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EFFECTS OF VARIOUS QUENCHING MEDIA ON MECHANICAL PROPERTIES OF ANNEALED 0.509Wt%C –0.178Wt%Mn STEEL

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ABSTRACT
Evaluation of palm kernel oil, cotton seed oil and olive oil as quenching media of 0.509Wt%C medium carbon steel was investigated. To compare the effectiveness of the oils, the samples were also quenched in water and SAE engine oil which are the commercial quenchants. The samples were quenched to room temperature in the quenching media (palm kernel oil, cotton seed oil and olive oil). The machined specimen of the steel was heated at 880^{0}Cthen quenched in water, engine oil, palm kernel oil, cotton seed oil and olive oil. Tensile strength, hardness and impact energy were used to measure the quenching effectiveness of the various media. The microstructures and mechanical properties of the quenched samples were used to determine the quench severity of the oils. The test of the mechanical properties shows that the hardness of steel quenched in water was (1740.54 HBN), while the hardness of steel quenched in palm kernel oil was (740.34 HBN) which was recorded as the least in all samples quenched. As-received sample absorbed the highest amount of energy (183.10J) before fracture while sample quenched in water absorbs the least energy (28.50J). The microstructure of the samples quenched in the oils under study revealed the formation of low proportions of martensite and in the case of olive oil, there was retained austenite. Hence, olive oil can be used where cooling severity less than that of water and SAE 40 engine oil is required for hardening of plain carbon steels.

Keywords: *hardening characteristics, medium carbon steel, palm kernel oil, cotton seed oil, olive oil and quenchant.*

1. INTRODUCTION

Quenching is an essential element in developing the desired properties of many steel and aluminum alloys. Agitation, or forced circulation of the quenchant is required to shorten the cooling times. Without agitation, natural convection of the quenchant, and quenchant vaporization limit, the heat transfer rate through the fluid film boundary are at the surface of parts [1]. Heat treatment is a multi-parameter process. Selection of the appropriate parameters helps in predicting possible behavior of treated components. The kind of quenching medium, selection of quenching medium temperature and the selection of the medium state (unagitated, agitated) are determining factors [2, 3].

Plain carbon steels are widely used for many industrial applications and manufacturing on account of their low cost and easy fabrication [4]. They are classified on the basis of their carbon content as their major alloying element is carbon. According to [5], steels with carbon content varying from 0.25% to 0.65% are classified as medium carbon, while those with carbon content less than 0.25% are termed low carbon. The carbon content of high carbon steels usually ranges within 0.65-1.5%. Hardness and other mechanical properties of plain carbon steels increase with the rise in concentration of carbon dissolved in austenite prior to quenching during hardening heat treatment [5, 6], which may be due to transformation of austenite into martensite [7]. Therefore, the mechanical strength of medium carbon steels can be improved by quenching in appropriate medium. However, the major influencing factors in the choice of the quenching medium are the kind of heat treatment,

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composition of the steel, the sizes and shapes of the parts [7].

Applications of steels for engineering components require a complete understanding of material properties and design requirements. Through the last few decades a category of steels known as high strength steels have undergone constant research [7, 10]. As a result, quenched and tempered micro alloyed steels are most likely candidate materials for the next generation of high – strength steel sheets. For a given alloy content, quenched and tempered micro alloyed steel exhibit good combination of strength and toughness [7, 10 – 14]. Traditionally, quenched and tempered steel sheets are employed in automotive industry in the areas of structural members, power transmission and impact resistance systems.

Certain engineering components require high hardness values so that they may be used successfully for heavy duty processes. Hardening as a form of heat treatment has been used to achieve these requirements in metal or alloy components [15]. Hardening essentially involves heating the metal alloy to a sufficiently high temperature, holding at that temperature followed by rapid cooling in a media usually water, oil or salt bath [16]. This consequently causes an increase in hardness of the metal/alloy, which due to phase transformation will accompany rapid cooling which occur at a considerably low temperature leading to the formation of non-equilibrium products [5]. The transforming phase is austenite and the product of low temperature transformation of austenite is martensite which is a hard micro-constituent in steel [12]. The presence of this micro constituent in rapidly cooled steels thus accounts for the increase in hardness of steel [18]. This process of rapidly cooling of steel is referred to as quenching and the media in which the steel is quenched is called quenchant [17].

