

Effects of Various Quenching Media on the Mechanical Properties of Inter - Critically Annealed 0.267% C - 0.83% Mn Steel

Joshua T.O, Alao O.A, Oluyori R.T

Abstract- *The mechanical properties of a medium carbon steel of known composition after been subjected to various quenching media at various inter - critical temperatures were evaluated. The microstructures obtained were used to explain the results. Tensile test specimens were produced from the medium carbon steel, which was in the as - rolled condition. Samples were quenched in water, distilled water and palm kernel oil respectively after been allowed to attain the following inter - critical temperatures 760^oc, 770^oc, 780^oc, 790^oc, 800^oc. After each treatment, the mechanical properties and microstructures of each specimen were evaluated. Samples quenched in water and distilled water were observed to produce martensitic structures in ferrite matrix, just that the grains observed in the distilled water quenched samples were fine and hence responsible for the higher strength and hardness values. While the samples quenched in palm kernel oil were observed to produce higher level of bainite in ferrite at the grain boundaries. These results therefore implies that for higher strength and hardness value, samples are recommended to be quenched in distilled water, while for strength and toughness palm kernel oil will be the best.*

Keywords: *Mechanical Properties, Medium Carbon Steel, Quenching media*

I. INTRODUCTION

The rapid and vast development of technologies and the best performance of the service or functional requirement of steel today are mostly, achieved by various kind of heat treatments operations.

Heat treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. It is a process utilized to change certain characteristics of metals and alloys in order to make them more suitable for a particular kind of application [5].

Heat treatment involves the application of heat, to a material to obtain desired material properties (e.g. mechanical, corrosion. electrical, magnetic, e-t-c.). During the heat treatment process, the material usually undergoes phase microstructural and crystallographic changes [5].

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The purpose of heat treating carbon steel is to change the mechanical properties of steel, usually ductility, hardness, yield strength tensile strength and impact resistance. The electrical, corrosion and thermal conductivity are also slightly altered during heat treatment process. The standard strengths of steels used in the structural design are prescribed from their yield strength. Most engineering calculations for structure are based on yield strength [4].

These operations can greatly influence mechanical properties such as strength, hardness, ductility, toughness and wear resistance of the alloys.

Heat treatment of carbon steel and carbon alloy steel is done for improving mechanical properties such as tensile and yield strength. This is accomplished by altering the molecular structure of steel in order to produce more durable micro structure. The structure of steel is compose of two variables: Grain structure (The arrangement of atom in a metal) and Grain size (The size of the individual crystals of metals). Light Grain size is generally associated with low strength, hardness and ductility [6].

Hardening by quenching is performed to prevent ferrite or pearlite formation and allow bainite or martensite to be formed. Quenching medium selection depends on the harden ability of particular alloy, the section thickness and shape involved, and the cooling rate needed to achieve desired microstructure.

Steel with low carbon content has the same properties as iron, soft but easily formed. As carbon content rises, the metal becomes harder and stronger but less ductile and more difficult to weld [4].

Higher carbon content lowers steel melting point and its temperature resistance in general

Carbon steel with at least 0.4%C is heated to normalizing temperatures and then rapidly cooled (quenched) in water, brine, or oil to the critical temperature. The critical temperature is dependent on the carbon content, but as a general rule is lower as carbon content increases. This result in a martensitic structure, a form of steel that possesses a super-saturated carbon content in a deformed body centered cubic (BBC) crystalline structure.

structure, properly termed Body-Centered Tetragonal (BCT), with much

internal stress. Thus quenched steel is extremely hard but brittle, usually for practical purposes. These internal stresses cause stress cracks on the surface.

Quenched steel is approximately three to four (with more carbon) fold harder than normalized steel [2]. Including carbon, alloy of Iron and other elements is known as “Steel”. When carbon is the main alloying element, the contents in the steel ranges from 0.002 % to 2.1% by weight. The properties can be modified by the process of other alloying element such as Manganese, Silicon, Chromium, Nickel, Aluminum, Titanium, Molybdenum etc. steel are broadly classified into two: Carbon steel and alloy steel. Carbon steel owes their properties modified by the presence of the particular alloying element.

Medium carbon steel; approximately 0.29% to 0.54% carbon content with 0.60 to 1.65% manganese content (e.g AISI 1040 Steel), balance ductility and strength and has good wear resistance; used for large parts, forging and car parts [2].

