JOURNAL OF ADVANCEMENT IN ENGINEERING AND TECHNOLOGY
Journal homepage: www.scienceq.org/JAET.php
ISSN: 2348-2931 V6I4.08
Research Article Open Access

Assessment of Coconut and Ghee Oils as Quenchants in Hardening of Plain Carbon Steel Process

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Received: July 12, 2018, Accepted: August 23, 2018, Published: August 23, 2018.

ABSTRACT

Certain engineering parts require high hardness values, high tensile strength and impact values so that they can be used successfully for substantial duty processes. Hardening as a form of heat treatment has been used to achieve these requirements in both metal and alloys parts using different quenching media such as water, SAE 40 engine oil and other vegetable oils. The effectiveness of using coconut and ghee oils as quenchants for hardening and tempering processes of plain carbon steel with composition of 0.35% C were investigated. The plain carbon steel samples were austenitized by heating to 850 °C, soaked and quenched in the various selected quenching media. Some of the samples were tempered at 350 °C. The mechanical properties and microstructures of the samples were studied. The mechanical properties and microstructure were compared as-received, annealed quenched in water, coconut and ghee oils respectively. The results showed that tensile strength increased from 754 N/mm^2 in the as-received conditions to 918, 976, and 998 N/mm^2 for water, coconut oil and ghee oil respectively. The hardness values of the plain carbon steel also increased from 30HRC in the as-received conditions to 73HRC in water, 59HRC in coconut oil and 55HRC in ghee oil. The as-received conditions plain carbon steel samples gave the highest impact energy value and water quenched sample gave the least impact energy. The impact energies of the plain carbon steel samples of as-received conditions, water, coconut oil and ghee oil were 49, 4.3, 12 and 14 Joules respectively. The microstructures of the plain carbon steel samples quenched in both coconut oil and ghee oil revealed the formation of martensite, little bainite and retained austenite. The high hardness values obtained in these results can be attributed to the various microstructures obtained in the as-received, quenched and hardened in water, coconut and ghee oils respectively. From the investigation carried out, the coconut and ghee oils are suitable as an alternative quenchants to that of water and petroleum based SAE 40 engine oil for carbon steels without cracking or distortion, the most suitable among them being coconut oil. Hence, the oils can be used where cooling severity less than that of water is required for engineering components. The oils are cost effective and environmental friendly..

Keywords: *Coconut oil, Ghee oil, plain carbon steel, martensite, mechanical properties, microstructures*

INTRODUCTION

Steels still remains the most widely used materials considering its relevant properties, availability, ease of fabrication and relative cost. However, there are so many materials used for design and construction purposes. Idenyi et al. (2005) included metals and their alloys, ceramics, plastics, composites and biomaterials. However, most engineering components require high hardness, tensile values in order to be used for heavy duty processes as observed by [1]. Hardening is a form of heat treatment that has been used to achieve these requirements in metal or alloy components it essentially involves heating the metals/ alloys to a sufficiently high temperature, holding at that temperature followed by rapid cooling in media such as water, oil or salt bath [2].

The use of animal, vegetable oils and fats as quenchants in the heat treatment industries had been investigated by numerous researchers who studied the correlation between the quench severity with fluid source and viscosity in addition to oxidative stability for various naturally derived fluids. Previous works had shown that vegetable oils, SAE 40 engine oil used extensively and the results were compared with of water and as-received respectively [3]..

Effect of various quenching media on the mechanical properties of intercritically annealed 0.15wt%c – 0.43wt%mn steel using water, SAE 40 engine oil and brine was carried out by [4]. It was concluded that water has the highest hardness values followed by brine engine oil respectively. In the same vein, the potentials of using fatty-based the overall mechanical behaviour of the composites, the vegetable oils as quenching media for austempering of steels, and cast irons was studied by [5]. Cotton seed, groundnut and shear butter oils were used as hot quenching bath for austempering of these materials. His findings showed that the microstructures obtained proved that hot shear butter and groundnut oils formed bainite and ausferrite structures respectively at different austempering time in carbon steel and ductile cast iron.