Mineral oils have been found to exhibit best cooling capacity for the majority of alloy steels [19], but they are relatively expensive, toxic and non-biodegradable. Therefore, there has been considerable work in the past on the possibility of replacing mineral oils with aqueous solutions of chemical substances and polymers [19-21]. More recently, the use of locally available cooking oils, which are relatively cheap, non-toxic and environmental friendly, as quenching media, has begun to generate attention [22].

The aim of this paper is to examine the mechanical properties on the annealed steel samples quenched in palm kernel, olive oil and cotton seed oil on the steel and the result compared with that quenched in water and engine oil. Water is being used here to serve as a standard. Such mechanical properties include: tensile strength, impact strength, hardness, percentage elongation and yield strength of the material.

2. MATERIALS AND METHODS

The chemical composition of the medium carbon steel samples used for this investigation is given in Table 1

2.1. Materials

Materials used in this study are medium carbon steel, while palm kernel, cotton seed and olive oil, water and SAE 40 engine oil as quenching media. In this study, medium carbon steel was used by virtue of its availability, properties and relatively cheap cost.

2.2 Equipment

The equipment used in this work includes: Lathe machine, heat treatment furnace, Avery Denison Izod impact machine, Monso Tensometer, Avery hardness machine, mounting press, and a Metallurgical Microscope.

2.3 Methods

Samples were machined from the medium carbon steel. One set of the machined test samples (for hardness, tensile and impact) were kept aside to be tested in the as-received condition. The remaining samples were taken into the muffle furnace and austenitized at 880^{o}Cand soaked using a muffle furnace for 1hr before been removed and cooled in air. The samples were taken back into the furnace and heated to 880^{o}c again, soaked for 1hr after which a set of test samples for (hardness, tensile, impact) each were removed and quenched in water, engine oil, cotton seed oil, palm kernel oil, and olive oil respectively. The quenched samples were then removed, cleaned and subjected to hardness, tensile and impact tests respectively. The results obtained were recorded and tabulated.

Table 1: Chemical composition of the mild steel sample (wt.%)

C%	Mn%	Si%	Cr%	Mo%	Al%	Co%	Cu%	Ti%	V%	Pb%	Sn%	Zn%
0.509	0.178	0.187	0.0051	0.079	0.107	0.012	0.295	0.0034	0.034	0.017	0.0334	0.03

2.3.1 *Mechanical Properties*

2.3.1.1 Tensile Properties Test

The tensile properties of the quenched steel sample were carried out using "MONSO TENSOMETER". After measuring initial gauge length (l_o) and diameter, the specimen testing was done, the graphs of load versus extension were plotted on a graph paper fixed to the stylus from which yield load, maximum load, were taken for the calculation of yield strength and tensile strength respectively.

$$\text{Yield strength; } \sigma y = \frac{P_y}{A_o} \quad (1)$$

Where σy is the yield strength in N/mm^2, P_y is the yield load in Newton (N), A_o is the original cross sectional area in mm^2.Tensile strength or ultimate tensile strength,

$$\sigma_{max} = \frac{P_{max}}{A_o} \quad (2)$$

Where σ_{max} is the Tensile strength (N/mm^2), P_{max} is the maximum load (N).

The broken ends of the specimen were fitted together after fracture and the measurement of final gauge length (L_f) and the smallest diameter of local neck for the calculation of percentage elongation from the following formula:

$$\% \text{ elongation} = (l_f - l_o)/ l_o \text{ X } 100 \quad (3)$$

Where

L_o is the initial gauge length (mm), L_f is the final gauge length (mm)

2.3.1.2 Hardness Test Measurement

Avery hardness testing machine was used for the hardness measurement. After placing the test specimen on the anvil of the machine, the load was then applied manually which caused a round indentation to be impressed on the sample. The loss was then released and the diameter of the impression or indentation was measured with low power microscope and calibrated lens. The Brinell number was calculated according to the formula

$$HBN = \frac{2P}{\pi(D - \sqrt{D^2 - d^2}} \quad (4)$$

$P$is the applied force (kgf), $D$is the diameter of indenter (mm) and d is diameter of indentation (mm)

2.3.1.3 Charpy Impact Test

The charpy impact test of the quenched steel sample was carried on Avery Denson impact testing machine. The specimens were supported horizontally with the V-notch opposite to the strike end. The trigger was released for the pendulum to strike the specimen from an initial potential energy of 0J.The energy absorbed before fracture was then read directly on the gauge of machine.

