Investigation of the Microstructure and Mechanical Properties of Quenched - Heat affected Zones of Mild Steel Weldments

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Abstract: The work investigates the microstructure and mechanical properties of quenched heat-affected zones of mild steel weldment. Here, fifteen samples of mild steel with weldment from metal arc welding process was used and five of the samples were each quenched in palm oil, water, and air respectively. Then the microstructure of the heat-affected zone of the samples were observed. Again, the tensile strength and hardness developed for each of the samples were also studied. For water quenched samples, high hardness, fine grain structure and high cooling rate was observed. This is because water has high specific gravity. Oil quenched sample revealed less hardness and coarse grain structure. While Air cooled sample has hardness and fine microstructure close to that of water quenched. Considering the tensile strength, water quenched samples has highest ultimate tensile strength followed by air cooled sample and oil quenched sample has the least. Again, it was observed that air cool is more ductile than water quenched and oil quenched samples. Finally, oil quenched samples has highest engineering fracture stress followed by water quenched and air cooled samples.

Keywords: microstructure, mild steel weldment, mechanical properties, quenching.

1.0 INTRODUCTION

Welding is the process of joining metals together so as to ensure the continuity of the assembled materials. This is usually done by melting the metals and adding a filler material to form a pool of molten material, called a weld pool, which eventually cools, forming a strong joint. Different sources of energy are used for welding, such as gas flame, electric arc, laser and friction.

Again, welding is a process with many variables that should be monitored. When performing welding and thermal cutting operations on metals, the base materials are typically subjected to rapid heating and cooling in localized areas, such thermal conditions can produce distortion and result in detrimental mechanical properties of the material if not controlled. Contaminants on the material to be welded such as grease, dirt, rust and other debris should be cleaned and removed. If such impurities are not removed before welding, the strength of the weld assembly could be compromised.

Non-destructive testing methods, such as radiographic testing and dye penetrant are often used to detect flaws, such as cracks, porosity, lack of fusion and slag entrapment. Destructive testing methods, such as bend tests and tensile tests are often performed to determine if a weldment is of adequate strength and soundness.

More so, during welding as the heat source interacts with the material, the severity of thermal excursions experienced by the material varies from region to region, resulting in three distinct regions in the weldment. (S.A David, S.S Babu and J.M. Vitek Junu 2003 Jom) These are;

- The fusion zone (FZ). Also known as the weld material.
- The heat – affected zone (HAZ)
- The unaffected base metal (bm)

Fig 1: Weld or fusion zone

However, the heat-affected zone (HAZ) is the area of base material, either a metal or a thermoplastic, which has had its microstructure and properties altered by welding or intensive cutting operations. The heat from the welding process and subsequent re-cooling causes this change from the weld interface to the termination of the sensitizing temperature in the base metal. The extent and magnitude of property change depends primarily on the base material, the weld filler metal, and the amount and concentration of heat input by the welding process (Klas, 2003). The factors that influences the size and microstructure of the heat affected zone. They include: - the type of welding technique employed, the amount and concentration of the heat input, the thermal properties of the base material, the design of the joint, the rate of cooling the weld.

Furthermore, the mechanical property of main importance for steel is the hardness and for any alloy type the hardness of the heat affect zone gives an induction of the degree of embrittlement there. Therefore, for any given steel with a particular carbon equivalent value, the heat affected zone hardness produced by any given welding operation will depend mainly on the cooling rate experienced by the HAZ. Again, much rapid cooling rates will favour the formation of hard and brittle martensite in all the sub zones of the HAZ or to increase the martensite region in size relative to the other regions. The presence of martensite in the HAZ results in very high hardness value for the heat affected zone.

Therefore, it is the intent of this work to investigate the microstructure and mechanical properties of quenched heat affected zones of mild steel weldments.

1.1 Research Problem

The observed problems that prompted this research/ study are as follows:

- There is need to address the low reliability problems of heat affected zones of weldment.
- Since the microstructure of heat affected zone of weldment of mild steel after welding have been altered, there is need to know the level of changes that occur in the microstructure of heat affected zone and the ways to avoid them.
- Wastage of materials (mild steel) are experienced/ recorded due to the negative effect of weld heat and quenching on heat affected zone of mild steel.

1.2 Aim and Objectives

The aim of this research work is to investigate the microstructure and mechanical properties of quenched-heat affected zone of mild steel weldment. To achieve this the specific objectives includes;

- To determine the effect of weld heat on mild steel microstructure
- To investigate the effect of quenching on heat affected zone of mild steel
- To determine how original properties of material (mild steel) can be altered or affected by weld heat and quenching.
- To determine which quenching media that can give high hardness and still maintain its mechanical properties without destruction in any form.

2.0 MATERIAL AND METHODS

2.1 Material

The material used for this work includes; Mild Steel, polishing Reagent (Diamond powder and alumina powder), water, etching reagent (nitric acid and ethanol).

