Evaluation of Khaya Seed Oil (Mahogany Oil) as Quenchant in the Hardening Process of Plain Carbon Steel.

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ABSTRACT

Evaluation of Khaya seed oil (Mahogany oil) as a quenchant for hardening process of 0.34%C plain carbon steel was investigated. This was done by comparing with water and SAE 40 engine oil quenched. The properties of the plain carbon steel in the annealed, normalized and quenched and tempered conditions were also investigated. The samples were austenitized by heating to 870°C, soaked and quenched in the various selected quenching media. The properties investigated includes: microstructure, tensile strength, hardness and impact energy.

The results show that hardness value of the carbon steel increased from 14.3HRC in the as-cast condition to 56.3, 48.8 and 46.4HRC while tensile strength increased from 732N/mm^2 in the as-cast condition to 906, 927 and 953N/mm^2 for water, Khaya seed oil, and SAE40 engine oil, respectively. The as-received steel sample gave the highest impact energy value and water quenched sample gave the least impact energy. The impact energy of the plain carbon steel samples is 46.0, 9.8, 2.0, and 11.0 Joule for as-cast condition, Khaya seed oil, water, and SAE 40 engine oil quenched, respectively. The microstructure of the samples quenched in the Khaya seed oil revealed the formation of martensite. Hence, Khaya seed oil can be used where cooling severity less than that of water but greater than SAE 40 engine oil is required for hardening of plain carbon steels.

(Keywords: hardening, characteristics, plain carbon steel, Khaya seed oil, quenchant)

INTRODUCTION

Certain engineering components require high hardness values so that they may be used successfully for heavy duty processes (Hussein, 2002). Hardening as a form of heat treatment has been used to achieve these requirements in metal or alloy components (Kashim, 2010).

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 (Higgins, 1993; Hassan et al., 2009). This consequently causes an increase in hardness of the metal/alloy which due to phase transformation accompanying rapid cooling which occur at a considerably low temperature leading to the formation of non-equilibrium products (Rajan, 1988). The transforming phase is austenite and the product of low temperature transformation of austenite is martensite which is a hard micro-constituent in steel (Calister, 1997; Hassan, 2005). The presence of this micro constituent in a rapidly cooled steel thus accounts for the increase in hardness of steel (Muhammed, 2007). This process of rapidly cooling of steel is referred to as quenching and the media in which the steel is quenched is called quenchant (Hassan, 2005).

The effectiveness of a quenching process depends largely on the characteristics of the quenchant used in addition to some other factors such as chemical composition of steel used, design of the steel component, surface condition of the steel and efficiency of the quenching process (Isah and Hassan, 2008).

Water is the most widely used quenching medium (Isah and Hassan, 2008). This can be attributed to its low cost, availability, ease of handling, relatively no pollution problem, since it can be disposed easily. The use of water in practice has been mainly for plain carbon steels and a few grades of low alloy steels (Muhammed, 2007). The layer of scale formed on the surface during heating of the work piece is broken up by water quenching, thus eliminating any further surface cleaning. Though water abundant and low cost has the drawback of inducing crack or dimensional changes on the quenched component due to its high cooling rate.

Others quenchant such as oil has the problem of not inducing enough hardness. Polymer quenchant though can provide severity between those of water and oil has the problem of varying concentration during the quenching process and it is also more expensive. Brine produces more quenching severity than water; but it also has a problem of corrosive attack on the components and the equipment used for the quenching (Hassan, 2005). Hence, there is a need for the development of a quenching medium with good economics like water having less severity of quench and yet producing appreciable hardening. Hence this work is aimed at investigating the suitability of using Khaya seed oil (mahogany oil) as a quenching medium for hardening process in plain carbon steel.

Khaya seed oil (mahogany oil) is a soft natural insecticide, safe, eco-friendly and bio-degradable. Nigeria is blessed with abundance of Khaya trees especially in northern parts of the country where it is used as shelter - belts for afforestation. Almost every part of the tree is useful especially in cosmetics, medicine, and agriculture. The seeds which are neglected and of environmental nuisance/wastes are indeed "green gold", where the oil is extract (Isah and Hassan, 2008).

EXPERIMENTAL PROCEDURE

Materials

The main materials used for this research work includes: plain carbon steel obtained from National Metallurgical Development Centre, Jos, Khaya seed oil was obtained from Michika Local Government of Adamawa State, SAE 40 engine oil obtained from Total Filling Station, Jos, Nigeria. The chemical composition of the carbon steel is shown Table 1 and the chemical composition of the Khaya seed oil (mahogany oil) is shown in Table 2.

Table 1: Chemical Composition of Steel Used.

%C	%Si	%Mn	%P	%S	%Fe
0.34	0.33	0.98	0.04	0.02	Balance

Table 2: Composition of Khaya Seed Oil (Mahogany Oil).

Oil	Free fatty acid (wt%)	Saponification value (mg KOH)	Iodine value (g/100g)	Density (g/cm^3)	Peroxide value (meq/kg)	Acid value (mg KOH)	Viscosity (at 26^{o}C)	Flash Point
Khaya oil	6.07	198.2	71.35	0.9575	6.78	5.9	125.2	336^{o}C

Other materials used included: Bakelite, silicon grit papers, (120, 180, 230, 320, 400, and 600 grades), cerium oxide and 2.5% nital solution.