Evaluation of palm kernel oil, cotton seed oil and olive oil as quenching media for 0.509Wt%C medium carbon steel was also studied by [6]. The mechanical properties shows that the hardness of steel quenched in water was highest followed by cotton seed oil and palm kernel oil. 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. Investigation of Khaya seed oil (Mahogany oil) as a quenchant for hardening process of 0.34%C plain carbon steel. The khaya seed oil was compared with that of water and SAE 40 engine oil as quenching media. The results show that the hardness values of the carbon steel was in the following order i.e water> Khaya seed oil >SAE 40 engine oil respectively [7].

This will eventually causes an increase in hardness of the metal/alloy which was due to phase transformation accompanying rapid cooling which occur at a considerably low temperature leading to the formation of non- equilibrium products.

However, 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 and surface condition of the steel and efficiency of the quenching process as observed by [8].

Water is the most widely used quenching medium and the reasons can be attributed to its low cost, availability, ease of handling, relatively no pollution problem and easily disposal. The use of water in practice has been mainly for plain carbon steels and a few grades of low alloy steels [9]. The drawbacks of using water as quenchant include cracks or dimensional changes on the components 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 that of water and oils 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 [10].

The challenge facing the quenching process is said to be the choice of quenching medium that will yield the desired as-quenched mechanical properties such as hardness, but with minimum induced distortion. Searching for a quenching medium with good economic value, moderate severity and appreciable mechanical properties is thus the focus of this work. Hence this work is aimed at investigating the suitability of using coconut and ghee oils as quenching media for hardening process of plain carbon steel. There is no previous work where the mechanical properties and microstructure behaviour of coconut and ghee oils were compared with that of as-received and water.

Nigeria is blessed with abundance of coconut trees and ghee oil in southern and northern parts of the country where the trees are used for afforestation. Almost every part of the tree is useful especially in agriculture and medicine. The ghee oil is obtained from cows which are milked, boiled and set into yogurt.

MATERIALS AND METHODS

The materials used for this research include the followings: plain carbon steel obtained from Nigeria foundries limited, Lagos, coconut oil, Ghee oil and water. The chemical analyses of the plain carbon steel and the oils used are presented in (Tabs. 1 and 2) below. Other materials used for this work also include the followings: Silicon grit papers of various grit (140, 180, 220, 320, 400, and 600 grades), bakelite, 2.5% nital solution and cerium oxide. The equipment used include: copper calorimeter, weigh balance, muffle furnace (electric resistance furnace), polishing machine, K-type thermocouple, pyrometer, Optical Metallurgical microscope (OM), Universal hardness testing machine (Rockwell) and lathe machine [8].

Table 1 : Chemical Composition of the Steel

Elements	C	Si	Mn	Cr	P	S	Fe
(W%)	0.35	0.37	0.96	0.010	0.01	0.02	Balan

Table 2 : Composition of coconut and ghee oils

Analyses	Coco-nut oil	Ghee oil
Iodine value (g/100g)	86.66	76.55
Viscosity (at 30 ^{0}C	182.34	145.45
Flash point ^{0}C	296.3	232.5
Density (g/cm^3)	0.985	0.956
Saponifications value (mg KOH)	188	199
Free fatty acid (wt%)	6.67	5.98
Acid value (mg KOH)	6.4	6.7

Methods

The machining of the plain carbon steel samples was carried out using the lathe machine to the standard test samples for tensile strength was shown in figure 1 [11]. The prepared samples were loaded in the heat treatment furnace and heated to a temperature of 850 ^{o}C for 40 minutes to attain uniform homogenization. After soaking, about three sets of samples each comprising of tensile strength, impact, hardness and metallography were quenched in the water, coconut oil and ghee oil respectively. Agitating by stirring the system was ensured during this operation to avoid the formation of vapour skin around the specimens in thequenchants. After cooling, three samples each were totaling nine (9) removed and cleaned. The cooled samples were then annealed and tempered at 350 ^{o}C [9].