3. RESULTS AND DISCUSSIONS

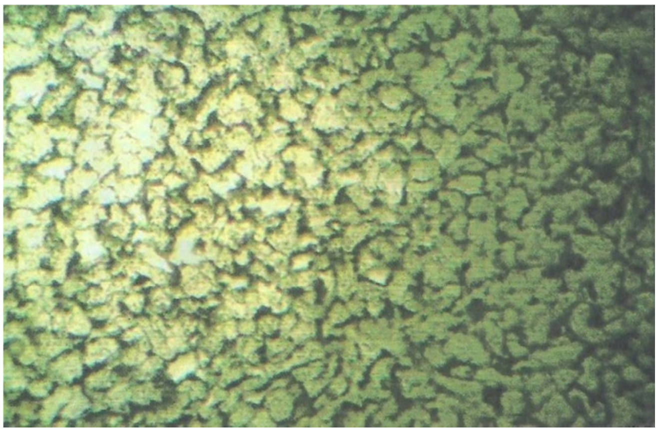
The microstructures of the as-received and as-quenched samples are presented in Micrographs 1-6.

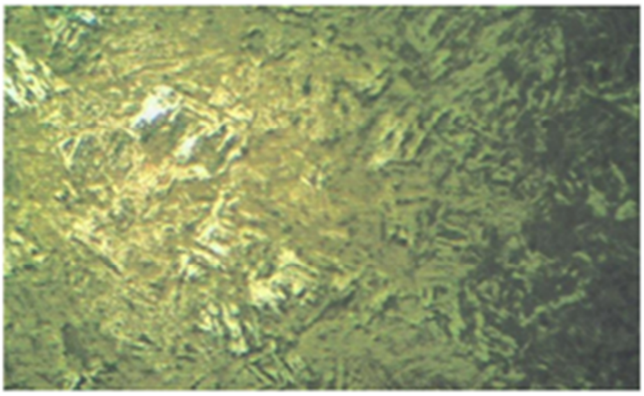
3.1 Metallographic and Mechanical Properties Analysis

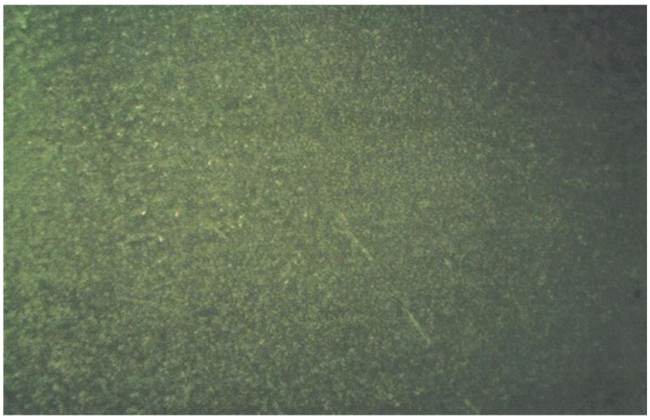
To evaluate the quenching effectiveness, metallographic analysis of the received and quenched prepared specimen were carried out and compared for 0.509% carbon content. The as–received sample as shown in A1, showing pearlite (dark) in ferrite (white) matrix. The as-quenched in water sample shown in A2, is showing martensite structure (dark) with retained austenite (white).The sample quenched in engine oil as shown in A3, is showing full martensite (dark).The sample quenched in palm kernel oil shown in A4, is showing low proportion of martensite structure (dark) in ferric (white) matrix. The sample quenched in cotton oil is showed in A5, is showing low proportion of martensite structure (dark) in ferric (white) matrix. The sample quenched in olive oil shown in A6, is showing low martensite structure (white) with retained austenite (dark). All these three microstructures are in par with what is obtainable in literature [16]. However, water quenched specimen has the highest presence of martensite phase with retained austenite. Also evidence of less retained austenite and martensite was seen more in the plain carbon steel specimen quenched in the cotton seed oil, palm kernel oil and olive oil than those quenched in SAE 40 engine oil.

