

# Comparison of Mechanical Properties of Austempered, Normalized and As-Weld Carbon Steel Weldment

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**Abstract**— More often than not, welded joints experience failure such as fracture which jeopardize their reliability and ergonomics when put in perspective. Attempting a significant improvement in the mechanical properties of welded joint through heat treatment could ensure joints stability and reduce the costs associated with constant repairs and replacements. In this study, the effects of heat treatments (austempering and normalization) on the mechanical properties of weldments were examined. The locally recycled steel sample was sourced from the Delta Steel Company Aladja, Delta State and the spectro-analysis was carried out on it. The test samples were machined as per properties for tests, fractured locally and were welded using shielded metal arc welding (SMAW) with stainless steel electrode. They were then heat treated in electric furnaces. The mechanical properties (tensile strength, yield strength, hardness and impact toughness) were determined and the microstructure examined using scanning electron microscope. They were also examined physically using hand lens. The result indicated that the austempered samples improved significantly in terms of its tensile strength, yield strength, hardness and ductility. It was also found that the untreated sample produced the greatest impact toughness. The result of the physical examination also suggested that heat treatment using oil

based quenchant have the potential to inhibit rust at weld joints.

**Keywords**— *Weldment, Heat treatment, Mechanical properties.*

## I. INTRODUCTION

Heat treatment involves various heating and cooling procedures performed to effect microstructural changes in a metal which in turn affect its mechanical properties Groover (2010). Krauss (1990) reported that the mechanical properties of steel can be improved by isothermal heat treatment. Also, Charkraborty and Manna (2012) submitted that the tensile strength, hardness and impact strength of metal can be enhanced by austempering heat treatment. Austempering of steel have many industrial applications and the processes are explored by researchers. It is defined by both the process and the resultant microstructures. Generally, the steps involved in this process include heating a medium-to-high carbon ferrous metal to an austenitic condition usually 800°C to 950°C for a specified time, quenching rapidly enough in a heat extracting medium maintained at temperature between 200°C to 400°C for a specified time sufficient to avoid the pearlitic and martensitic formation and then cooling to room temperature usually in steel air. This is summarized in the austempering cycle in figure 1.

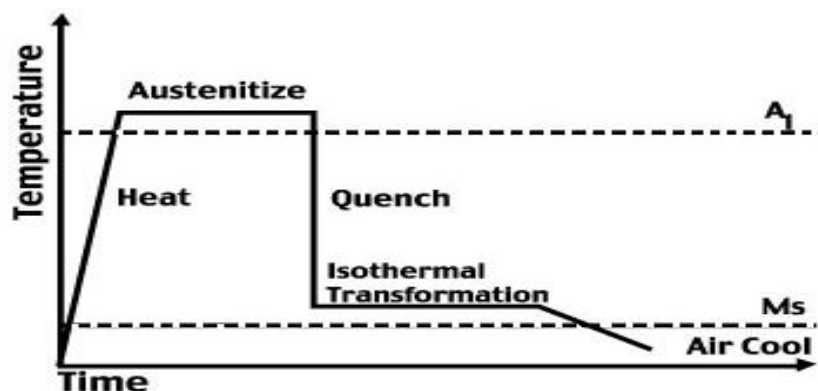


Fig.2.4: Schematic diagram for austempering process

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In normalization, the material is heated to the austenitic temperature range and this is followed by air cooling. It is usually carried out to obtain mainly pearlitic matrix which result in higher strength and hardness. It also removes undesirable free carbide in steel.

The aim of this research was to examine the effect of these processes on welded steel joint. Some other authors have earlier investigated certain aspect of this subject area. Notable include; laser beam welding of carbide free bainitic steel (Benjamin Bax 2009), welding of austempered ductile cast iron (Morsy and El-kashif, 2011).