Tensile test

For the tensile properties, tensile specimens were loaded into a 2000-kg Mosanto Tensometer hooked up to a data logger. Load-elongation data were recorded and converted into stress-strain graphs. Tensile stress was calculated using equation 1 by [12]:

$$\text{Ultimate tensile strength (UTS)} = \frac{\text{Ultimate tensile load}}{\text{Initial area } (Ao)} \quad (1)$$

The values of percentage elongation were calculated using the following expression as given by in equation 2.

$$\text{Percentage Elongation} = \frac{Lf - Lo}{Lo} \times 100 \quad (2)$$

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

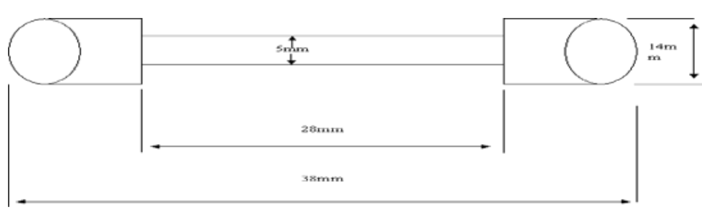

Fig. 1 Standard size of tensile test specimen

Hardness test

Hardness tests were carried out by using a Rockwell indenter, under a load of 150 Kg for HRA scale for 10 seconds. Each specimen was examined / tested for three hardness readings at different positions on the specimens, using a Rockwell indenter in accordance with [11]. The average of the three hardness value was determined and recorded.

Impact test

The impact test was carried out in accordance with [12]. The impact specimen was placed on a horizontal stand of the Izod impact machine. The test specimen was then gripped vertically in a vice, the suspended mass was released from a height to hit the specimen and the registering pointer of the quadrant scale indicated the energy absorbed in joule by the specimen. The energy absorbed by the specimen was reflected on a graduated scale.

Microstructural Examination

The specimens for microstructural observation were mounted with Bakelite and grinded with grit papers of grades 120-600. 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 done using silicon carbide paste and final polishing operation was carried out using alumina polishing paste. The grinding process was on one direction movement of hand (to avoid crossing flakes on the specimen). Etching of the specimen was carried out using a cotton wool soaked in nital to wipe the specimen's polished surface to give a dull reflection surface. The etched specimen was then viewed under a computerized microscope [13,14].

RESULTS AND DISCUSSION

Mechanical properties

Tables 1, 2 show the chemical composition of plain carbon steel, composition of coconut and ghee oils respectively. Fig. 1 shows the size of standard specimen for tensile test. The mechanical properties such as tensile strength, hardness, impact and percentage elongation for plain carbon steel samples of as-received, quenched in water, coconut oil and ghee oil were shown in figures 2-5. The microstructures of the as-received, as-quenched and tempered are presented in figures 6-12.

Fig. 2 illustrates values the tensile strength of the as-received conditions, water, coconut oil and ghee oil quenched are 754, 780, 765, 976 and 998 N/mm^2. Although samples quenched in water showed the least tensile strength and coconut oil produced the highest after quenching. The result of water quenched plain carbon steel specimen could be ascribed to internal and transformation stresses developed after rapid quenching. These results also agreed with the earlier works of [17].

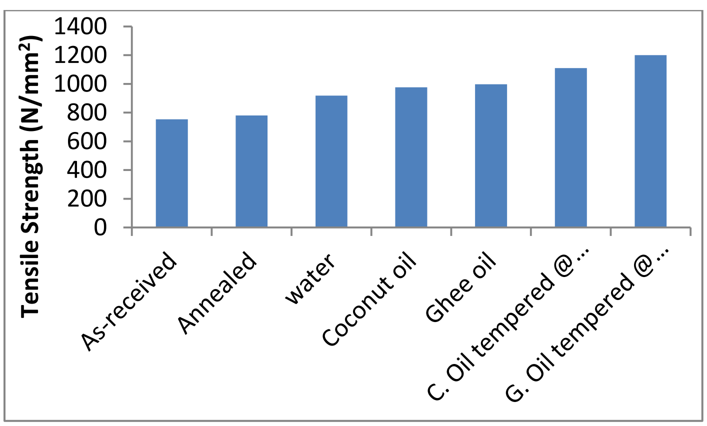

Fig. 2: Tensile Strength Values of Plain Carbon Steel in As-Received, Annealed and Quenched Conditions

Fig. 3 shown below illustrated the results of hardness values carried out on plain carbon steel. The hardness values of the as-received conditions, water, coconut oil and ghee oil are 30, 73, 59 and 55 HRC respectively. From the bar chart, samples quenched in water produced the highest hardness value and ghee oil produced the least after quenching and tempered at 350 °C. The high values obtained for samples quenched in water can be ascribed to the hard structures (martensite, retained austenite, bainite) obtained during quenching. Coconut oil developed hardness between that of water and ghee oil. Similar findings had been reported during investigations of quenching media for steel products [15]

