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Physiochemical Properties of Vegetable Oils on Quench Distortion of C-Ring: A Comparative Study

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ABSTRACT: *Quenching is necessary to increase or improve the mechanical properties of steel; however, it's often associated with thermal stresses that may lead to distortion or a tendency of steel cracking. It is therefore desirable to select quenching media that maximize the desired properties while at the same time minimize the degree of distortions. Distortions in quenched steel are majorly influenced by the physiochemical properties of quenching media used, quench severity and microstructure. This study compares the effect of these oil properties (between edible and non-edible oils) on the distortion of C-ring, measures the degree of distortion that arises when quenched with these quenchants. The comparative results show that distortion is more prone with the use of non-edible oil quenchants than with edible oil quenchants but they exhibits better mechanical strength. Edible vegetable oils show the most desirable quenchants for quenching carbon-steel with minimum or least distortion values.*

KEYWORDS: *Quench distortion, quenchants, quench severity, C-ring, hardness*

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I. INTRODUCTION

Quenching of engineering components plays significant roles in most thermal processes industries in modifying or altering both metallurgical and mechanical properties to desired properties by cooling in a medium (usually brine, water, oil or mineral) [1]. These modifications in heat treatment allows experts to be able to direct these desired/obtained properties of heat treatment steels to a wide range of engineering applications. The rate of cooling may be fast enough or moderate. More so, factors such as steel and oil composition, heating temperature, rate of cooling, degree of oil agitation or steel geometry influence the level of distortion after heat treatment [2]. Distortion otherwise known as changes or deviation in dimension is usually an irreversible and unpredictable in the components during heat treatment process and temperature variations [3]. The term distortion is used to denote changes in both size (net change in volume between the parent and transformation product produced by phase transformation without a change in geometrical form) and shape or warpage (change in geometrical form and is revealed by changes in curvature or curving, bending, twisting, and/or non-symmetrical dimensional change without any volume change); it is often described by engineers as an uncontrolled movement that occurred in a part as a result of heat treatment operation [3,4]. According to Janez et al, (2001) distortion in steel resulted in deviation that occurs between internal and the yield stress of material in a given moment that is at a given temperature during quenching of steel part. It is generally known to be a major challenge confronting the heat-treatment industries; it is only in the simplest thermal heat-treatment methods that the mechanism of distortion is understood [3,6]. More importantly, the ability to make proper and adequate quenchants selection that may provide desirable mechanical and metallurgical properties that is accompanied by a tolerable degree of quench distortion has also become a major challenge associated in quenching because success or failure of a quenching process is determined by selecting appropriate quenchants [7]. However, there are numerous quenching medium capable of providing an acceptable range of cooling rates; a suitable quenching medium must have enough quench severity to prevent diffusional phase transformations, thermal oxidative stability, acceptable flash temperature, oxidation stability, low sludge forming tendency, thermal oxidative stability and appropriate heat transfer characteristics [7]. By proper quenchants selection, the risk of distortion and dependence on foreign heat treatment material would be reduced. In the quest for better heat treatment quenchants, several studies has been conducted in the past on emphasis such as cooling mechanism, wetting behaviour of quenchants, heat transfer of vegetable oils. However, little or no information on distortion that arises after quenching steels in vegetable oil quenchants. This study is aimed to address this gap in the knowledge of quenching by measuring and comparing the effect of physiochemical properties that exist between some common edible oils such as melon, palm, groundnut, walnut and Africa elemi oils, non-edible such as castrol oil, neem, jatropha, and sheabutter oils in quench distortion with AISI 1035 steel using conventional quenchants (water and SAE 40 oilS) as control. The use of C-ring specimen in measuring the degree of distortion become imperatively significant as it enables a simple strain measurement at upper notches of the ring and in monitoring of strains and possible cracks close to the C-ring notches [5]. For adequate distortion measurement, the ring is composed of three notches/points 'a, b, c'. Point ''a'' permitted measurement of the changes in size and shape (distortion of the shape of the left and right leg) of the ring. Points ''b'' and ''c'' of the C-ring permit measurement of dimensional variation as well as assessment of the crack susceptibility of steel after heat treatment.

