.com*

ABSTRACT

This paper reports investigations made on the quenching heat treatment effects on steel welds. The properties of the weld investigated were hardness value and toughness. Micro examination of the samples was also done with optical microscopy. Four (4) different grades of steel rods in 10mm diameter were obtained. The range of the carbon contents of the steel rods was from 0.16 wt% C to 0.33 wt % C. From each grade of the steel materials, grooved specimen of about 150 mm were prepared. The grooves were then filled to create welds using arc welding. A set of the welds were quenched immediately after welding. The hardness values and toughness of the welds were determined. The microstructural analyses of the welds were carried out as well. The results show that hardness and toughness were dependent on the carbon content. There was also significant microstructural modification due to quenching.

(Keywords: welding quenching, heat treatment, hardness, toughness, microstructure)

INTRODUCTION

The desired levels of mechanical properties can be obtained by altering the size, shape, and distribution of various constituents. This is achieved in practice by the heat treatment process. Not only the presence of these phases micro-constituents but also the morphology of these products is significant in deciding the resultant properties.

For steels, generally, the structural make-up consists of transformed products from austenite. Depending on various parameters and the heat treatment process employed, transformed products from austenite may be pearlite, bainite, or martensite. For steel welds, a complex steel weld microstructure which consists of two or more micro constituents may be formed. Most often micro constituents such as: proeutectoid ferrite, polygonal ferrite, aligned and non-aligned side plate ferrite, ferrite carbide aggregates, and acicular ferrite are formed (IIW, 1988; Adedayo et al., 2010; da Trindade Filho et al., 2004).

Sometimes, upper and lower bainites, martensites and the A-M (austenite with martensite) micro constituents may be formed (Grong, 1992; Evans, 1991). This complex microstructure mixture can lead to highly varied properties of the weld (Adedayo, 2009; Adedayo et al., 2010).

While, da Trindade Filho et al., (2004) discussed effects of normalizing heat treatment on steel welds, Adedayo et al., (2010 and 2011) discussed effects of annealing and tempering on steel welds.

In this study, the effects of quenching heat treatment on mechanical properties and microstructure of plain carbon steel weld is investigated.

EXPERIMENTAL PROCEDURE

Materials used are 10mm steel rods supplied as-rolled from Universal Steel Rolling Mill, Ogba-Ikeja, Lagos, Nigeria. These are four (4) different steel which are essentially different in carbon content. The compositions of the steel rods are given in Table 1. 150 mm long pieces were cut from all grades of the steel rods. The middle of each piece was grooved 6 mm deep and wide using a grinding wheel as illustrated in Figure 1.

The grooved samples were then filled in the course of welding to create a weld. AWS E 6013 electrodes were used with a.c. arc welding process. The current used was 100 A with a terminal voltage of 80 V. Eight pieces of welds were prepared in all, two from each grade of steel. A set of four welds were untreated and kept as control, the other set was quenched with water immediately after welding.

Table 1: Composition of Steel Rods Used.

Element (wt %)	Sample 1	Sample 2	Sample 3	Sample 4
C	0.2529	0.1576	0.2756	0.3320
Si	0.1468	0.1821	0.1769	0.3116
S	0.0510	0.0598	0.0523	0.0520
P	0.0419	0.0288	0.0275	0.0274
Mn	0.3658	0.6440	0.6247	0.7523
Fe	Rest	Rest	Rest	Rest

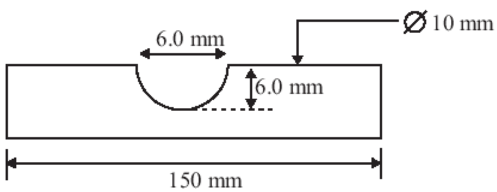

Figure 1: Dimension of grooved specimen.

Hardness values of the welds were determined using a LECO micro-hardness tester which uses a diamond indenter. The test load was 98.07mN (10gf) and the dwell time was 10 seconds. The LECO micro-hardness tester automatically calculates the hardness values in Vickers hardness (VHN). The hardness values of the steel welds were evaluated at three points: (i) the weld pool region (ii) the weld pool and base metal junction (iii) the heat affected zone (HAZ) see Figure 2.

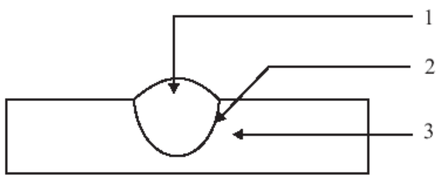

Figure 2: Hardness Test Specimen (1) Weld Pool, (2) Weld Pool and Base Metal Junction, and (3) Heat Affected Zone (HAZ)

The toughness values were determined from notched specimen of circular cross section prepared from the steel welds. The specimens were notched at the required points to evaluate their toughness at those points. Micro-examination of the steel welds was carried out with optical microscopy. The microstructures were captured with an Olympus metallurgical microscope which has a minisee optical viewing system connected to a computer.