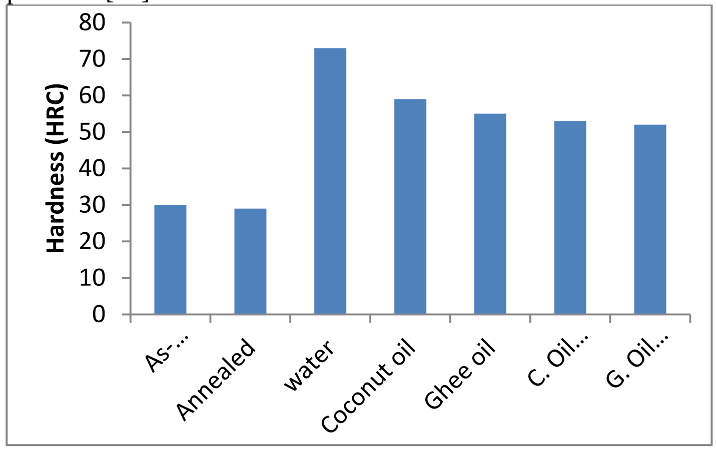

Fig. 3: Hardness Values of Plain Carbon Steel in As-Received, Annealed and Quenched Conditions

The impact energy results obtained from the quenched and tempered at 350 °C was illustrate in fig. 4. The impact energies of the as-received conditions, water, coconut oil, ghee oil are 35, 4.3, 12 and 13 J respectively. Water has the least impact energy before fracture. The least impact strength observed for the quenched samples in water could be attributed to the hard structure (martensite) obtained [16]. The impact strength in both coconut oil and ghee oil were improved significantly after quenched and tempered. This direction showed that after tempering, there was an increased in precipitation of cementite which was in fine structure of ferrite and bainite as a result of the decomposition of martensite and retained austenite. These findings were also in line with [21].

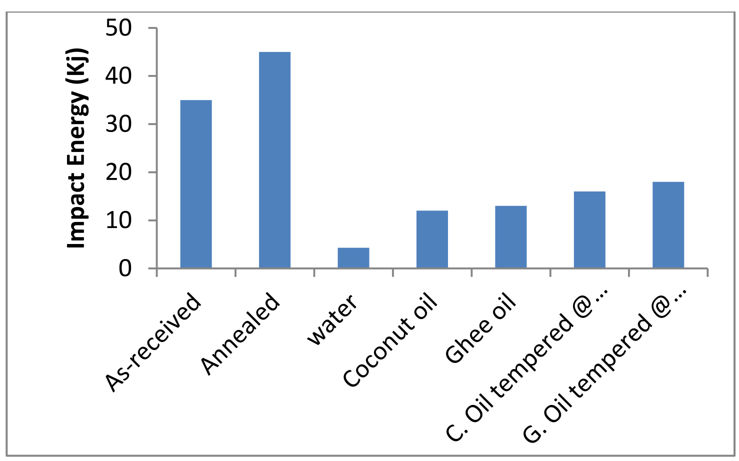

Fig. 4: Impact Energy Values of Plain Carbon Steel in As -Received, Annealed and Quenched Conditions.

Fig. 5 shows percentage elongation of the as-received, annealed, water, coconut oil and ghee oil to be 28.0, 31.5, 3.8, 16and 18.0%, respectively. The oils percentage elongation tempered increased from 16 and 18 to 26 and 28.7% respectively. These results show that oils are effective and in line with the findings of [9]. The water quenched samples produced least value and are also in line with the explanation given on microstructure observed for water, coconut oil and ghee oil on impact energy discussed above. It also agreed with the previous works [17].