It is necessary for an engineer engaged in testing work to have a general understanding of the common methods of

testing properties of the metals. Mechanical properties are the most important requirements of the metals from the engineering point of view in selecting them for design purpose. Mechanical properties and micro structures of metals describe their behavior under mechanical and physical usage [1].

The required mechanical properties can be altered by method of heat treatment.

In this project, the effect of various quenching media on the mechanical properties of inter-critically annealed 0.26%C – 0.83% Mn steel are demonstrated by using water, distilled water and palm oil. It clearly reveals the various effects on the mechanical structure / properties of medium carbon steel by using water, distilled water and palm kernel oil as a quenching media which have not been used before. Water contains minerals but distilled water does not

II. EXPERIMENTAL PROCEDURE

The materials used for this project include: Medium carbon steel of known composition, water, distilled water sourced from the chemistry laboratory of the School of Preliminary Studies, Kogi State Polytechnic Lokoja Nigeria, Palm Kernel Oil was obtained from Abobo Okehi Local Government of Kogi State Nigeria. The chemical

Table 1: Chemical Composition of the Medium Carbon Steel used

%Fe	%C	%Si	%Mn	%P	%S
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The equipments used in this work includes: Mass spectrographic Analyzer (computerized type) for chemical analysis of the medium carbon steel, Euro – therm heat treatment furnace, Hardness test machine, Universal Instron

A. Materials

composition of the used carbon steel is as shown in Table 1, other materials used for metallographic works include, Bakelite, silicon carbide papers, (220, 320, 400, 600, 800, 1200 grades) cerium oxide and 2% nital as etchant for general purpose.

98.068	0.2601	0.2217	0.82	0.0494	0.0464
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B. B. Equipments

Tensile test machine (1195), mounting press, Buhler Grinder/polishing machine and computerized inverted Metallurgical Microscope.

C.Method

Sixteen pieces, each of 100mm long were cut from the project sample and machined to a standard specifications using the lathe machine at School of Engineering, Kogi state Polytechnic, Itakpe campus.

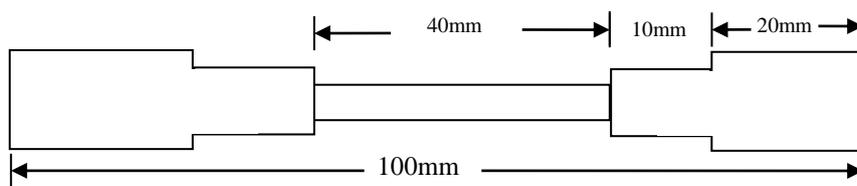


Figure 1: The drawing of the tensile test specimen

The prepared test specimens were subjected to quenched hardening heat treatment operations as follows:-Three samples were heated to 800^oc, held for 1 hour and each quenched in water, distilled water and palm kernel oil, three samples were heated to 790^oc, held for 1 hour and each quenched in water, distilled water and palm kernel oil. Three samples were heated to 780^oc, held for 1 hour and each quenched in water, distilled water and palm kernel oil three samples were heated to 770^oc, held for 1 and each quenched in water, distilled water and palm kernel oil. Three samples were heated to 760^oc, held for 1 hour and each quenched in water, distilled water and palm kernel oil, after cooling, the samples were removed and cleaned, lastly there was one non – heat treated as - received sample.

Tensile test was carried out on all the sixteen test samples including the as –received sample using a gauge length of 100mm. The grip ends of the tensile specimen were attached to the grip holder of the instron tensile machine and a gradual application of tensile load through a wheel was applied on the steel specimen until fracture. The tensile strength was obtained by the equation.

$$\text{Ultimate tensile strength (UTS)} = \frac{\text{Ultimate load, } P_{\text{max}}}{A_0} \dots\dots (1)$$

The final length of the specimen was measured by tightly fitting back both separated parts and the final diameter of the area of fracture was obtained all with the aid of a vernier caliper. The value of percentage elongation was obtained in mathematical expression in equation 2

$$\% \text{ Elongation} = \frac{(L_f - L_o) \times 100}{L_o} \dots\dots\dots (2)$$

Where L_f = Final gauge length, L_o = Initial gauge length

Hardness test was carried out using the Vicker’s hardness testing machine. The hardness specimen was placed on a flat horizontal stand with a preload of the indenter which was used to indent the surface of each specimen and three hardness values were recorded per specimen after which the average was taken.

III. RESULTS AND DISCUSSION

The microstructure developed in the specimens after heat treatment are described in the Table 2 and micrographs 1 – 15.

Table 2: Microstructure of Medium Carbon Steel quenched in different media at varying inter – critical temperatures.