In the current investigation, locally recycled medium carbon steel was used. This was due to its adaptability to the local environment given that most of the steel used in Nigeria are recycled steels. This was economically advantageous too since according to Alabi and Onyeji

(2010) there are currently no functional steel making industry in the country. The welding process adopted SMAW process with stainless steel electrode. In the austempering process, the present study explored the use of shear butter oil as a quenching medium. The results of the study were discussed on the basis of the mechanical properties of the treated and the untreated weldments with emphasis at the fusion zone.

**II. EXPERIMENTAL PROCEDURE**

The test sample was a 22mm diameter by 1000mm length steel rod for all condition. The chemical composition of the test sample was conducted at the start of the investigation using a spectro-analytical instrument. The average values computed and recorded are as presented in table 1.

Table.1: Chemical Composition of Steel Material

Elements	C	Si	Mn	P	S	V	Cr	Cu	Fe
% wt	0.453	0.08	0.97	0.062	0.038	0.0008	0.22	0.0051	98.171

From the analysis, the sample was found to contain 0.453% carbon. According to AISI and SEA classifications, steel with carbon content in the range of 0.3% to 0.61% are known as medium carbon steel. The steel composition therefore satisfied the minimum carbon point requirement for it to be materially affected by heat treatment since it has 45 point of carbon which is above 25 Linberge (1977).

**PREPARATION OF TEST SAMPLES**

Three mechanical properties were examined. For each property test, a specific shape and size was prepared from the steel rod. The samples were machined in accordance to ASTM 2012 specification. They were machined using lathes and millers and then finished in ends. A total of twenty seven samples were prepared by machining. The properties investigated, the sample dimension and the mode of evaluation are summarized in table 2.

Table.2: Samples, Dimensions and Mode of Evaluation

Properties	Sample dimension	Mode of evaluation
Tensile strength	Standard round test piece measuring $\phi$ 6mm gauge diameter by 82mm gauge length	MT2021 Universal tester of stress capacity 20KN
Hardness	16mm by 60mm with 12mm flat at longitude	Digital Display Rockwell hardness tester with 136°

		pyramid diamond indenter and 1471N load capacity
Impact toughness	Standard 10mm X 10mm X 60mm	Charpy V-Notch tester of 100J capacity.

**WELDING OPERATION**

Prior to welding, to assume failure by fracture, the prepared samples were cut at the middle with hack saw. Two millimetres were removed from each of these edges using rotating grinding stone of grade P150C. Both ends were chamfered at 45° angle each making a 90° groove angle and two millimetres depth was made. This created a wider surface area for weld deposits and penetration hence stronger joint. They were tack welded unto a jig with the chamfered edges facing each other for each pair of samples. Preheating was done at 300°C. This was to reduce the cooling rate and minimize the chances of forming martensite in the weld. They were then welded using SMAW with a 3.5mm AWS-E11018-G alloyed electrode. The chemical composition as received from the manufacturer as 0.11%C, 0.715Si, 1.52%Mn, 0.5%Cr, 2.0%Ni, 0.63%Mo and 94.53%Fe. They were allowed to cool slightly to 200°C. Each weldment was examined visually and by dye penetrant test before heat treatment. A 2mm V-Notch was cut at the middle of the fusion zone on the impact test sample. The samples are as presented in figure 1 to figure 3.