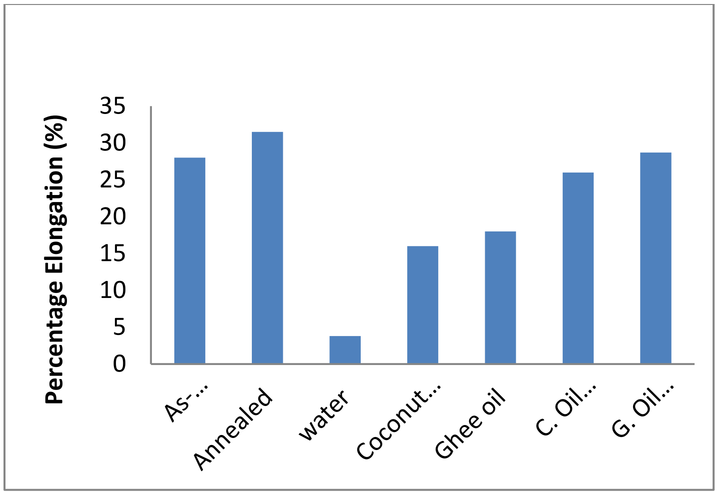

Fig. 5: Percentage Elongation Values of Plain Carbon Steel in As-Received, Annealed, and Quenched Conditions

Figs. 3-5 above showed that annealed 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 values. Similar observations were found in the work of [18].

Coconut oil and ghee oil quenched specimen and tempered at 350 °C had their tensile strength improved with a slight decreased hardness and improved impact energy However, the choice of quenching medium for particular steel would be determined by the mechanical properties required by the materials. From the plain carbon steel hardened and tempered at 350 °C in both coconut oil and ghee oil produce quality mechanical properties. Their hardness, toughness and strength were optimized in both oils.

The higher values obtained in hardness for the steel quenched in coconut oil than that of ghee oil can be attributed their compositions presented in Table 2. It can be seen from the Table that the amount of reactive radicals present and the stability of the fatty acid molecule film that form on the metal surface may be responsible for the result obtained for coconut oil in this work [9]

Microstructure

The microstructures of the as-received, annealed, quenched in water, coconut oil, ghee oil and quenched-tempered samples were shown below. The as-received plain carbon steel showed the structure of pearlite in ferrite and presented in fig. 6. The microstructure of annealed plain carbon steel specimen showed a ferritic structure matrix and also presented in figure 7. The as-quenched plain carbon steel specimen in water, coconut oil and ghee oil developed essentially martensitic structure as shown in figure 8. However, water quenched specimen has the highest presence of martensite phase with retain austenite because of the high hardness value obtained from the sample. It is also evident that less retain austenite and martensite was seen more in the plain carbon steel specimen quenched in coconut oil in figure 9 than those quenched in ghee oil in figure 10 respectively. Coconut oil and ghee oil quenched samples showed martensite proportion lower than that of water quenched sample. Figs. 11 and 12 showed the microstructures of quenched, harden and tempered at 350 °C. The microstructures are associated with retained austenite and this is also in line with the findings of [19,20].

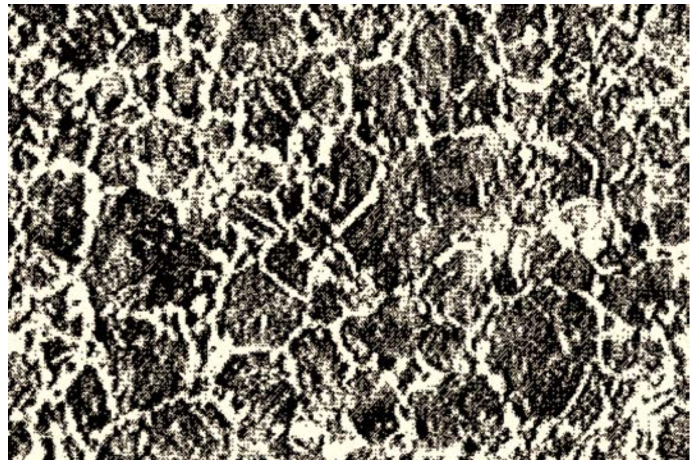

Fig. 6: Microstructure of as-received plain carbon steel with dark pearlite in white ferrite, x500