HEAT TREATMENT	MICROSTRUCTURE
As – Received	Banded ferrite – pearlite structure
For the water quenched samples	Marten site structures are randomly distributed in ferrite matrix, since they are all heated up within inter – critical temperatures.
For all the samples quenched in distill water	Highly martensite structure randomly distributed in ferrite matrix is formed.
For all the samples quenched in palm kernel oil	Bainite structure with ferrite at the grain boundaries were formed. These ferrite structures were formed as a result of austenitizing at temperatures within the critical range.

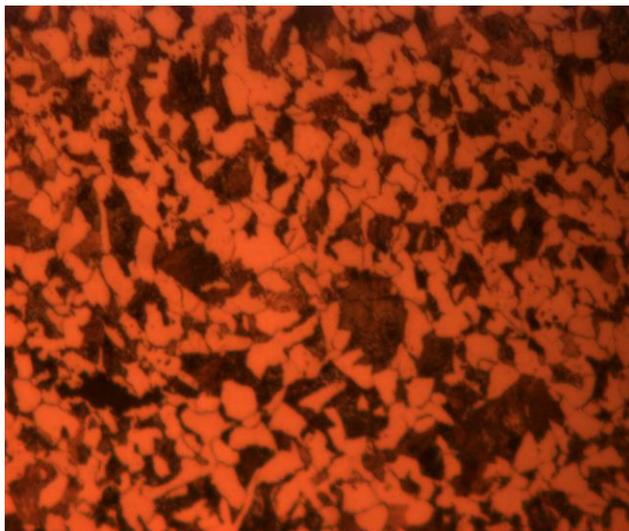


Plate 1: Microstructure of As - received Medium Carbon Steel. The structure revealed banded ferrite - pearlite structure of the non - heat treated as rolled specimen at x 200

The specimens for microstructural observation were mounted with Bakelite and grinded with grit papers of grade 220,320,400,800 and 1200. This was carried out by moving the specimen on the grit paper. The polishing was carried out using a polishing machine, which had a rotating wheel carrying a circular cloth pad on its surface. Rough polishing was carried out first using silicon carbide paste by placing the specimen on the rotating surface of the machine and moving in a direction anticlockwise to the rotating machine and final polishing operation was carried out using alumina polishing paste. Etching of the specimen was carried out using a cotton wool soaked in 2% nital to wipe the specimen’s polished surface to give a dull reflection surface. The etched specimen was then viewed under a computerized microscope[3].

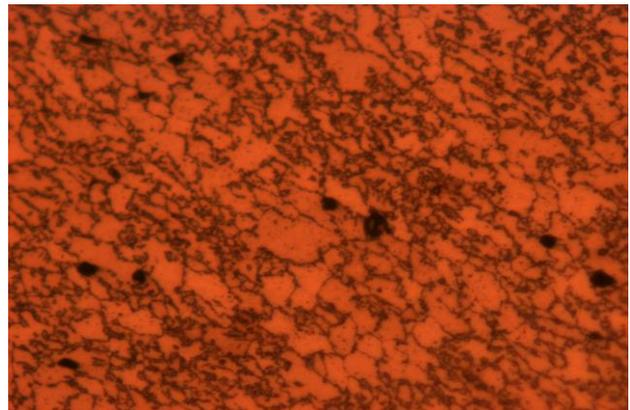


Plate 2: Microstructure of Medium Carbon Steel rod heated to 800°C, held for 1 hour and quenched in cold water at x 200

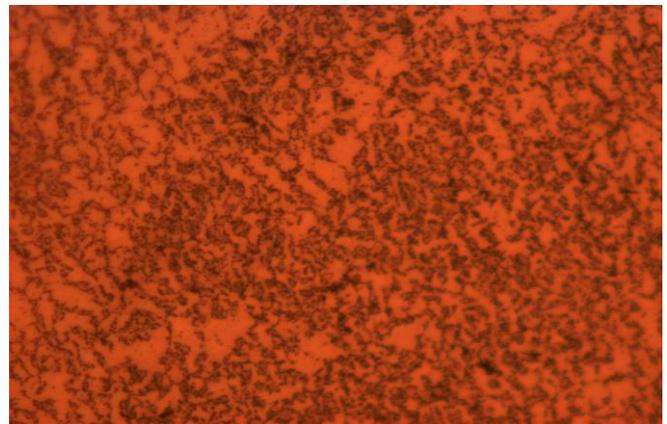


Plate 3: Microstructure of Medium Carbon Steel rod heated to 790°C, held for 1 hour and quenched in cold water at x 200