II. METHODOLOGY

2.1 Physiochemical Properties of Quenching Media.

The physicochemical properties of the oil quenchants put into considered these properties that directly or indirectly affect their use as quenching medium, such important properties include: Kinematic viscosity, flash points, iodine number, acid value and heat transfer coefficient. Viscosity at 40 ^{o}C and 100 ^{o}C of the vegetable oils was measured according to ASTM D445-06 standard while Viscosity index (VI) from Kinematic Viscosity at 40 ^{o}C and 100 ^{o}C was calculated based on ASTM D2270-10 and ISO 2909 Standard Practice. Flash point is the reduced point in that a substance can momentarily take fire. The test was conducted according to I.S.O 2592. Iodine number is the measure of the degree of unsaturation of oil. It was measured in accordance to ASTM D5554-95 while Acid value was measured according to I.S.O 66. Percentage yield for the oils were measured mathematically as expressed in the equation below;

$$\text{Percentage oil yield} = \frac{\text{mass of oil extracted}}{\text{Mass of oil sample}} \times 100$$

2.2 Preparation of Specimen.

This study discuss the distortion arising after quenching using modified C-rings test specimen as described by Civera et al, (2014) (see figure 1). A 50.8$\pm$0.5 mm diameter was punched out from a 150×150 mm sheet plate of 1.5mm thickness; concentric hole was bored to specification. As a result of the immense practical importance for the assessment of steel capabilities, also a standardised test for the evaluation of the changes of shape and in size under various chosen conditions of heat treatment, C-rings was interrupted 5.1 × 5.1mm. Eleven (11) specimens of the C-rings was produce for the study. Chemical composition of the steel is presented in Table 1.

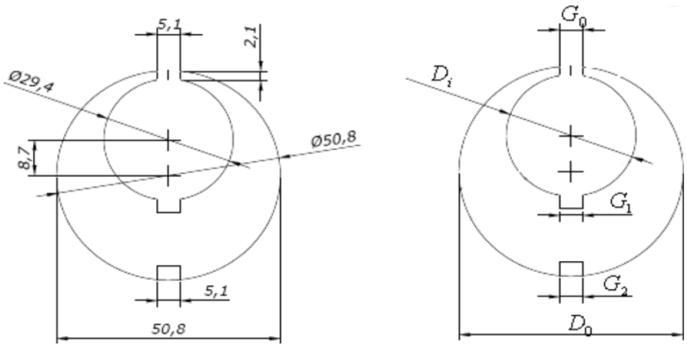

Fig. 1. Dimensions (mm) of C-ring [8]

2.3 Oil Extraction.

Africa elemi fruit otherwise known as 'Atili and Ube' in Hausa and Igbo languages were sourced from Panshin Local Government of Plateau State, Jos. They were thoroughly washed and natural made to dry and afterwards transferred into a bowl. Warm water of about 60 $\pm$ 10 ^{o}C was poured into the bowl, covered with a lid and allowed to stay for 10-20 minutes. Thereafter, the fruits were removed from heated water and dehusked, thereby separating the hard seeds from the mesocarp (soft fleshy part). The seeds under investigation (melon, walnut, groundnut, and Africa elemi and palm seeds) oil were sourced from a market in Niger State, Nigeria while jatropha, sheabutter and neem seeds were harvested. castrol oil was purchased from a supermarket. The seeds under study were locally produced by sun drying the seeds under the scourged heat of the sun for five (5) days; they were roasted under an intense heat for 25 minutes and grinded to powder. Half a litre of hot water was transferred into each bowls containing the grinded products and stirred until oils float on top of the grinded product. The oils were locally sort out with the use of a bowl. The oil containing n-hexane was transferred to a soxhlet extraction apparatus for several hours until reasonable amount of pure vegetable oils for the study was collected in a round bottom flask and transferred to a bottle for further experimentation.