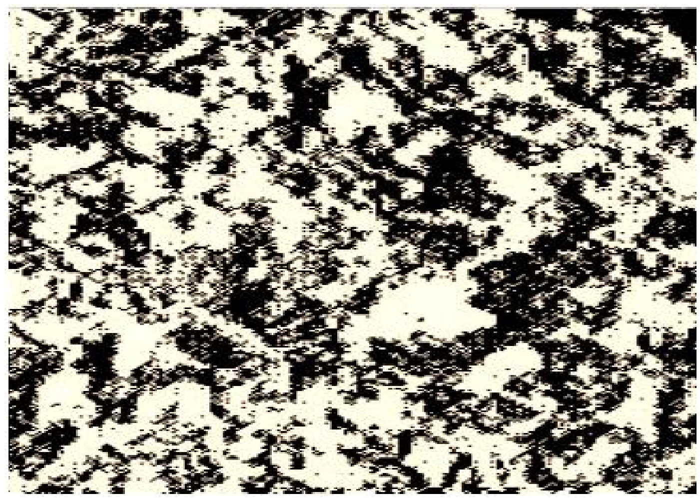

Fig. 7: Microstructure of annealed plain carbon steel showing mainly white ferrite, Matrix x500

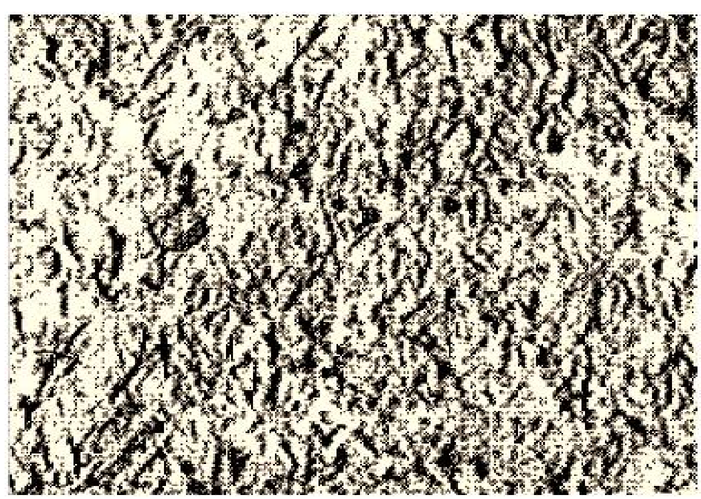

Fig. 8: Microstructure of plain carbon steel quenched in water revealing martensite and retained austenite x500

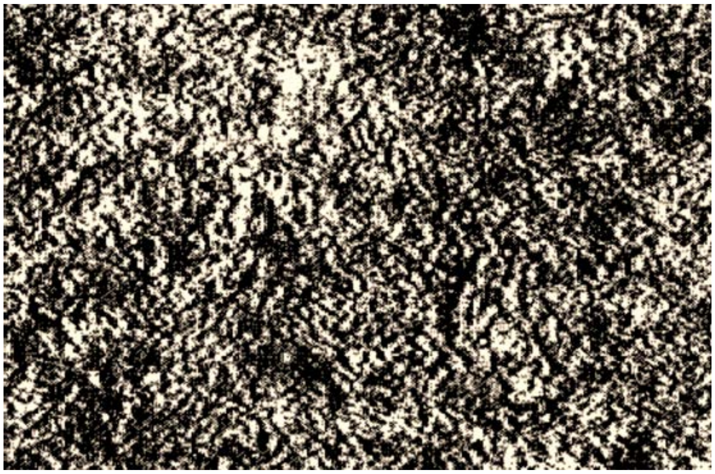

Fig. 9: Microstructure of plain carbon steel quenched in coconut oil showing martensite, retained austenite and bainite x500

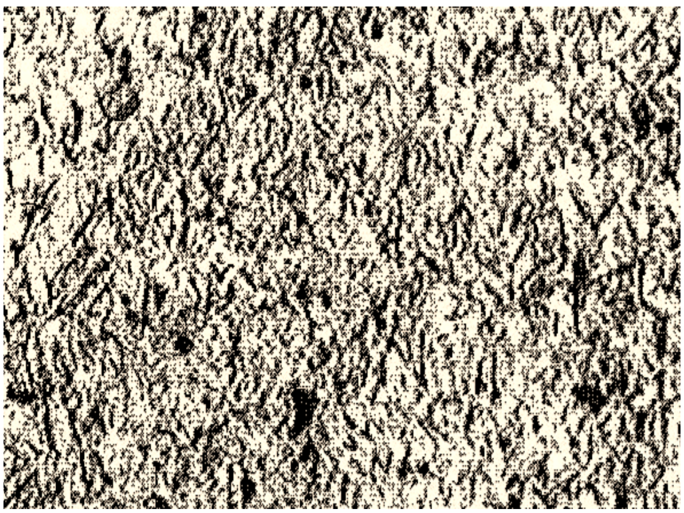

Fig. 10: Microstructure of plain carbon steel quenched in ghee oil showing martensite, retained austenite and bainite x500