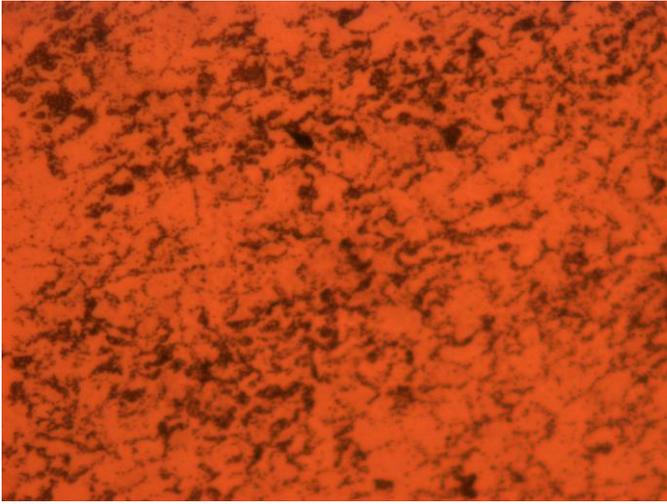


Plate 4: Microstructure of Medium Carbon Steel rod heated to 780°C, held for 1 hour and quenched in cold water at x 200

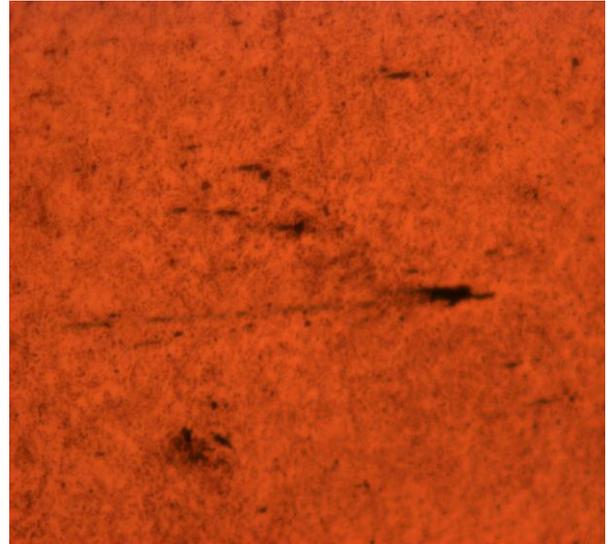


Plate 7: Microstructure of Medium Carbon Steel rod heated to 800°C, held for 1 hour and quenched in distilled water at x 200

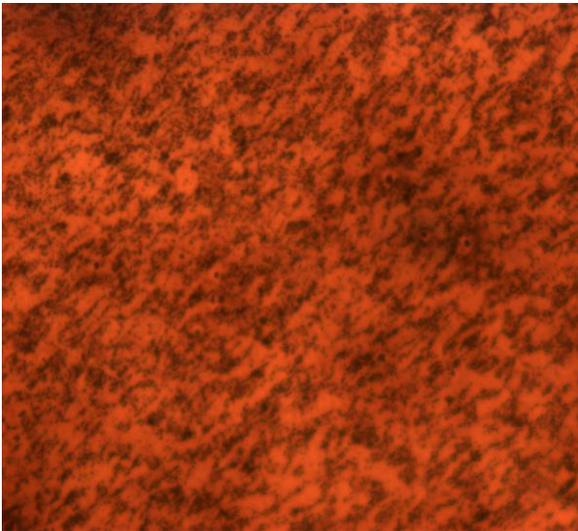


Plate 5: Microstructure of Medium Carbon Steel rod heated to 770°C, held for 1 hour and quenched in cold water at x 200

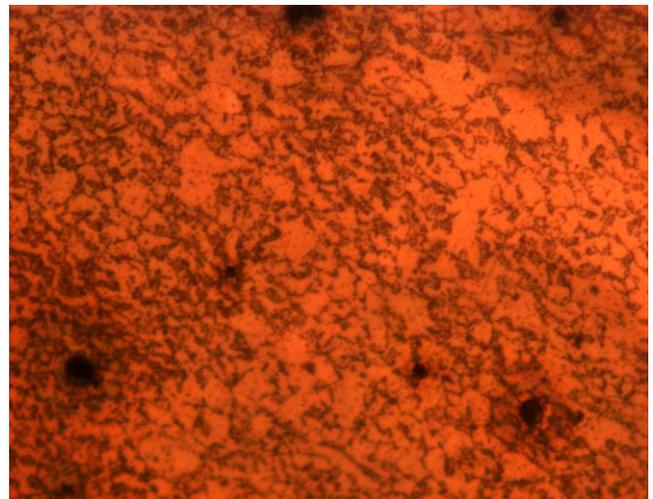


Plate 8: Microstructure of Medium Carbon Steel rod heated to 790°C, held for 1 hour and quenched in distilled water at x 200