Equipment

The equipment used in this work includes: Lathe machine, heat treatment furnace, Avery Denison Izod impact machine, Tinus Olsen tensile machine, Rockwell hardness machine, mounting press, polishing machine and computerized Metallurgical Microscope.

Methods

The machining of the plain carbon steel samples was carried out using the lathe machine to the standard test samples for tensile and impact (see Figures 1-2) (American Society of Metals, 1995).

The prepared test specimens were loaded in the heat treatment furnace and heated to a temperature of 870^0C, soaked at this temperature for 45 minutes to attain uniform homogenization. After soaking three sets of four samples each comprising of tensile, impact, hardness and metallography were quenched in the water, Khaya seed oil and SAE 40 engine oil quenchants respectively. Vigorous stirring of the system was ensured during the quenching to avoid the formation of vapor skin around the specimens in the quenchants. After cooling, the samples were removed and cleaned. Some of the samples were annealed, normalized and tempered at 350^0C.

The tensile test was carried out using a gauge length of 50mm. The grip ends of the tensile specimen were attached to the grip holder of the Tinus Olsen 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 Equation 1 (American Society of Metals, 1995).

$$\text{Ultimate tensile strength (UTS)} = \frac{\text{Ultmate tensile load}}{\text{Initail Area } (A_0)} \quad \textbf{(1)}$$

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 values of percentage elongation was obtained in mathematical expression in equation 2(American Society of Metals, 1995).

$$\text{Percentage Elongation} = \frac{L_f - L_0}{L_0} \times 100 \quad \textbf{(2)}$$

Where L_f = Final gauge length , L_0 = Initial gauge length , A_0 = Initial Area, A_f = Final Area

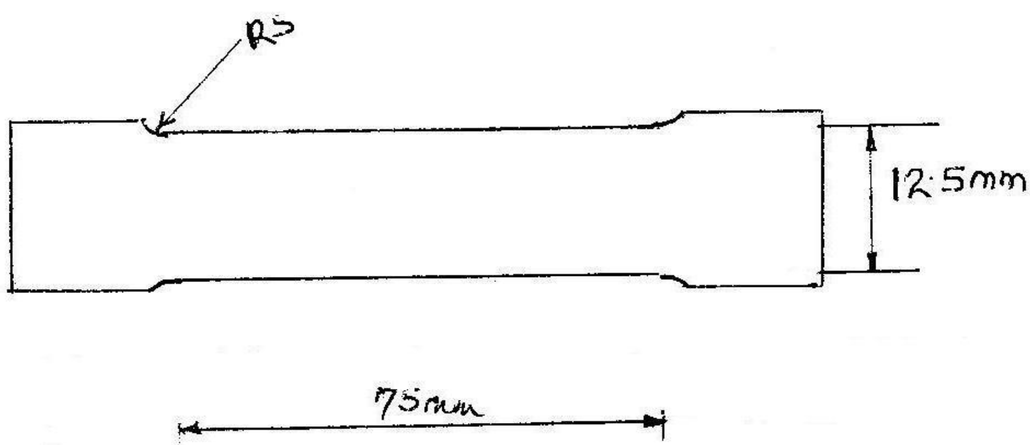


Figure 1: Tensile Test Specimen.

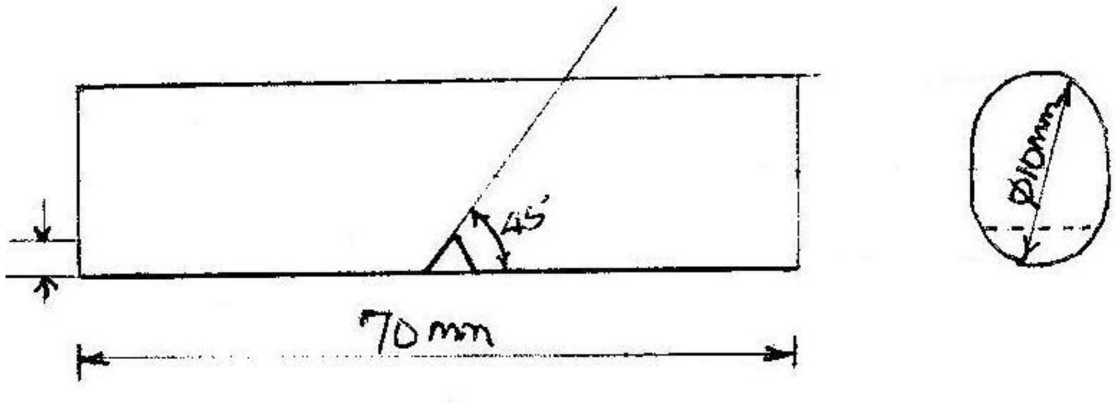


Figure 2: Impact Test Specimen.