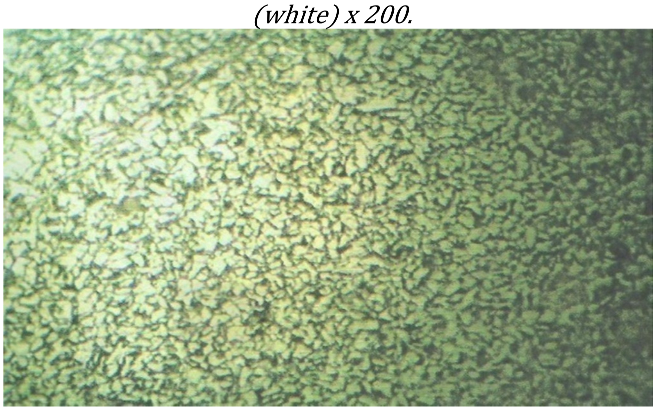
The medium carbon steel specimen hardened in these oils showed an increased precipitation of ferrite due to the transformation of retained austenite. The results obtained in the present study are at par with the earlier observation of [16].

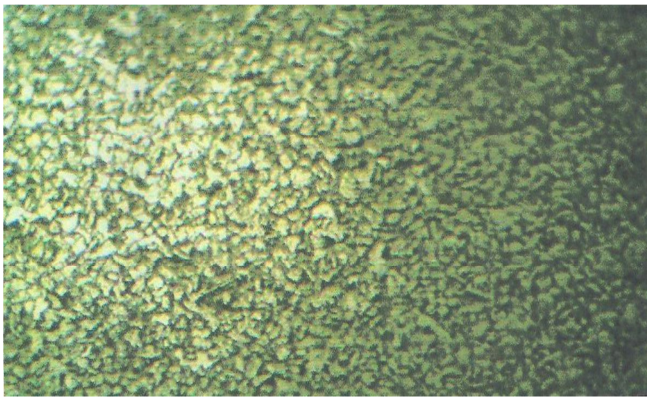
To evaluate the effectiveness of the media on the mechanical properties of the received and quenched specimens, comparisons were carried out based on the results obtained. From the results obtained, the hardness value of both the medium carbon steel increased after quenching in all the media (see Figures 1-5).The quenched samples in the various quenching media have a lower hardness values as compared to water.

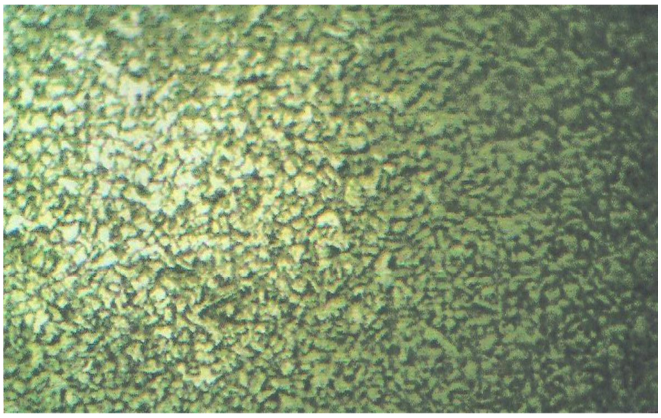

Micrograph A1: Microstructure of as-received structure of 0.509% carbon steel showing pearlite (dark) in ferric (white) matrix x 200


Micrograph A2: Microstructure of water quenched microstructure of 0.509% carbon steel showing martensite structure (dark) with retained austenite (white) x 200.


Micrograph A3: Microstructure of 0.509% carbon steel quenched in engine oil, showing full martensite (dark) x 200.


Micrograph A4: Micrograph of 0.509% carbon steel quenched in palm kernel oil, showing low proportion ofmartensite structure (dark) in ferric (white) matrix x 200.


Micrograph A5: Micrograph of 0.509% carbon steel quenched in cotton seed oil, showing low proportion of martensitic structure (dark) in ferric (white) matrix x 200.