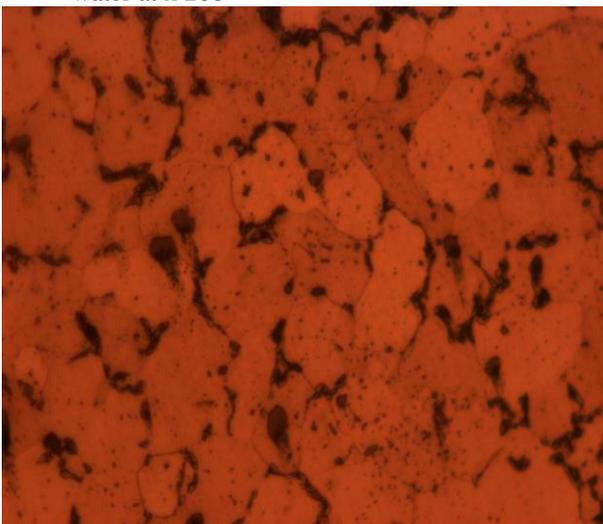


Plate 6: Microstructure of Medium Carbon Steel rod heated to 760°C, held for 1 hour and quenched in cold water at x 200

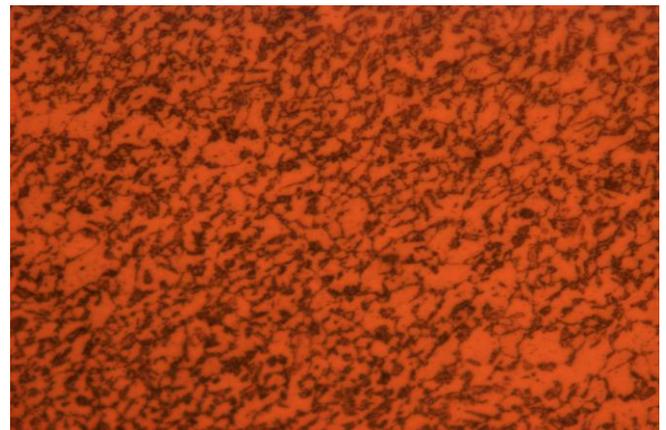


Plate 9: Microstructure of Medium Carbon Steel rod heated to 780°C, held for 1 hour and quenched in distilled water at x 200

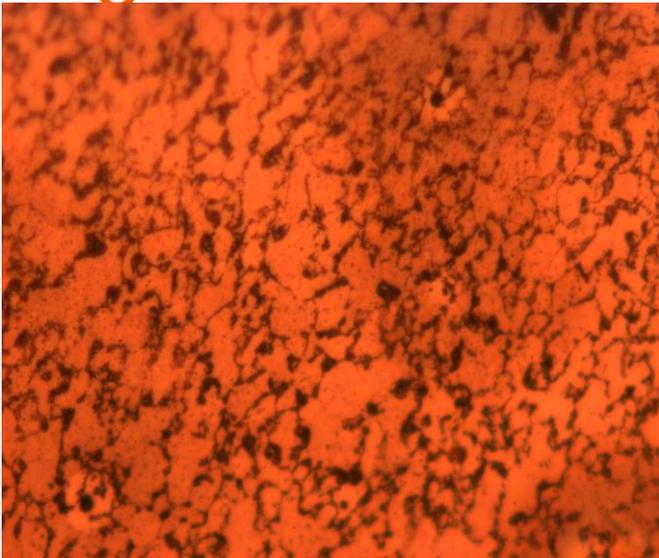


Plate 10: Microstructure of Medium Carbon Steel rod heated to 770°C, held for 1 hour and quenched in distilled water at x 200