The impact specimen was placed on a horizontal stand of the izod impact machine. It was arranged such that the notch was directly opposite the point of impact of a heavily suspended mass. With the gauge set properly, the suspended mass was released from a height to hit the specimen. The energy absorbed by the specimen was reflected on a graduated scale.

The hardness test was carried out using the Rock well hardness machine. The hardness specimen was placed on a flat horizontal stand, with a preload of the diamond cone indenter was used to indent on the surface of the specimen and its hardness value was reflected on a dial gauge of the machine and the readings read from the calibrated C-scale of the gauge.

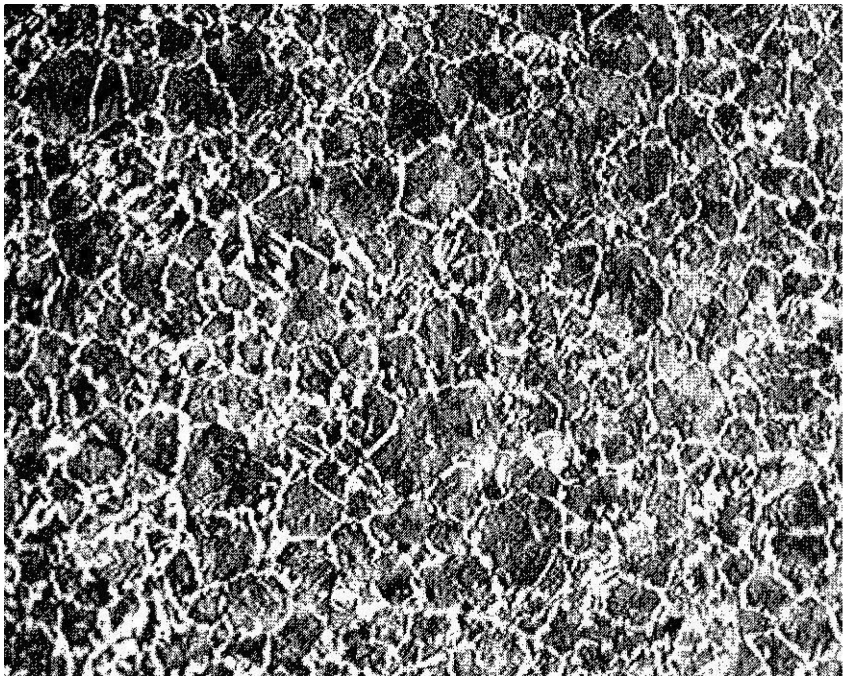
The specimens for microstructural observation were mounted with Bakelite and grinded with grit papers of grades 120, 180, 240, 320, 400, and 600. This was carried out by moving the specimen on the grit paper. The polishing was carried out using a polishing machine, which had a rotating wheel carrying 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 nital to wipe the specimen's polished surface to give a dull reflection surface. The etched specimen was then viewed under a computerized microscope.

RESULTS AND DISCUSSION

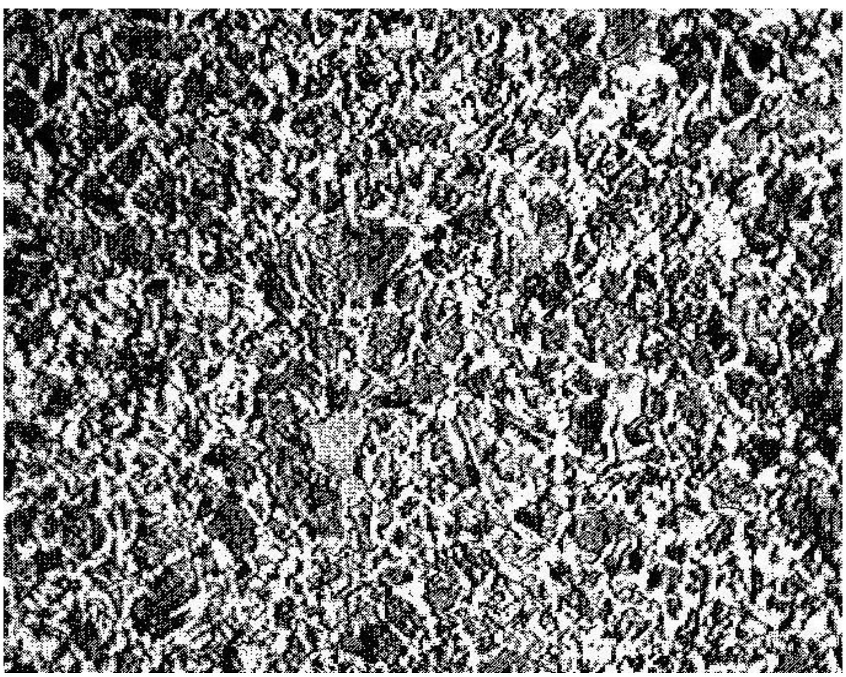
The microstructure developed in the specimens after heat treatment are described in the Table 3 and Micrographs 1-7.

Table 3: Microstructure of Plain Carbon Steels in Various Conditions.