RESULT AND DISCUSSION

Tables 2 to 5 were used to generate Figures 3 to 6. Figures 3 and 4 show the variation of the hardness values, while Figures 5 and 6 show the toughness values of the specimen along the weld. These figures show a general trend for each of the quenched samples. There is increase in hardness values with increase in carbon content, while the toughness decreased.

This is also the trend for the untreated samples. Normally, the structure of the steels investigated, viz: 0.16wt%C, 0.25wt%C, 0.28wt%C and 0.33wt%C are essentially ferritic. Ferritic structures could be: proeutectoide ferrite, polygonal ferrite, aligned and non-aligned side plate ferrite, ferrite carbide aggregates, acicular ferrite, bainitic etc (IIW, 1988). IIW DOC IX-1533-88 (IIW, 1988) gives a detailed classification of weld metal microstructures.

The maximum solubility of carbon in ferrite is 0.025wt%C (Higgins, 1998; Brophy et al., 1964). This suggests that the ferritic structures in the investigated steels were supersaturated with carbon. This saturation leads to straining of the ferrite matrix and thus consequently leading to increase in hardness values with increase in carbon content. The higher the carbon content, the higher the straining. The straining of the ferritic structure is actually evidenced by Figures 7 A2 and 7 A3 which show bainitic structures.

Bainitic structures are actually fine dispersion of iron carbide in a strained ferrite matrix (Brophy et al., 1964) The lower toughness of the weld metal with increase in carbon content is also a result of this straining.

Table 2: Vickers Hardness Values for Untreated Samples.

Vickers Hardness Value				
Sample	Carbon content	Weld pool zone	Weld pool and parent metal junction	HAZ
1	0.16	230	543	805
2	0.25	243	553	827
3	0.28	281	566	874
4	0.33	296	570	892

Table 3: Vickers Hardness Values for Quenched Samples.

Vickers Hardness Value				
Sample	Carbon content	Weld pool zone	Weld pool and parent metal junction	HAZ
1	0.16	236	552	825
2	0.25	248	564	850
3	0.28	286	578	896
4	0.33	302	583	914

Table 4: Toughness Values of Untreated Samples.

Toughness Values (J)				
Sample	Carbon content	Weld pool zone	Weld pool and parent metal junction	HAZ
1	0.16	20.16	15.6	8.32
2	0.25	18.32	12.6	7.78
3	0.28	16.6	11.64	6.02
4	0.33	15.84	9.8	4.84

Table 5: Charpy Toughness for Quenched Samples.

Toughness values (J)				
Sample	Carbon content	Weld pool zone	Weld pool and parent metal junction	HAZ
1	0.16	12.6	8.89	4.84
2	0.25	10.52	7.02	4.43
3	0.28	8.68	5.8	3.92
4	0.33	6.74	4.82	3.12

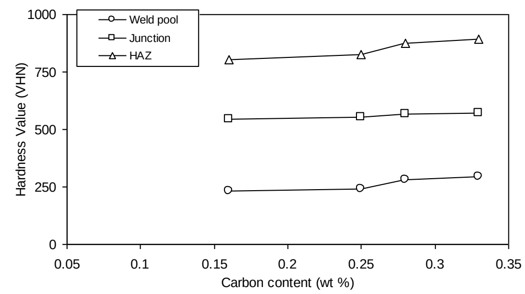

Figure 3: Variation of Hardness with Carbon Content for Untreated Sample.

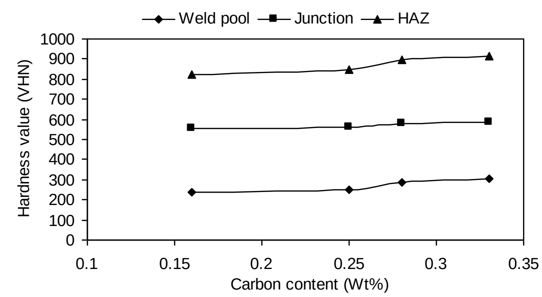

Figure 4: Variation of Hardness Values with Carbon Content for Quenched Samples.