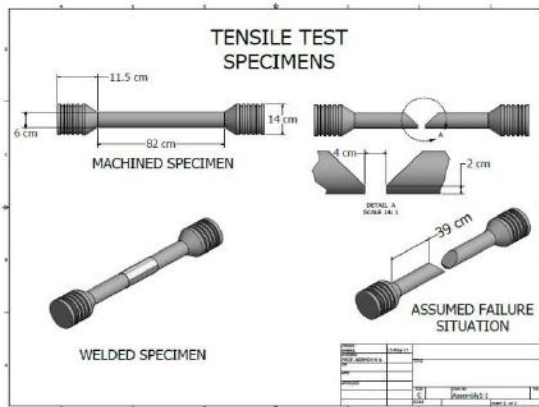


Fig.1: Tensile strength specimen

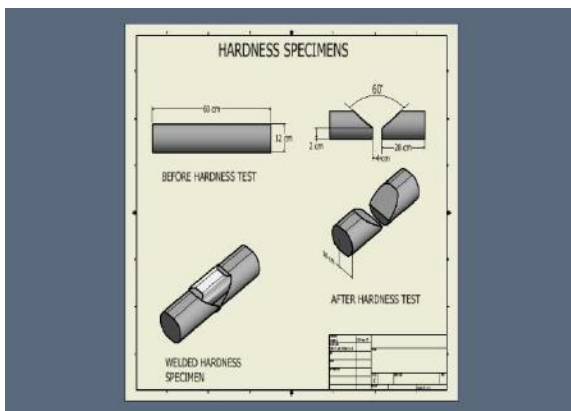


Fig.2: Hardness test specimen

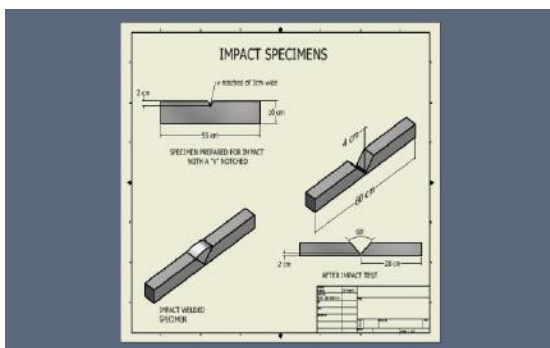


Fig.3: Impact strength specimen

**HEAT TREATMENT**

The sample set to be heat treated were loaded on and heated in first furnace. They were raised to austenitizing temperature of 900°C and soaked for one hour in order to induce austenite in microstructure. One set was brought out and cooled in air (normalized samples). The remaining samples were quickly transferred to the quenching medium (shear butter oil) placed in oil bath and heated to a constant temperature of 340°C in a muffled electric furnace. This ensured that the samples were quenched at a temperature above the martensite start temperature, Ms of the material. The following empirical formula founded by Nerenberg was adopted to estimate the Ms Temperature.

$$M_s = 500 - (300 \times \%C) - (33 \times \%Mn) - (22 \times \%Cr) - (11\%Mo)$$

For the present study, the calculated Ms Temperature is 326°C. The samples remained soaked in this medium for a designed time of 60mins and were finally brought out and allowed to cool in still air. The samples investigated were then tested for mechanical properties.

**Tensile Strength test**

From the tensile strength test carried out, the percentage elongation and the percentage reduction in area of the sample were determined using formulae according to Ndaliman (2006).

Percentage elongation =

$$\frac{Final\ length - Gauge\ length}{Gauge\ length} \times \frac{100}{1}$$

And the percentage reduction in area is given by:

Percentage reduction in area =

$$\frac{Original\ CSA - Final\ CSA}{Original\ CSA} \times \frac{100}{1}$$

Where,

*CSA = Cross sectional area of specimen*

$$CSA = \frac{\pi d^2}{4}$$

Where, *d* = diameter of the gauge length, in millimeter.

**Hardness test**

The hardness of the test sample was read directly from a digital display Rockwell hardness tester. The indenter was lowered using lever to actuate the indentation of the sample and the value displayed was recorded. Three indentations were made at different spots of the sample and the average was computed and recorded.

**Impact test**

The machine was properly set up and the sample was position for impact test. The striking hammer was raised at 90° which struck the sample with 100J of energy at a velocity of 5.2m/s directly from behind the notched side. The result were instantaneously taken from the gauge and recorded.

Each test was carried out three times and the average was computed and recorded.

**III. RESULTS AND DISCUSSIONS**

**PHYSICAL CHARACTERISTICS AFTER WELDING AND HEAT TREATMENT.**

It was observed that the quenched sample showed high resistance to rust while the untreated (as-weld) and normalized samples experienced rusts predominantly at the heat affected zones (HAZ). This is attributable to the thermal agitation of the ferrite grains at this zones which reacted with air oxygen during cooling to form oxides hence the rusts. The oil film which coated the metal

surface in the quenched sample cut off atmospheric or water oxygen attack there by preventing rusts.