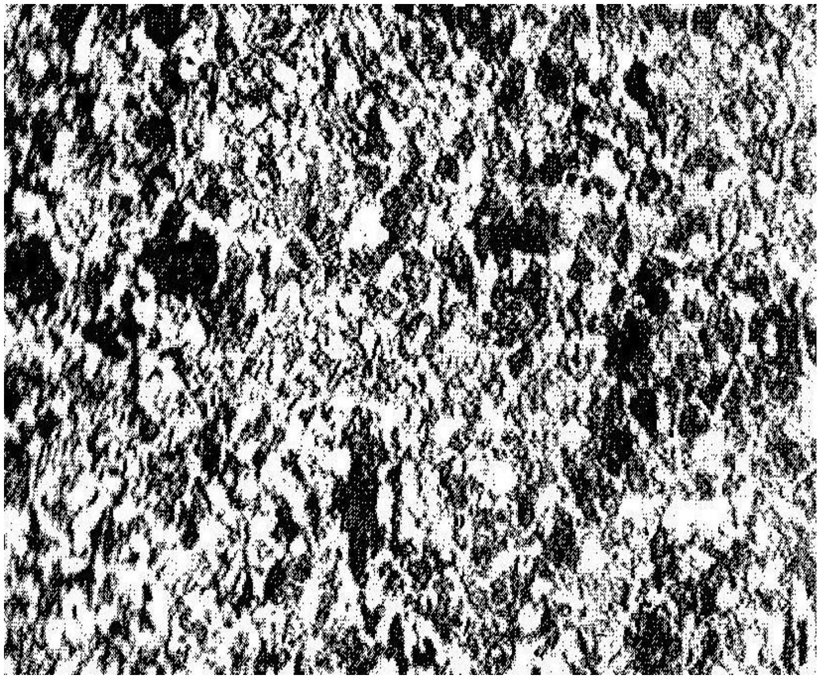
HEAT TREATMENT	MICROSTRUCTURE
As-Received	Pearlite in ferrite matrix
Normalized	A highly pearlitic matrix
Annealed	An essentially ferritic matrix
Water quenched	A martensitic with retained austenite
Khaya Oil	Higher level martensite present with some retained austenite and little bainite
Engine Oil	Martensite present, retain austenite and slight increase in bainite
Quenched in Khaya oil and tempered (350°)	Tempered martensite structure



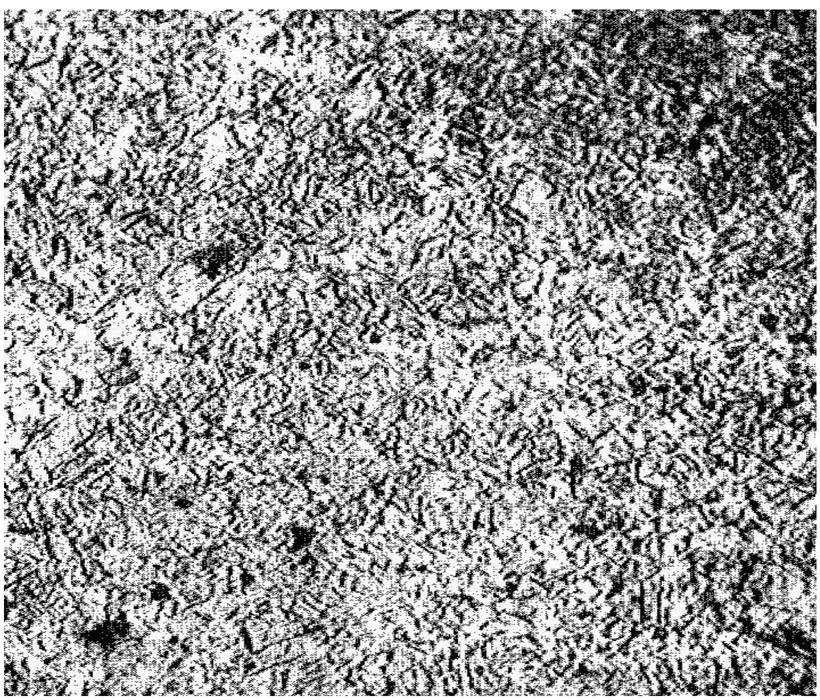
Micrograph 1: Microstructure of As-Received Plain Carbon Steel. The Structure Reveals Pearlite (dark) in Ferrite (white) Matrix x500.