2.4 Heat Treatment.

C-ring test specimens were heated to an austenitized temperature of 860^{o}C $\pm$3^{o}C, hold for 15 min at same temperature and was transferred instantly (within 2 s) from the furnace to a each beaker containing 1000 ml of quenchants with a K-type thermocouple inserted on each specimens. Probe temperature, time of cooling were recorded using an SD card digital data logger (MTM-380SD) to establish a cooling curves with respect to time of cooling.

2.5 Assessment of Distortion.

C-ring specimens were measured before and after heat treatment using a digital vernier calliper and a micro-metre screw gauge. Individual points on the C-ring were marked with lower case letters 'a, b, c'. Each point exhibits same dimensional values (5.1×5.1 mm), tagged G_o and G_1 as distortion arising after quenching. Average percentage distortion was calculated for each specimen respectively.

2.6 Hardness Test.

The C-ring specimen is composed of two sections (left and right sides) and both sections were selected as most appropriate in evaluating the hardness of the specimen before and after quench hardening. Hardness impressions were measured at three (3) points on each sides of the ring (see Fig. 2) using indenter Rockwell hardness machine (Model: 6187.5B) under an applied load of 187.5kg for 8 sec of 'C' scale (HC). Hardness values measured at these points were automatically read from the digital counter. Six repeated tests were taken on each specimen and an average hardness value was calculated and recorded.

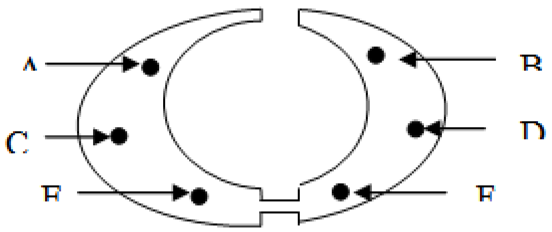

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Fig. 2. Hardness Measurement on C-ring

III. RESULTS AND DISCUSSION

3.1 Steel Composition.

Chemical composition of the C-ring steel specimen is presented in Table 1.

Table 1: Chemical composition (wt %) steel use

Element	C	Si	Mn	P	S	Cr	Fe
% Composition	0.357	0.16	0.75	0.032	0.0041	0.1	98.2

The C-ring composition meet the minimum carbon content required for material to be efficiently heat treated [9,10].

3.2 Physiochemical Properties of the Quenching Media.

Physiochemical properties of the quenchants used were recapped below;

Table 2: Physiochemical Properties of Quenching media

Quenching media	Viscosity @40 °C	Viscosity @100 °C	Viscosity index (VI)	Flash point (°C)	Acid value (mgKOH/g)	Iodine value (gI_2/100g)	Oxidatn stability (meq/kg)	Oil yield (%)	Heat transfer coefficient (w/m^2k)
Water	-	-	-	-	-	-	-	-	4777
Melon oil	30.300	6.230	161.302	149	4.48	19.40	24.53	49	3588
Groundnut oil	33.650	6.960	174.098	249	5.60	18.40	34.83	58	2058
A.elemi oil	39.410	7.875	176.073	123	10.30	15.82	42.78	39	1987
Walnut oil	36.320	7.460	178.313	117	22.44	11.21	48.63	29	580
Palm oil	40.600	8.240	183.567	247	30.86	10.51	50.24	52	1587
S.A.E 40 oil	15.600	3.500	100.990	220	22.40	3.080	17.63	-	284

Table 3: Physiochemical Properties of non-edible oils

Quenching media	Viscosity at 40 °C	Viscosity at 100 °C	Viscosity index (VI)	Flash point (°C)	Acid value (mgKOH/g)	Iodine value (gI_2/100g)	Oxidation stability (meq/kg)	Oil yield (%)	Heat transfer coefficient (w/m^2k)
Jatropha oil	36.200	6.250	121.883	283	2.15	56.38	19.66	48	4365
Neem oil	22.400	5.030	160.060	271	22.41	70.92	20.73	41	3692
Sheabutter oil	23.600	5.060	148.204	274	14.81	50.63	19.94	46	4013
Castrol oil	35.200	7.210	174.620	185	25.28	74.18	25.11	-	1793