2.2 Equipment

The equipment used include; Electric arc welding machine, hardness testing machine, tensile testing machine, mass spectrometer, high powered metallurgical microscopic, grinding machine, moulding machine, polishing machine, shielded arc welding machine, lathe machine, veneer caliper, hack saw, sand paper. The sample (material) used in this research is mild steel. Length is 100mm, width is 46mm, and thickness is 1mm.

2.3 Sample Preparation

The samples (9) were prepared by cutting the 100mm by 46mm mild steel in two equal parts and chamfering the edges to be joined to create a "single v" kind of groove.

2.4 Quenching Media

The quenching media used for the purpose of this research work are Oil, Water and Still air.

2.5 Methods

Immediately after welding the sample, (while still red hot) was immersed into its respective quench medium with the aid of hand tongs.

- Three samples was quenched in water, three was quenched in oil and three samples was left to cool in the open air
- After the samples had cooled to room temperature each sample was removed from its quench medium and labeled according to the quench medium used for it.

Controlled Stilled Air

Water Quenched

Oil Quenched

2.6 Tensile Test

Tensile test was conducted on the specimen to determine the strength of each group sample.

2.6.1 Method

The width thicknesses of the test specimen are measured before testing, and the area in square inches is calculated by multiplying these before testing, and the area in square inches is calculated.

- The tensile test specimen is then mounted in a machine that will exert enough pull on the piece to break the specimen.

2.7 Hardness Test

Hardness test was also conducted on the samples with the aid of Rockwell hardness tester (Indentec, 2007 Model):

2.7.1 Method

The specimen was placed on the anvil of the machine and the penetrator seated by means of 10 kg.

- The dial indicator is zeroed and then a major load of 60, 100 or 150 kg was applied, forcing the penetrator in to the specimen.
- Upon removal of major load, the indicator specimen recovers slightly, and the final depth of penetrator was registered directly on the dial indicator as a hardness number.

2.8 Microstructure Test

The procedure for preparing the specimen for micro examination involves the following steps:

- It was carried out by using emery paper of progressively finer grades.
- Four grades of abrasive used are 220 grits, 330 grits, 400grits and 600grits: the 330grits has particle sizes (of silicon carbide) as about 33microns and 600grits that of 17 microns. (1micron = 10-4cm).
- To start with the specimen was first ground on 220 grit paper, so that scratches are produced roughly at right angle to those initially existing on the specimen and produced through preliminary grinding or coarse filing operation.
- After removing the primary grinding marks the specimen was washed free of No. 220 grit.
- The grinding was continued on the No.320 data again turning the specimen through 900 and polishing until the previous scratch marks are removed.
- The process was repeated with No. 400 and 600 paper.

3.0 RESULTS AND DISCUSSION

3.1 Tensile Test Results

Table 1: Tensile Test Result

	Yield stress N/mm²	Ultimate tensile stress N/mm²	Engineering fracture stress N/mm²	Elongation mm	Ductility %	% reduction
Control sample	34	44.29	61. 64	5.56	15.89	54.6
Water quenched sample	39.29	51.43	65.97	5.25	15	55.2
Air cooled sample	42.86	50.00	65.88	7.813	22.32	49
Oil quenched sample	35.625	45	70.66	4.63	11.50	70

3.2 Hardness Test Results

Table 2: Hardness Test Results

Quenching media	Rockwell hardness value	Vickers hardness number (VHN)
Control specimen	61 HRB	108 Hb
Air specimen	72 HRB	125 Hb
Water quenched specimen	79 HRB	143 Hb
Oil quenched specimen	60 HRB	105 Hb

3.3 Microstructural Analysis

The microphotograph of specimens quenched in the various media are presented in plate 1-7

Plate 1: Control Sample X400

Plate 2: Air Cooled HZ X400

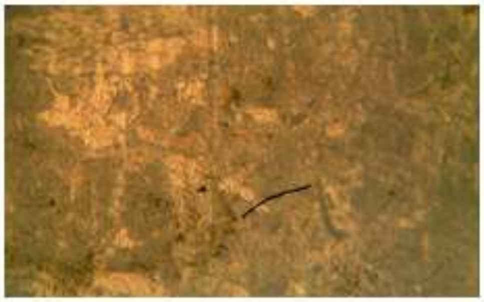

Plate 3: Air Cooled WJ X400

Plate 4: Water Quenched HZ X400

Plate 5: Water Quenched WJ X400

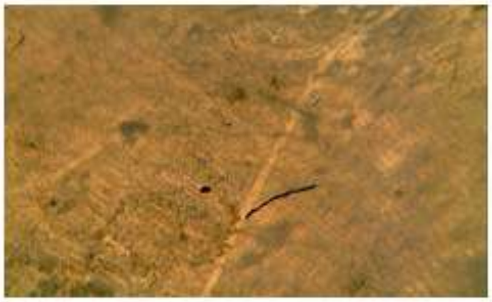

Plate 6: Oil Quenched WJ X400

Plate 7: Oil Quenched HZ X400

3.4 Discussion

3.4.1 Tensile Test

The result of the tensile strength test in Table 1 above, shows that ultimate tensile strength of sample quenched in water improved from 44.29 Nmm^2 (control sample) to 51.43Nmm^2, then that of the sample cooled in air improved from 44.29Nmm^2 (control sample) to 50.00Nmm^2 and the sample quenched in oil show a little increase from 44.29Nmm^2. Which means that sample quenched in water has highest ultimate tensile strength followed by sample cooled in air and then the one quenched in oil. Air cooled sample showed increase in elongation from 5.56mm (control sample) to 7.813mm and ductility from 15.89% (control sample) to 22.32%.