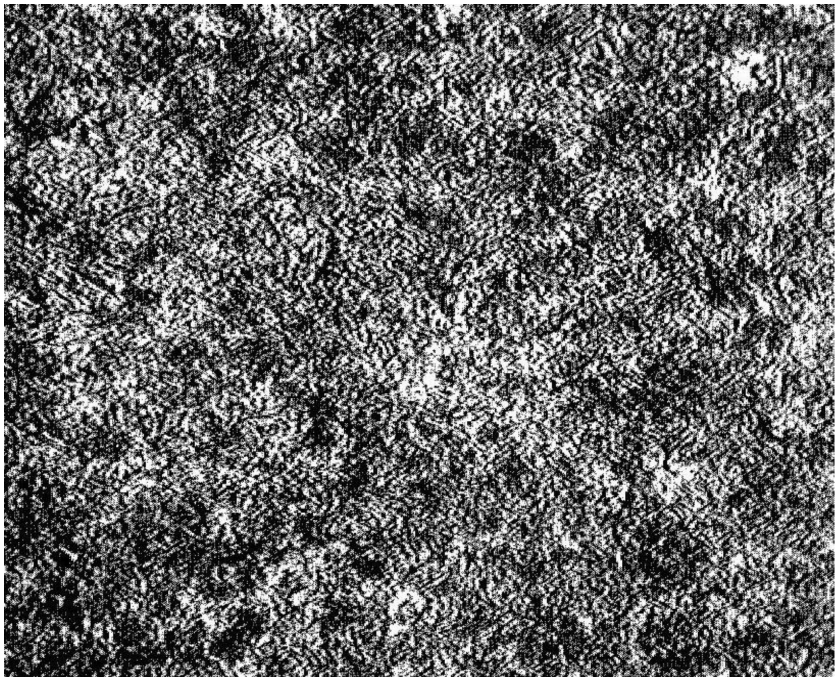
Micrograph 2: Microstructure of Normalized Plain Carbon Steel. The Structure Consists of Ferrite (white) in Pearlite (dark) Matrix x500.



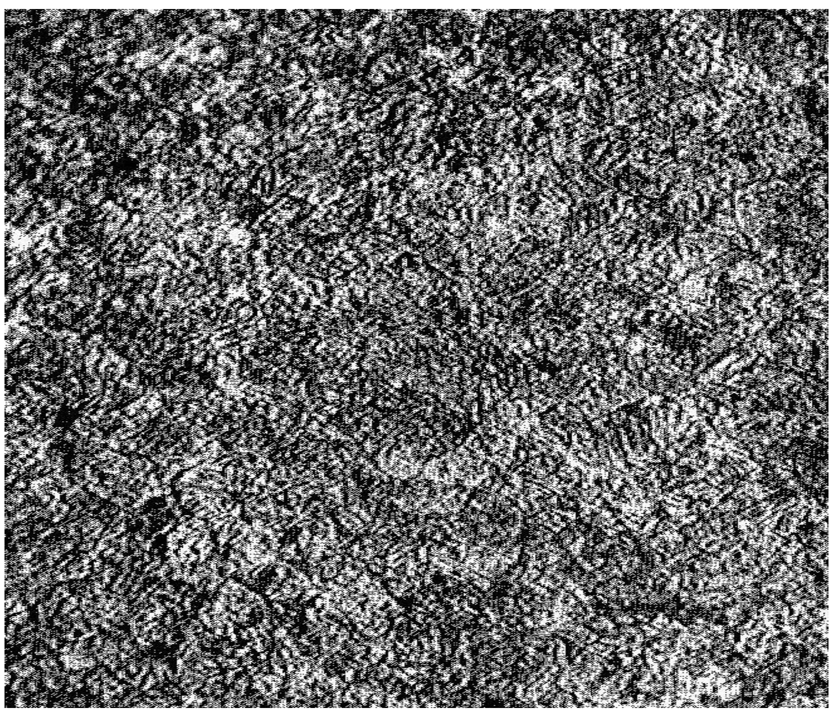
Micrograph 3: Microstructure of Annealed Plain Carbon Steel. The Structure Reveals a Ferrite (white) Matrix x500.



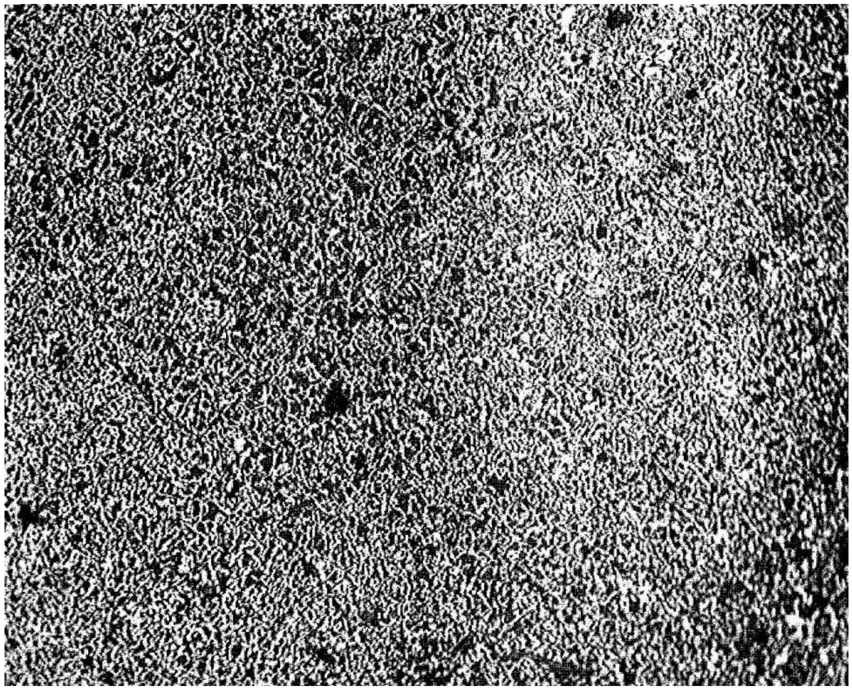
Micrograph 4: Microstructure of Plain Carbon Steel Quenched in Water. The Structure Reveals a Martensitic and Retained Austenite x500.