The quenching media (both edible and non-edible oils) shows significant increase in flash point values with Africa elemi showing a least value (117 °C). Flash point of the oils are highly recommended, is consistent with approved value for quenching medium and safer for operating temperature [11]. The flash points of quenchants also meet the ISO 2592 standard practice for quenching. Lower acid values were obtained with melon, groundnut, jatropha and sheabutter oils of 4.48, 5.60, 2.15 and 14.81 mgKOH/g respectively. Mineral base-oil (SAE 40 oil) competes favourably with the vegetable oils. Maximum iodine values were obtainable with non-edible oils which the high degree of unsaturation exhibited by non-edible oils when compared to edible oils. Decrease in iodine value of 0.03 – 0.90 gI_2/100g was observed with edible oils. This decrease indicates a decrease in level of unsaturation as a result of oil suffered from oxidation [12]. Amidst the edible vegetable oil quenchants, melon oil suffers higher level in unsaturated acid. The determined iodine values are in agreement with standard values obtained by Kirk et al., 1991 and Bello et al., 2011. Palm and walnut oils exhibits higher oxidation stability compared to other quenchants in use but show lower heat transfer coefficient. Non-edible oils exhibits higher heat coefficient than the edible oils. It can be observed that heat coefficient is highly dependent on viscosity and acid value of the quenchants, the value increases with decrease in viscosity and acid value. Palm oil does not follow the trend due to the highly saturated nature of palm among the vegetable oil [14]. Non-edible vegetable oils shows significant high heat transfer than edible oils. This can be attributed to lower viscosities when compared to edible oils and high degree of unsaturation present.

3.3 Cooling Curve Analysis.

Cooling curve was carried out according to ASTM D6200 in an un-agitated condition. Quenching characteristics for the selected local vegetable oils was experimented and documented with the cooling curve according to ASTM D6200 at an un-agitated state. Figure 3.0 and 4.0 present the cooling curves after quench hardening of c-ring in locally sourced edible and non-edible vegetable quenchants. Cooling rate curves (see figure 3a-g) was obtained by calculating the slopes of each cooling temperature with cooling curves.

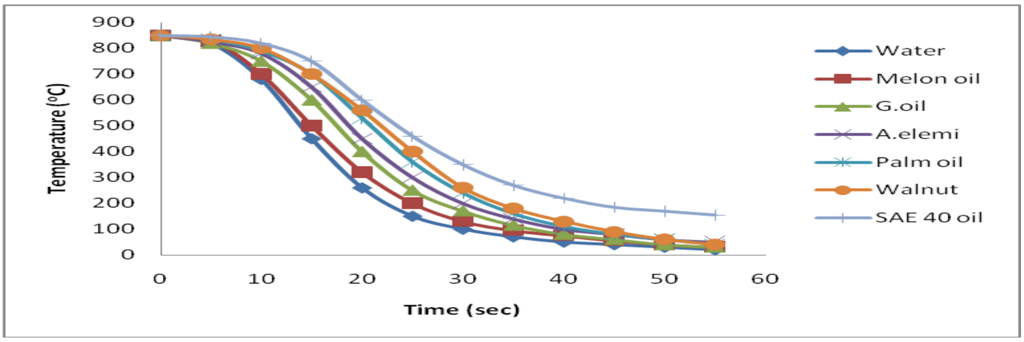
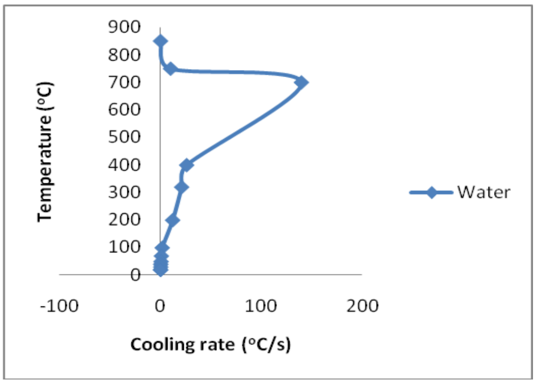
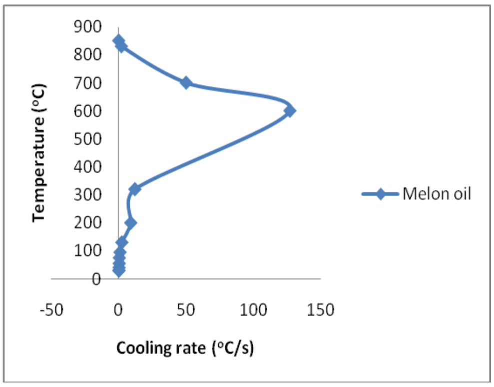