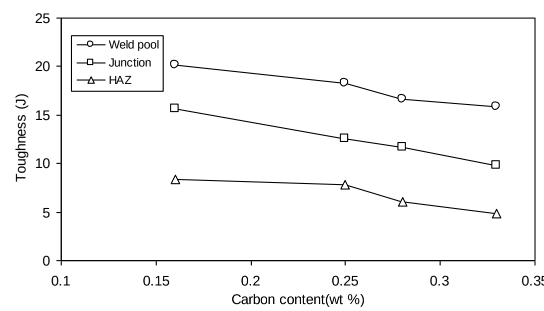

Figure 5: Variation of Toughness with Carbon Content for Untreated Samples.

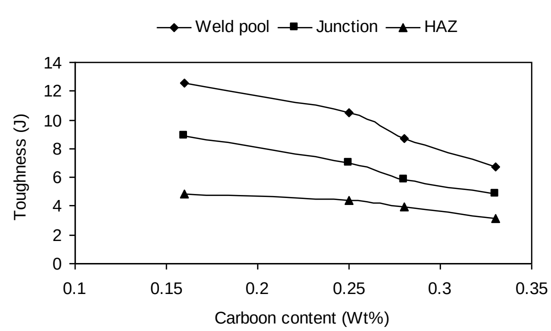

Figure 6: Variation of Toughness with Carbon Content for Quenched Samples.

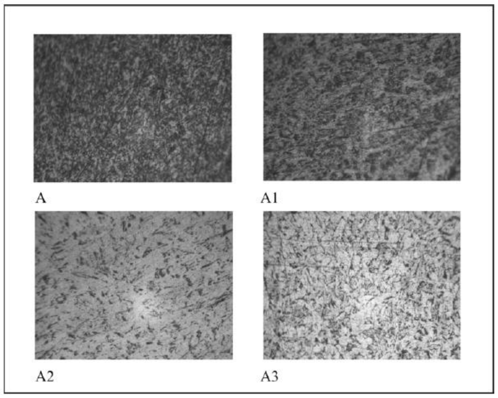

Figure 7: Microstructure of Tempered Steel Welds: (A) 0.16wt%C, (A1) 0.25wt%C, (A2) 0.28wt%C, (A3) 0.33wt%C.

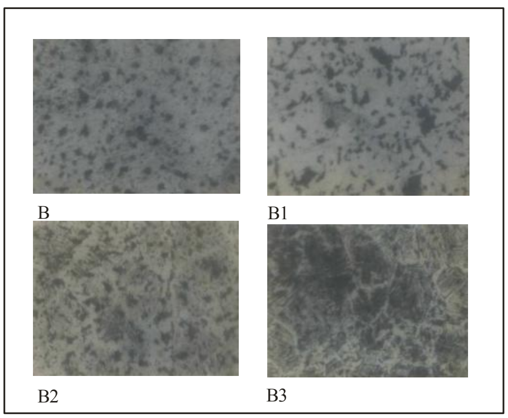

Figure 8: Microstructure of Quenched Steel Welds: (B) 0.16wt%C, (B1) 0.25wt%C, (B2) 0.28wt%C, (B3) 0.33wt%C.

By comparing the values of Figures 3 and 4, and Figures 5 and 6, it is obvious that the trend is increasing, i.e. hardness values increase from Figure 3 to Figure 4 while it decreased from Figure 5 to Figure 6. Figures 4 and 6 are for the quenched samples, while Figs. 3 and 5 are for the untreated samples. Generally, the values for the quenched samples are maximum for hardness and minimal for toughness. During quenching heat treatment, there is entrapment of carbon from the carbon saturated austenite phase (Rajan, et al., 1988). This leads to the hardening steel matrix by the formation of A-M (Austenite with Martensite) phases. This is evidenced as revealed in the fig. 8. Figure 8 (B, B1, B2, B3) reveals micrographs with increasing martensite from B to B3.

Also, it is obvious that the hardness values increased from the weld pool through to the heat affected zone (HAZ) where the hardness values are higher. The toughness however decreased. Generally, the electrodes have low carbon content; however, there is carbon pick-up in the weld pool due to dilution and solid state diffusion from the base metal. The higher the carbon diluted and/or diffused into the weld pool, the higher the hardness values.

CONCLUSION AND RECOMMENDATION

The result of the research shows that the hardness and toughness values of the specimen varies with the carbon contents of the specimen. Generally, there was increase in hardness values with increase in carbon content while toughness decreased. It was also found out that the hardness values were minimal at the weld pool compared to the HAZ. It is the other way round for toughness. Quenching significantly affects the microstructure and thus the mechanical properties of the weld.

The range of steels investigated in this work excludes high carbon steels. Further experiment should be carried out to investigate this range of steels.

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