Again, water quenched sample showed a decrease in the ductility from 15.89% (control sample) to 15% (Tested sample) and also little decrease in elongation from 5.56mm (control sample) to 5.56mm (control sample) to 5.25mm (tested sample) and oil quenched sample show a decrease in elongation from 5.56mm (control sample) to 4.63mm and also decrease in ductility from 15.89% (control sample) to 11.50%. The result showed also that air cooled sample improved in yield stress from 34Nmm^{-2} (control sample) to 42.86Nmm^{-2} followed by water quenched which has improved from 34Nmm^{-2} (control sample) to 35.629Nmm^{-2}. This result shows that air cooled samples have highest elongation, ductility and yield stress. Finally the values of tensile strength are influenced by the microstructure of the mild steel alloy sample, which are controlled by the quenchants cooling rate. This shows that the high strength produced by water quenched sample is due to the effectiveness of the quenchants and their characteristics.

3.4.2 Hardness Test

The result is presented in Table 2. The result shows that water quenched sample increase in hardness from hardness value of 61HRB (control hardness value) to 79HRB, It also shows that air cooled specimen increased also from 61HRB (control hardness value) to 72HRB and finally, the oil quenched sample has hardness value less than control sample i.e. it decrease in hardness from 61HRB to 60HRB. The homogenous distribution of the fine precipitate of carbon, in mild steel matrix is largely responsible for the hardness of the quenched mild steel samples. The result shows that water quenched sample shows highest value of hardness, followed by air cooled and oil quenched.

3.4.3 Microstructure Examination

The results of microstructural examination are presented in plate 1-7. In this work, the size of the grain of microstructure examination was determined by comparison method of measuring grain size with standard grain size ASTM chart which is one of the ASTM recommended method. It shows that specimen quenched in water has fine grain structure between number six, seven and eight and others has coarse grain structure which fall between one (1) to five (5).

The result of the microstructural examination of the specimens shows that the specimens quenched in water shows highest values of ultimate tensile strength as shown in Table 1. This is associated with fine precipitates of carbons and mantensite which impact improved strength as compared to other specimens, which have a little coarse dispersion of precipitates. The changes in structure of the specimen are associated with the temperature of solutioning and the cooling rate of the quenching medium.

The very high rate of heat extraction experienced by the specimen quenched in water could be said to be responsible for the fine microstructure observed in plate 2 (water quenched sample). Generally hardness and strength increase as grain size decreases. Both properties are proportional to the reciprocal of the square root of the average grain diameter.

The relatively slower cooling rate is responsible for the formation of platelet like precipitate, pearlite and martensitic structure in specimen quenched in oil. To a lesser extent, (compared to water quenching). The presence of ferrite and medium pearlite is observed in specimen cooled in air. The transformation of austenite to mantensite by a diffusion less share type transformation in quenching is also responsible for high hardness obtained and this property is attributed to the effectiveness of the interstitial carbon in hindering the dislocation motion

4.0 CONCLUSIONS

The study on the effect of various quenching media (water, Air and Oil) on mild steel was conducted and attempts were made to relate mechanical properties to microstructure. As a result of this investigation, the following conclusion were made;

- That specimen quenched in water has highest ultimate tensile strength and hardness this is because water has high heat extraction capacity which contributed to the formation of fine grain structures.
- Water among the quenching media proved to have the highest cooling rate. Its improvement in strength properties may be correlated with a more refined metallurgical structure and amount of mantensite.
- That specimen cooled in the air has highest value of Ductility, elongation and yield strength.
- Oil quenched specimen proved to have the lowest hardness value and highest engineering stress. This is because Oil has a very high boiling point, the transition from start of martensite formation to the finish is slow and this reduces the likelihood of cracking.
- Oil is used when a slower cooling rate is desired and in a structure of mild steel where hardness need to be reduced.
- Finally the martensite provide the strength in the mild steel, whereas the ferrite provides the ductility and increase in ductility and tensile strength leads to better formability and makes the steel very attractive for use especially in cold forming.

RECOMMENDATION

- Due to the variability of welding on this material, it is proposed that studies of alternative materials be conducted.
- Due to the unique properties of the various types of welding, it is proposed that other types of welding other than shielded metal arc welding may yield different results

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