Micrograph 5: Microstructure of Plain Carbon Steel Quenched in SAE 40 Engine Oil. The Structure Reveals Martensite, Retained Austenite, and Slight Increase in Bainite x500.



Micrograph 6: Microstructure of Plain Carbon Steel Quenched in Khaya Oil. The Structure Consist of little Bainite, with some Retained Austenite and a Higher Percentage of Martensite x500.



Micrograph 7: Microstructure of Plain Carbon Steel Hardened in Khaya Oil and Tempered at 350°. The Structure Reveals Tempered Martensite x500.

The microstructures of the as-received plain carbon steel specimen consist of pearlite in ferrite matrix (see Micrograph 1). However that of normalized plain carbon steel specimen was essentially a pearlitic structure (see Micrograph 2). The microstructure of annealed plain carbon steel specimen showed a ferritic structure(see Micrograph 3) all these three microstructures are in par with what is obtainable in literature(Hassan et al, 2009).

The as-quenched plain carbon steel specimen developed essentially martensitic structure(see Micrographs 4-6). However, water quenched specimen has the highest presence of martensite phase with retain austenite. Also evidence of less retain austenite and martensite was seen more in the plain carbon steel specimen quenched in Khaya oil than those quenched in SAE 40 engine oil.

The plain carbon steel specimen hardened in Khaya oil and tempered at 350°C showed an increased precipitation of ferrite and epsilon carbide due to the transformation of retained austenite. The researches obtained in the present study are in par with the earlier observation of (Hassan et al, 2009).

The result of the hardness values is shown in Figure 3. The hardness values of the as-cast condition, Khaya seed oil, water and SAE 40 engine oil quenched are 14.3, 48.8, 56.3, and 46.4HRC respectively (see Figures 3). Water quenched produced the highest hardness value and SAE 40 engine oil produced the least after quenching. The high hardness values obtained in these results can be attributed to the various microstructures obtained (see Micrographs 1-7). Khaya oil developed hardness between that of water and SAE 40 engine oil. The result of the tensile strength is shown in Figures 4.

The tensile strength of the as-cast condition, Khaya seed oil, water and SAE 40 engine oil quenched are 732, 927, 906 and 953N/mm^2 respectively (see Figures 4). Water quenched produced the least tensile strength and SAE 40 engine oil produced the highest after quenching. The tensile strength of water quenched plain carbon steel specimen was the lowest values could be attributed to internal stresses and transformation stresses developed after quenching as a resulted of rapid quenching. These results are on par with earlier observation of (Hassan et al., 2009).

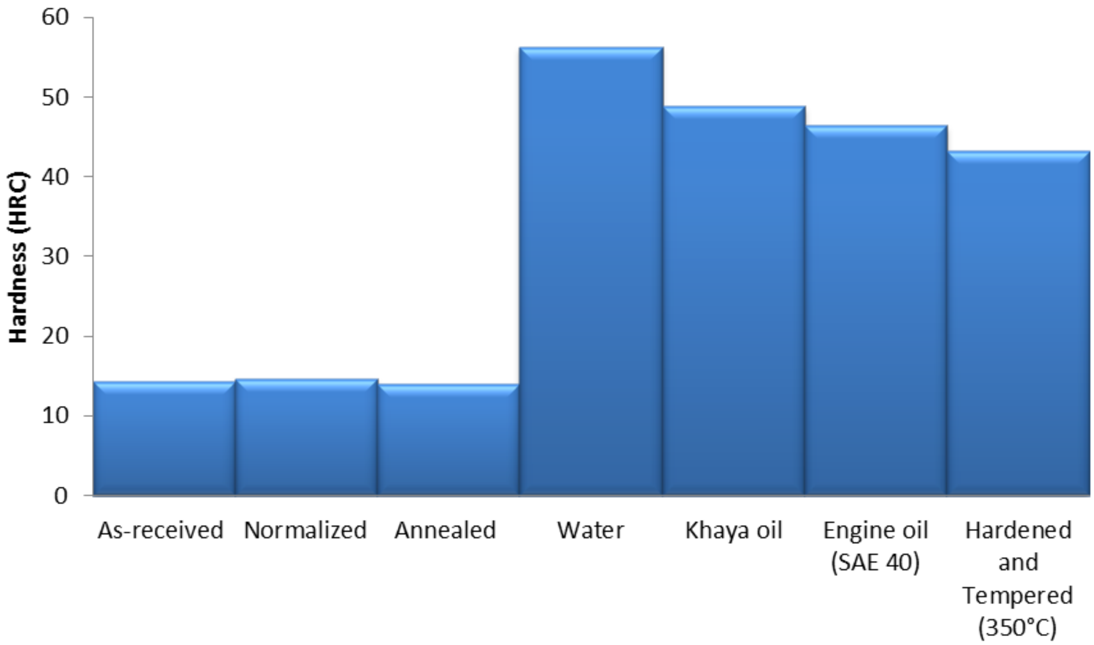


Figure 3: Bar Chart of Hardness Values of Plain Carbon Steel in As-Received, Normalized, Annealed, and Quenched Conditions.