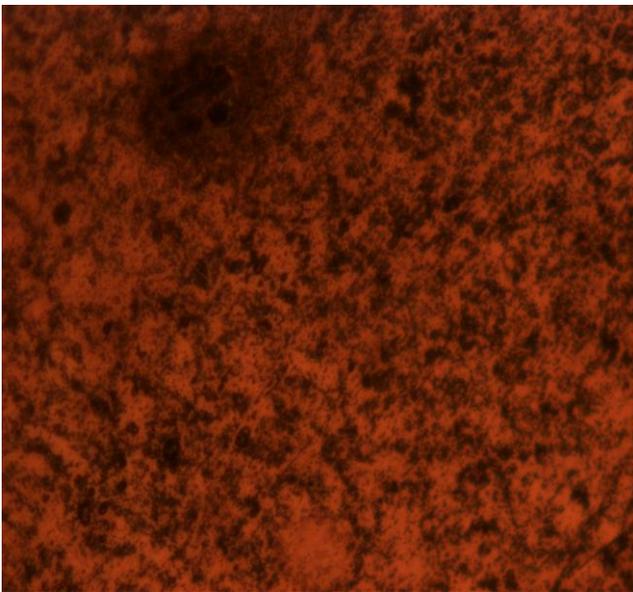


Plate 11: Microstructure of Medium Carbon Steel rod heated to 760°C, held for 1 hour and quenched in distilled water at x 200

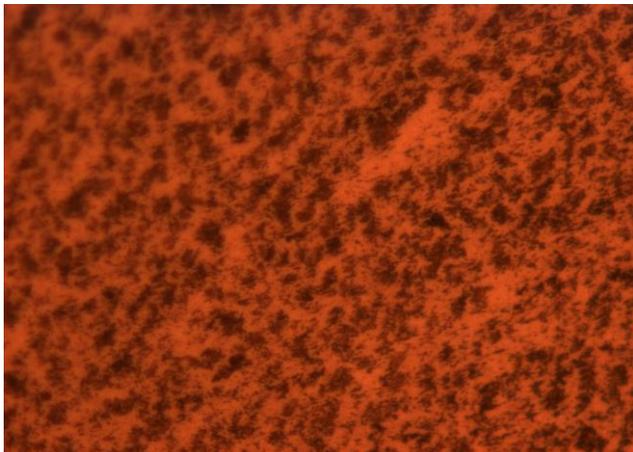


Plate 12: Microstructure of Medium Carbon Steel rod heated to 800°C, held for 1 hour and quenched in palm kernel oil at x 200

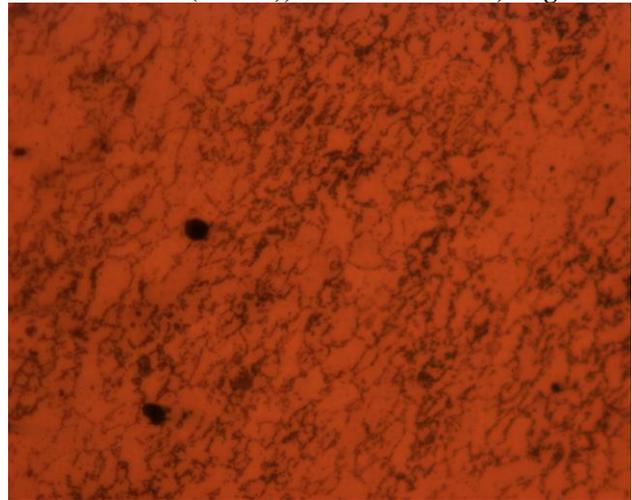


Plate 13: Microstructure of Medium Carbon Steel rod heated to 790°C, held for 1 hour and quenched in palm kernel oil at x 200

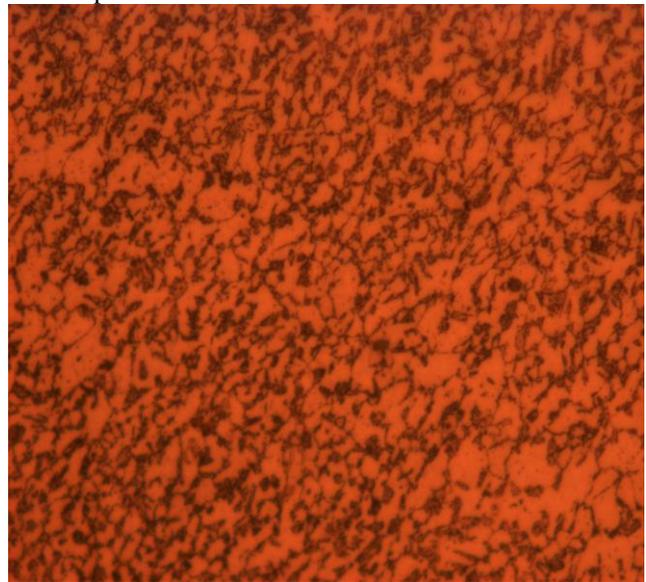


Plate 14: Microstructure of Medium Carbon Steel rod heated to 780°C, held for 1 hour and quenched in palm kernel oil at x 200