Micrograph A6: Micrograph of 0.509% steel quenched in olive oil, showing low proportion of martensitic structure (white) with retained austenite (dark).

This may be attributed to the fact that water has a higher cooling rate and highest free carbon in martensite than palm kernel oil, olive oil and cotton seed oil respectively. This is as reported by other researchers [22-24]. Furthermore, presence of fine dispersion of small particles in the pro-eutectoid ferrite and paralytic ferrite, which will hinder the dislocation movement, may have also contributed to higher hardness value of the water-quenched sample [25].

The results of yield strength reveal that sample quenched in engine oil has maximum yield strength of 574.97N/mm^2 and water quenched has least yield strength of 329.57N/mm^{2}This show that the sample quenched in engine oil can withstand more loads.

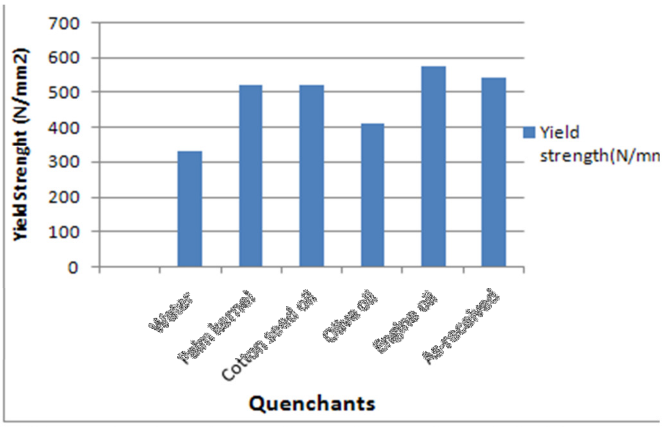


Figure 1: Yield Strength values of the medium carbon steel sample in different quenchants.

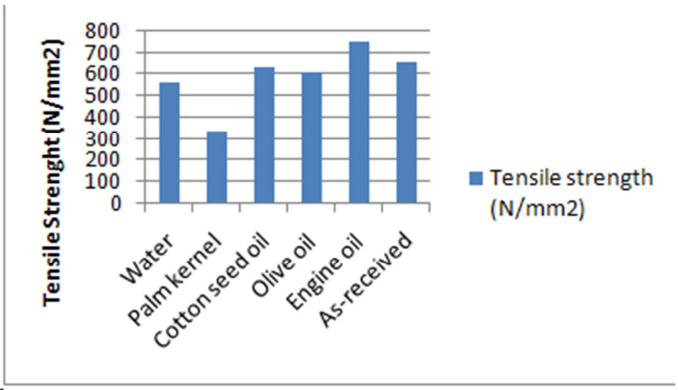


Figure 2: Tensile Strength values of the medium carbon steel sample in different quenchants.

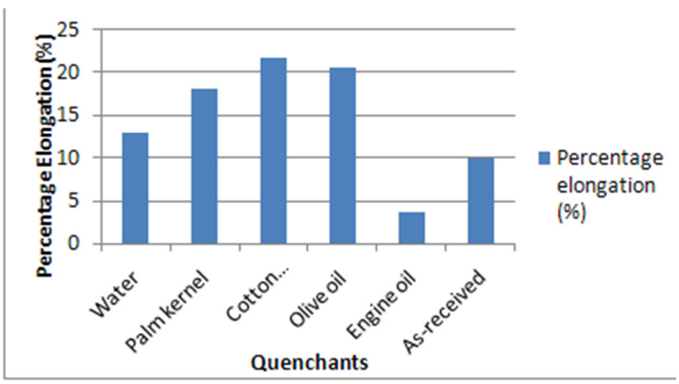


Figure 3: Percentage Elongation values of the medium carbon steel sample in different quenchants.