The results of the mechanical properties for the samples are as presented in table 3. This allowed for good comparison of the properties.

Table.3: Summary of Mechanical Properties for the Samples

Samples	UTS (N/mm <sup>2</sup> )	UYS (N/mm <sup>2</sup> )	Hardness (HRC)	Impact (J)	% Elongations	% Area Red.
Quenched	751.66	612.00	59.47	50.00	6.85	60.00
Normalised	706.05	521.07	32.00	42.00	1.54	35.91
As-weld	530.44	495.07	49.07	42.00	4.59	48.12

#### TENSILE STRENGTH

From the tensile test experiment, plastic strains occurred on the base metal with the resultant necking and then failure taking place outside the weld area. This implied that the weld strength exceeded the base metal strength as a result of heat treatment. When the welds strength is considerably lower than the base metals, failure occurs at the weld. This literally suggested that the tensile strength of the treated sample had increased as a result of heat treatment.

From table 3, the quenched sample gave a significant increase in terms of its ultimate tensile strength (751.66 N/mm<sup>2</sup>) and ultimate yield strength (612 N/mm<sup>2</sup>) when compared to the as-weld sample which gave 530.44 N/mm<sup>2</sup> and 495.07 N/mm<sup>2</sup> respectively. These indicated a 41.7% and 23.6% improvement respectively. The sample also improved above the normalised sample and indicated 7.64% and 17.45% enhancement in tensile and yield strengths respectively. From the percentage elongation in table 4, the quenched sample produced the greatest ductility which represented 344% and 49.2% improvement over the as-weld and the normalised samples respectively. This is consistent with Kolawole et al (2012). These increases in the quenched samples is a result of the transformation of the precipitated cementite carbide and martensite structure in the weldment into full or partial austenite during austenitization and finally to bainite structure in the austempering phase. This structure is better than the normalized samples which mainly produced pearlite matrix and few retained martensite structures. This is in contrast with untreated sample in which the ferrite structure was transformed to cementite carbide and martensite as a consequence of welding.

#### HARDNESS

The hardness of a material is a measure of its resistance to permanent indentation. High hardness generally means that the material is resistant to scratch and wears. From table 3, the quenched sample produced highest hardness value of 59.47HRC when compared with the untreated sample's 49.07HRC and the normalized sample's 32HRC. This is also consistent with its tensile strength and agrees with Najeeb et al (2014). This process can

therefore be used in critical application such as in tools used in manufacturing such as cutting saw, hammers, bolts and screw welds where scratch and wear resistance are important characteristics.

#### IMPACT STRENGTH

The impact test is a measure of the toughness of a material or its ability to absorb energy without sudden fracture. From table 3, the impact strength of the as-weld sample appeared higher (60J) than the quenched (50J) and the normalised (42J) samples. This is consistent with Ndalian (2006). The quenched sample however gave a better impact toughness than the normalised sample suggesting the superiority of this heat treatment process. This result showed that the material reacted in opposite manner when compared to its tensile strength and hardness results. This implies therefore that impact toughness of an untreated welded joint is higher than when treated and therefore could absorb more energy before failure.

#### IV. CONCLUSIONS

1. Physical examination of the test samples after several days under the same condition indicated significant rusts particularly at the HAZ. It was greatest at the untreated (as-weld) samples, least at the normalised samples while the quenched sample produced no rusts. This suggested therefore that heat treatment using oil based has the potentials to inhibit rusts at susceptible areas such as weld joints.
2. The normalised joints produced better mechanical properties in terms of tensile strength, yield strength, hardness and ductility than when it is not treated.
3. Quenching the joints further increased these properties significantly
4. The impact toughness of a weld joint is least affected by heat treatment.

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