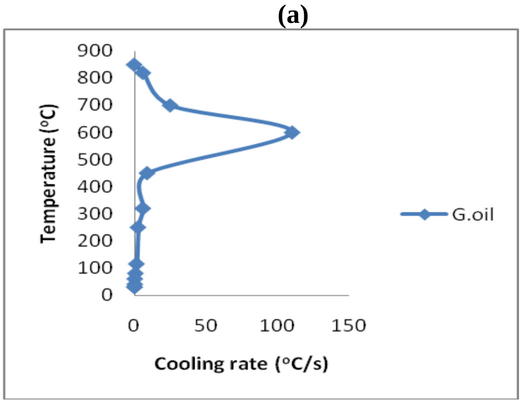
Fig. 3. Cooling curve of common edible, control oils quenchants



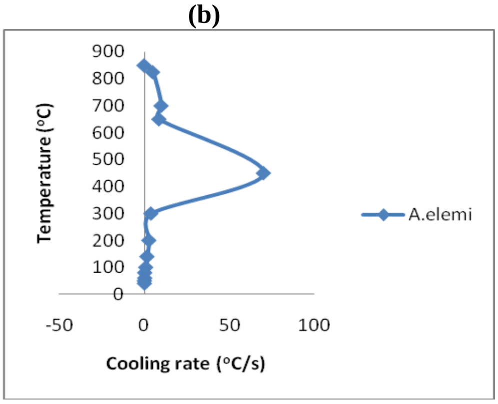
(a)



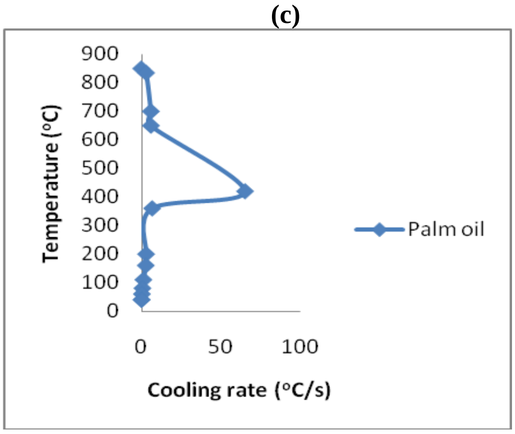
(b)



(c)



(d)



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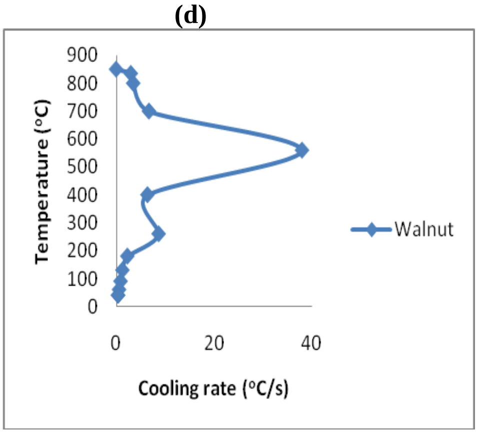
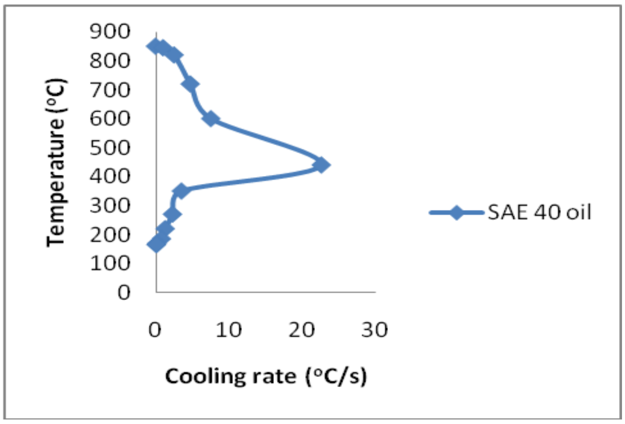