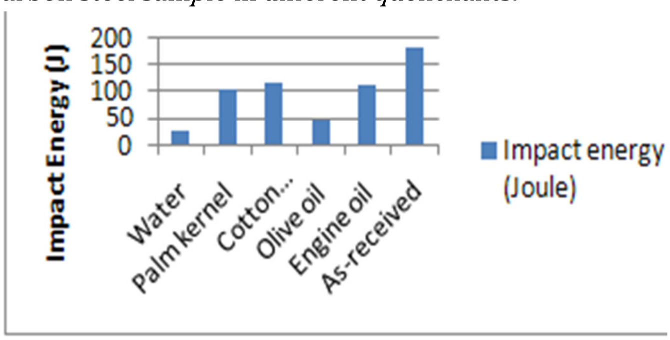


Figure 4: Impact Energy values of the medium carbon steel sample in different quenchants.

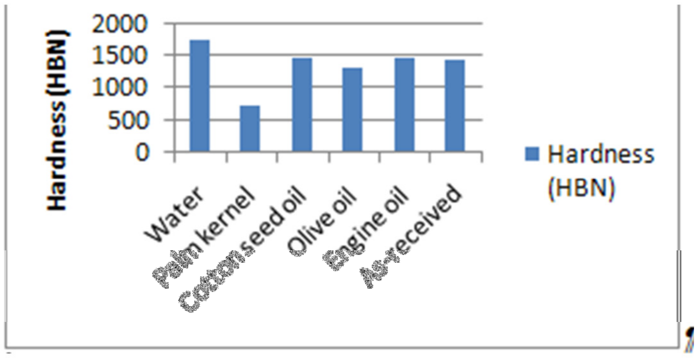


Figure 5: Hardness values of the medium carbon steel sample in different quenchants.

The tensile strength results reveal that the sample quenched in engine oil has the highest value of tensile strength of 753.30N/mm^2, while the sample quenched in palm kernel oil has the least of 333.59N/mm^2. The hardening process by quenching in all the liquid media reduced the impact energy (See figure 4). The as-received samples gave the highest impact strength value and water gave the least impact strength.

The impact strength of the medium carbon steel samples is 183.10J, 115.90J, 50.20J, 118.00J, 104.40J and 28.50J for SAE engine 40, olive oil, cotton seed oil, palm kernel oil and water respectively. The decrease in the impact energy value as the hardness increases are in agreement with the earlier research of [18] after quenching steel and ductile cast iron in various media.

As regards the % elongation, cotton seed oil quenched sample has a value of 21.74% which is the maximum, while engine oil quenched sample is least of 3.57%. It shows that cotton seed oil quenched sample can take more load before its fracture. The impact energy test reveal that the as-received sample absorbed the highest amount of energy (183.10J) before fracture while sample quenched in water absorbs the least energy (28.50J). These observations are in line with what are obtained in literature [15].This further show that the oils (palm kernel oil, olive oil and cotton seed oil) can be used to improve the toughness of plain carbon steel since it has higher impact energy values than water which is the common quenching medium.

Water quenched sample has the highest hardness value of 1740.54HBN. Followed by engine oil, cotton seed oil, as-received, olive oil and palm kernel quenched samples, which have hardness values of, 1475.06HBN, 1477.06HBN, 1457.06HBN, 1318.13HBN and 740.34HBN. It is observed that the cooling rate observed in the oils (palm kernel, cotton seed and olive oil) are lower than that obtained in both water and engine oil.

4. CONCLUSION

The effectiveness of the palm kernel oil, cotton seed oil and olive oil as quenching medium in the hardening process of plain carbon steel has been quantitatively assessed using hardness values, percentage elongation , yield strength and impact energy in particular. From the results obtained in this study, the following conclusions can be drawn;

1. The Olive oil, Palm Kernel oil and Cotton seed oil has hardnessvalues less than that of water and SAE40 engine oil. Hence, Olive oil, Cotton seed and Palm Kernel seed oil can be used where cooling severity less than water and SAE 40 engine oil is required for hardening of plain carbon steel, while for the Palm kernel oil and Olive oil, it was found that the hardness was lower than that of the as-received after quenching, hence, it means the quenchant is a slow quenchant which makes it undesirable for hardening. This could be further explained by its inability to form martensite but rather formed softer structures like ferrite and pearlite plus retained austenite.
2. Palm kernel oil, Cotton seed oil and Olive oil can be used to improve the toughness of these samples since it has higher impact energy values than water which is the common quenching medium.

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