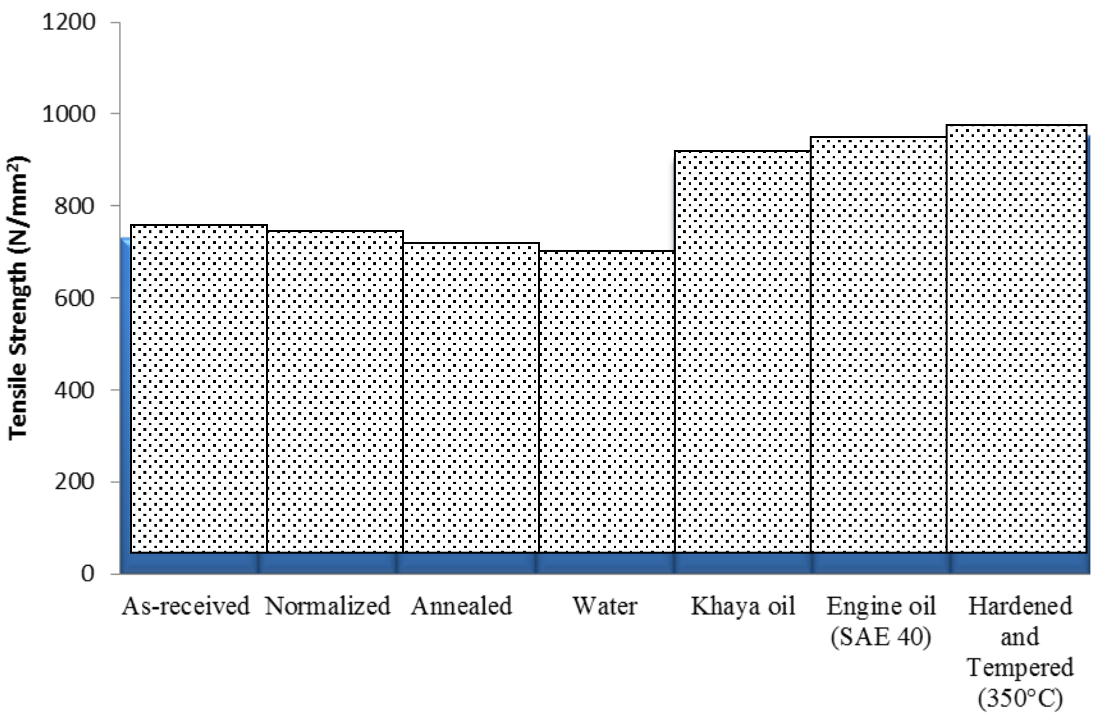


Figure 4: Tensile Strength Values of Plain Carbon Steel in As-Received, Normalized, Annealed, and Quenched Conditions.

The results of the impact energy and percentage elongation are shown in Figures 5-6. The impact energy of the as-cast condition, Khaya seed oil, water and SAE 40 engine oil quenched are 46.0, 9.8, 2.0 and 11J respectively (see Figures 5). The percentage elongation of the as-cast condition, Khaya seed oil, water and SAE 40 engine oil quenched are 26.0, 8.0, 1.3, and 10.0%, respectively.

From Figures 5-6, it shown that SAE40 oil quenched produced the highest impact energy and percentage elongation, while water quenched samples produced that least impact energy and percentage elongation. This results are in line with the microstructure observed for water, SAE40 and Khaya oil (see Micrographs 4-6). Khaya seed oil quenched produced toughness in between that of SAE 40 oil and water.

From Figures 3-6, it was observed that normalized plain carbon steel specimens had mechanical properties which were close to that of the as-received specimens. However, the annealed plain carbon steels specimens showed improved impact energy with lower tensile strength and hardness value. These observations are in line with what are obtained in literature (Kashim, 2010).

From the research it quite clear that the severity of quench of Khaya seed oil and SAE 40 are very close, since that results obtained for this two oils in this present work are close (see Figures 3-6). But Khaya seed oil has a little higher severity of quench than oil, that is why Khaya seed oil developed a higher hardness values than SAE 40 oil (see Figure 3).

Khaya seed oil quenched specimen when tempered at 350°C, the tensile strength is improved with a slight decreased hardness and improved impact energy. For practical purposes, the choice of quenching medium would be dictated by the mechanical properties of the steel required. The steel hardened using Khaya seed oil and tempered at 350^0C produces superior mechanical property as the hardness is optimized with an appreciable toughness and strength.

It is noteworthy to know that higher hardness was obtained for the Khaya seed oil than the SAE engine oil (see Figure 3). The hardness values of the water quenched and the observed microstructure conform to the expectation.