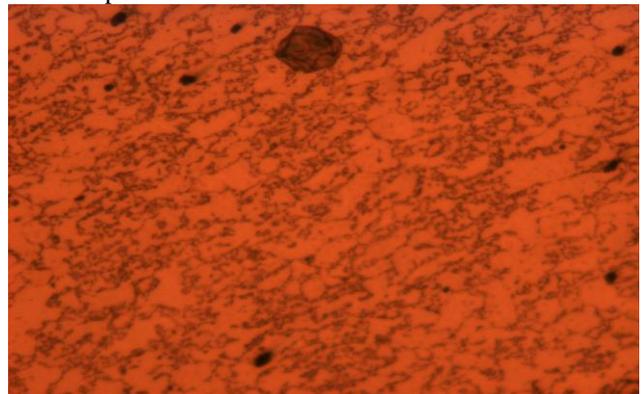


Plate 15: Microstructure of Medium Carbon Steel rod heated to 770°C, held for 1 hour and quenched in palm kernel oil at x 200

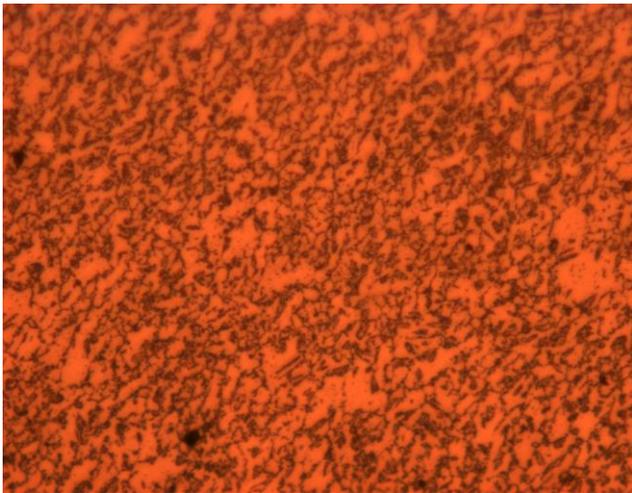


Plate 16: Microstructure of Medium Carbon Steel rod heated to 760°C, held for 1 hour and quenched in palm kernel oil at x 200

Hv, 198.8 Hv, and 186.4Hv respectively and palm kernel oil quenched samples produced the least hardness values after quenching as follows 196.9 Hv, 151.4 Hv, 177 Hv, 145.9 Hv, and 167.6 Hv respectively. The high hardness values obtained can be attributed to the various microstructures obtained.

The microstructure of the as - received medium carbon steel specimen consist of banded ferrite - pearlite structure. For all the samples quenched in water, martensite structures are randomly distributed in ferrite matrix, since they are all heated up within inter - critical temperatures. For all the samples quenched in distill water, there is highest presence of martensite structure randomly distributed in ferrite matrix is formed. For all the samples quenched in palm kernel oil, there was the formation of bainite structure with ferrite at the grain boundaries. This ferrite structure was formed as a result of austenitizing at a temperature within the critical range.

The result of the hardness values is shown in figure 1. The hardness values of the water quenched samples at 800 °c, 790 °c, 780 °c, 770 °c and 760 °c are 175Hv, 158 Hv, 166.05 Hv, 186.8 Hv and 165.4 Hv respectively. Distilled water quenched samples produced the highest hardness value as follows 183.7 Hv, 201.8 Hv, 150.6