(f)



(g)

Fig. 3(a-g). Cooling rate curves for edible quenchants under study

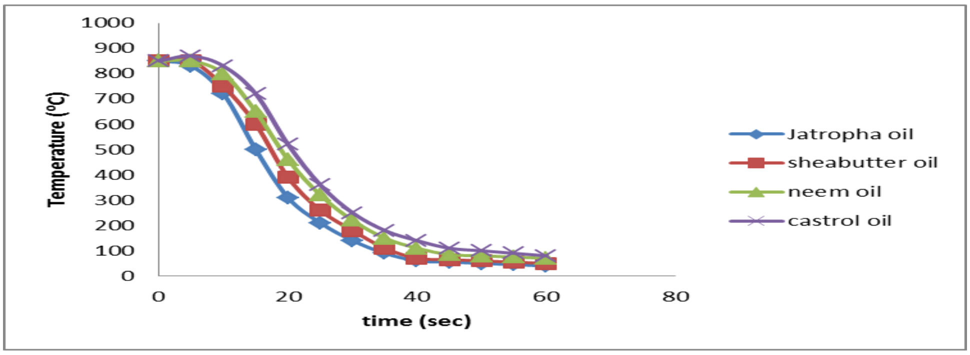
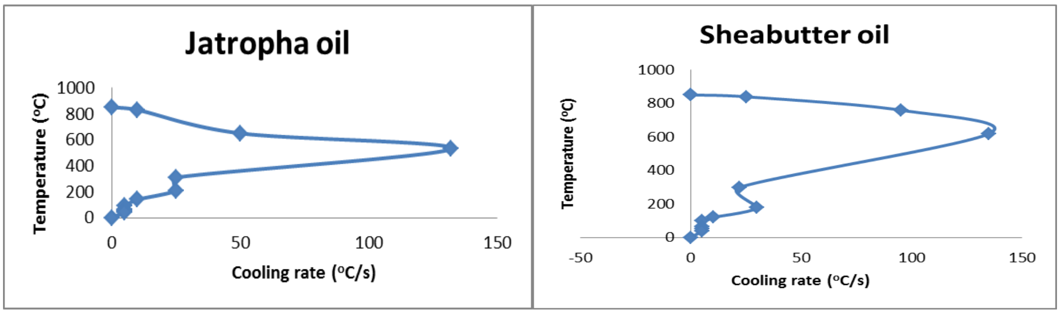
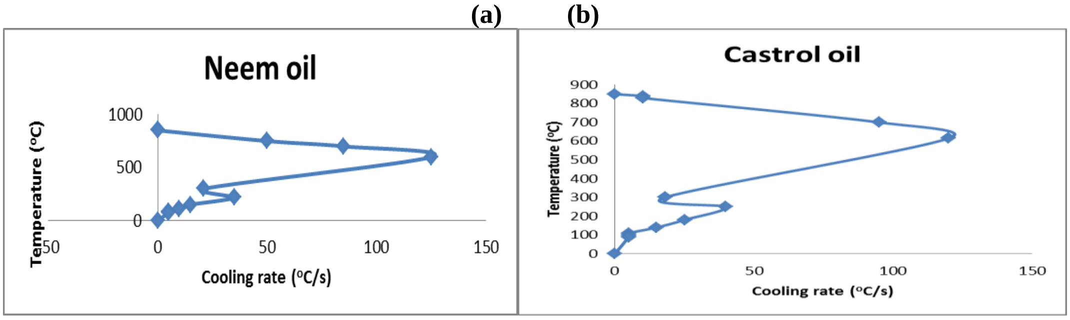