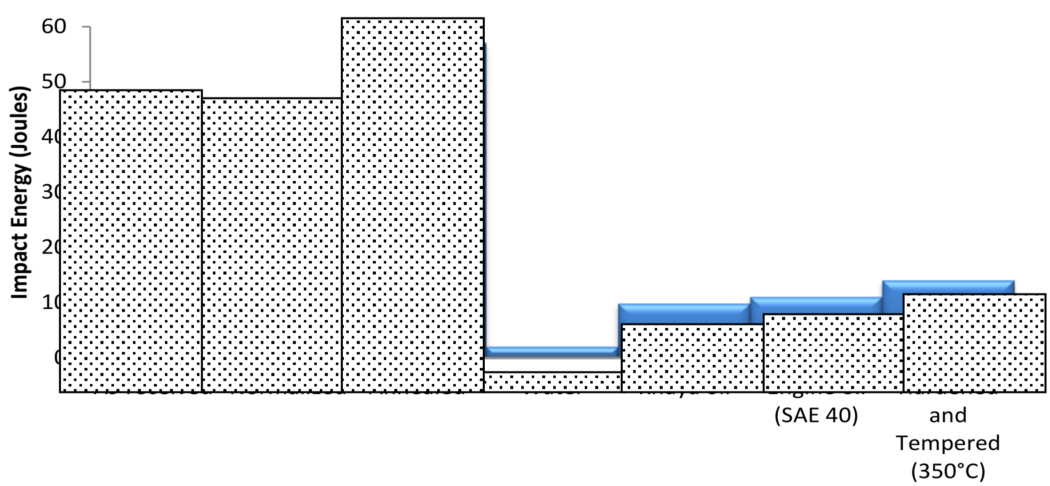


Figure 5: Bar Chart of Impact Energy Values of Plain Carbon Steel in As-Received, Normalized, Annealed, and Quenched Conditions.

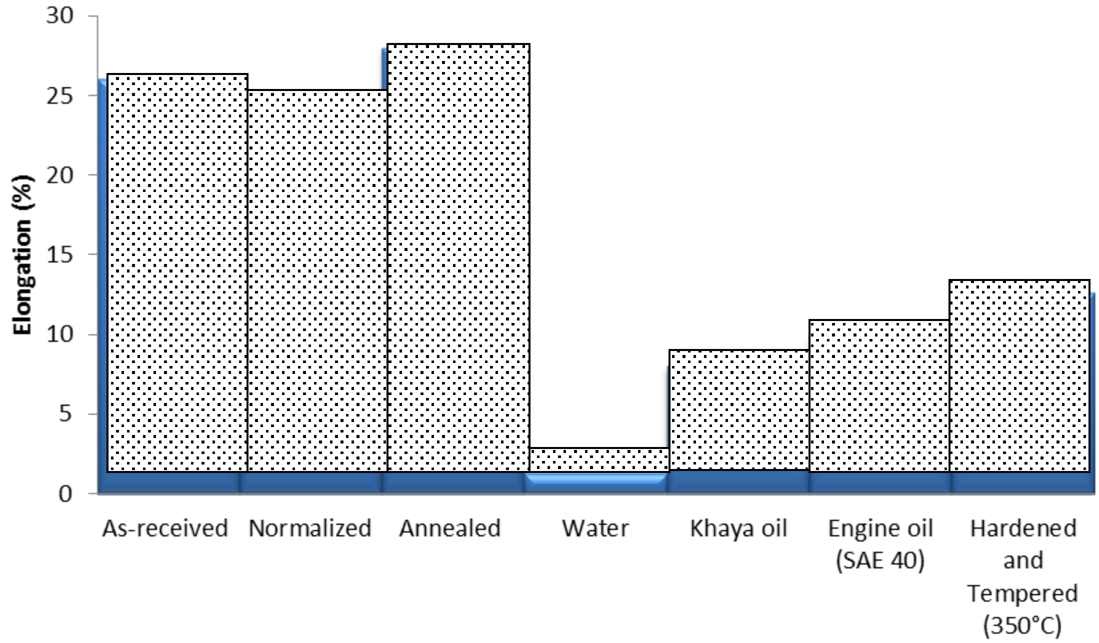


Figure 6: Percentage Elongation Values of Plain Carbon Steel in As-Received, Normalized, Annealed, and Quenched Conditions.

The degree of the free fatty acid and iodine values of the Khaya seed oil (see Table 2) shows the amount of reactive radicals present and the stability of the fatty acid molecule film that form on the metal surface (Kashim, 2010) may be responsible for the result obtained for Khaya seed oil in this research.

CONCLUSIONS

The suitability of the Khaya seed oil as quenching medium in the hardening process of plain carbon steel has been quantitatively assessed using microstructure, hardness values, tensile strength and impact energy in particular. From the results obtained in this study, the following conclusions can be drawn;

1. Khaya seed oil have a hardness value less than that of water but higher hardness value than that of SAE40 engine oil. That mean Khaya seed oil can be used where cooling severity less than water but greater than SAE 40 engine oil is required for hardening of plain carbon steel.

2. Khaya 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.

3. Khaya seed oil can be used for hardening process in plain carbon steel to produces properties in between that of water and SAE 40 engine oil. However when hardened and tempered the mechanical property of the steel is optimized.

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