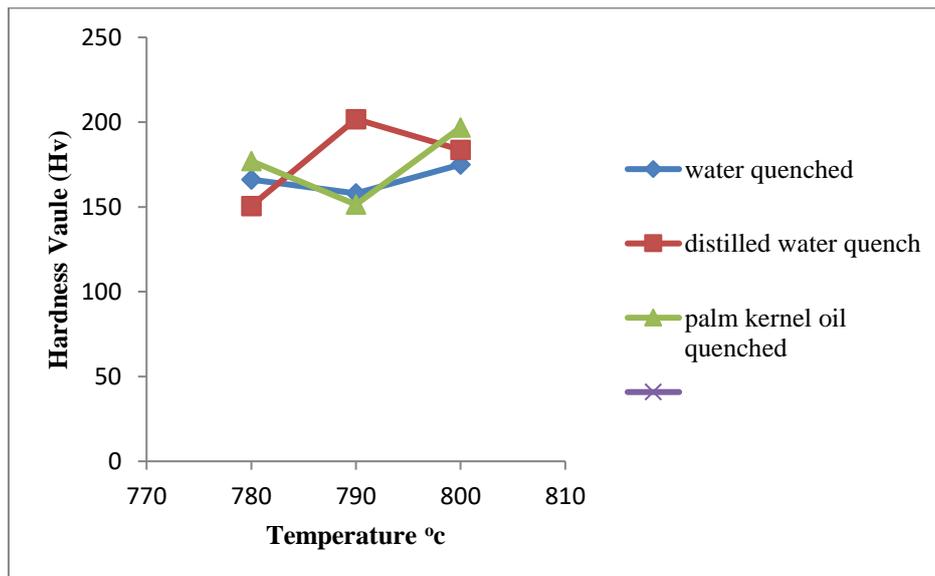


Figure 1: Hardness values of medium carbon steel quenched in different media at varying inter – critical temperatures

The results of the ultimate tensile strength are as shown in Figure 4. The ultimate tensile strength of the water quenched samples at 800 °c, 790 °c, 780 °c, 770 °c and 760 °c are 800.7 N/mm², 828.3 N/mm², 850.3 N/mm², 884.0 N/mm², and 846.8 N/mm² respectively, which produce the least ultimate tensile strength that could be attributed to internal stresses and transformation stresses developed after quenching as a result of rapid quenching. Distilled water

quenched samples produced the highest ultimate tensile strength values as follows 900.7 N/mm², 912.6 N/mm², 835.3 N/mm², 898.6 N/mm², and 894.0 N/mm² respectively, while palm kernel oil quenched samples produced ultimate tensile strength values as follows 902.8 N/mm², 838.6 N/mm², 883.7 N/mm², 825.3 N/mm², and 860.5 N/mm² respectively.

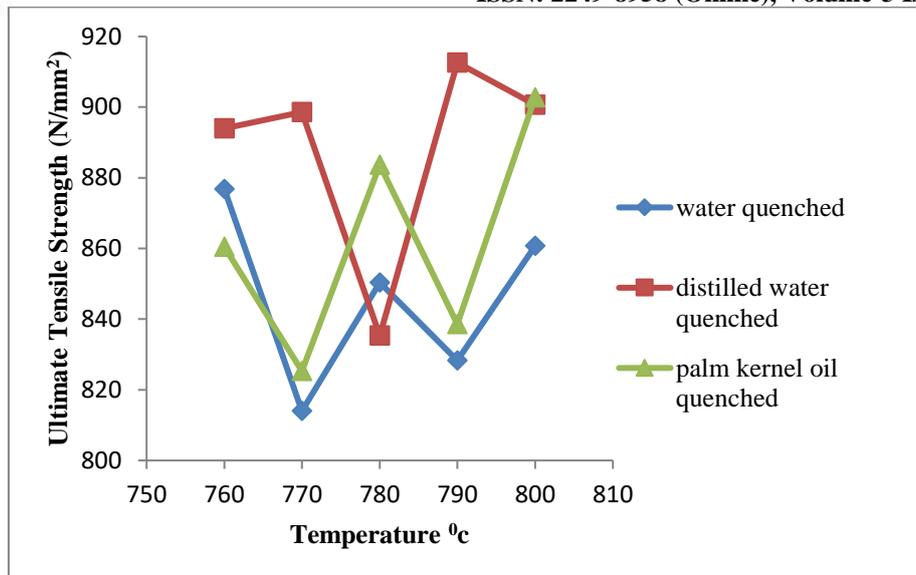


Figure 2: Tensile strength values of medium carbon steel quenched in different media at varying inter – critical temperatures.

IV. CONCLUSIONS

Samples quenched in distilled water were noted to produce the highest mechanical properties such as high hardness value and strength possibly linked to the fact that it is free from impurities and minerals such as fluorides, calcium ions and magnesium ions which presence would have reduce the severity of quench, followed by those quenched in palm kernel oil due to its density which is higher than that of distilled water thereby producing a final sample with improved toughness and ductility, and water produces the least strength that could be attributed to internal stresses and transformation stresses developed after quenching as a result of rapid quenching. Hence palm kernel oil has been proven to be a suitable quenching medium which has been quantitatively assessed using microstructure, hardness value and tensile strength value.

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