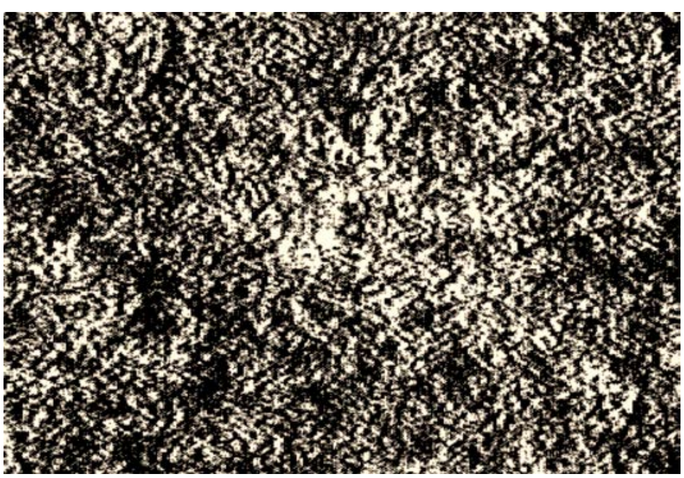

Fig. 11: Microstructure of plain carbon steel quenched in coconut oil and tempered at 350 °C showing tempered martensite x500

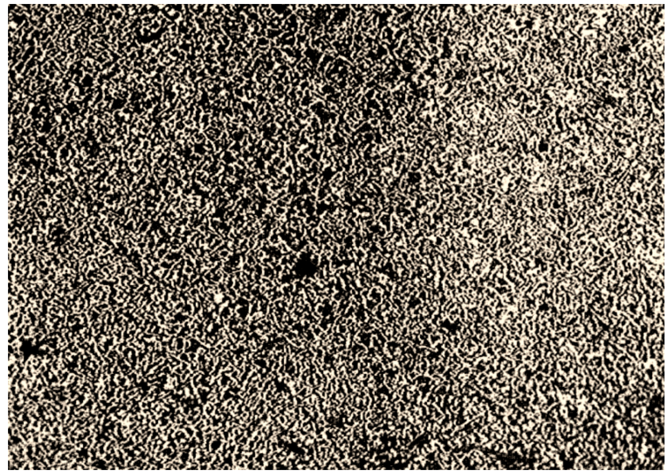

Fig. 12: Microstructure of plain carbon steel hardened in ghee oil and tempered at 350° C showing Tempered Martensite x500.

CONCLUSIONS

The use of coconut oil and ghee oil as quenching media in the hardening process of plain carbon steel had been assessed using tensile strength, hardness values, impact energy, percentage elongation and microstructures. Conclusions drawn from the results obtained in this work are:

- Coconut oil and ghee oil have hardness values less than that of water but higher hardness value than that of annealed and as-received.
- Both the coconut and ghee oil improved the toughness of plain carbon steel since they have higher impact energy values than that of water which is the common quenching medium.
- Both the coconut oil and ghee oil can be used for hardening process in plain carbon steel which produced properties in between that of water and as-received conditions. When hardened and tempered at 350 °C, the mechanical properties of the plain carbon steels were optimized.
- The microstructures of the plain carbon steel in the different media revealed the following structures: ferrite – pearlite, retained austenite, martensites, bainite in matrix.
- Environmental pollution has caused the search for new products in hardening of plain carbon steels. The use of coconut and ghee oils as quenching media are new and when compared with water and SAE 40 engine oi, there are many advantages concerning the environment and the health of workers.

Acknowledgement

The Authors are highly grateful to the Department of Metallurgical Engineering, Waziri Umaru Federal Polytechnic, Birnin Kebbi and also to the staff of Ahmadu Bello University, Zaria. Nigeria.

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Citation: I. Y. Suleiman *et al*. (2018). Assessment of Coconut and Ghee Oils as Quenchants in Hardening of Plain Carbon Steel Process, J. of Advancement in Engineering and Technology, V6I4.08. DOI: 10.5281/zenodo.1402683.