Fig. 4. Cooling Curve of non-edible Quenchants



(a) (b)



(c) (d)

Fig. 4(a-d). Cooling rate curves for non-edible quenchants under study

The Fig. 3, 3(a-g) and 4, 4(a-d) above shows that the vegetable oils quenchants under investigation shows the three significant stages in heat transfer mechanism during quenching which include film boiling, nucleate boiling and convection phases. The vegetable oils do not exhibits same film boiling or nucleate boiling behaviours as shown in Fig. 3&4. This was due to the differences in smoke points shown by the oils under atmospheric pressure condition.

Higher or maximum cooling rate of 140, 132, 135, and 125 for C-ring specimens quenched in water, jatropha, sheabutter and neem were measured at corresponding temperature of 700, 530, 620 and 600 ^{o}C respectively. Lower cooling rate of 110, 38, 70 and 65 ^{o}C/ measured with edible oils such as melon, walnut, Africa elemi, palm and SAE 40 oils at corresponding temperatures of 600, 560, 500, 430 and 436 ^{o}C oil. Groundnut oil compete favourably with castrol oil quenchant for each oil exhibit maximum cooling rate of 120 ^{o}C at corresponding temperature of 600 ^{o}C. This behaviour supports earlier work in the literature with respect to quench severity [16].

Cooling rates for all vegetable oils under investigation, however were somewhat slower, especially in the critical martensite temperature transition range (300 ^{o}C) than water quenchants evaluated shows that they may be desirable for hardening high alloy and crack sensitive steels [17]. Quench severity (Q_s) between both types of oil used in the study follows this order as shown below:

$$Q_s \text{ (non-edible oils)} > Q_s \text{ (edible oils)}$$

3.4 Measurement of Hardness Value.

The results of the hardness test of the specimens are presented in Fig. 5.

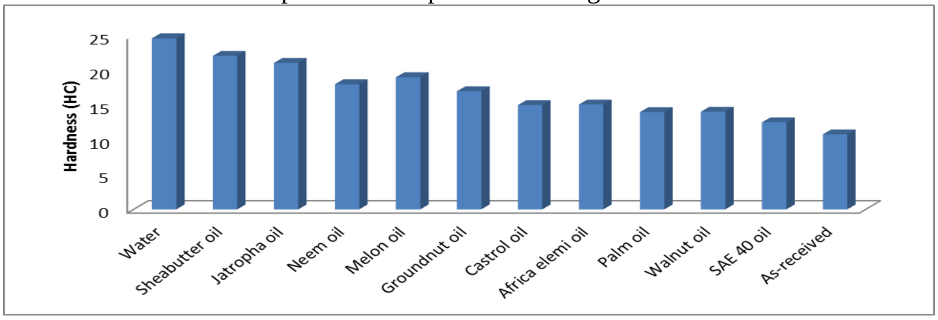


Fig. 5. Average Hardness (%) Value of Quenched Specimens in Various Quenchants

All quechants shows significant improvement in strength value when compared with as-received specimen and mineral-based oil with water exhibiting the highest strength value of 51.679 HC and was closely followed by sheabutter oil (51.204 HC). Walnut show the least strength value (46.008 HC) among the vegetable quenchants and SAE 40 oil with 39.566 HC value. Sheabutter and melon oils is most desirable of the non and edible oils, as it assures high mechanical strength values, as well as a uniform hardness at the entire volume of the specimens. The relative high quench severity and lower viscosity of sheabutter and melon oil resulting to higher hardness compared with other oils are partially attributed to high energies that were activated for good ability to wet [18].

3.5 Measurement of Distortion.

Average distortion obtained on the quenched specimens in various vegetable oils is presented in Fig. 6.

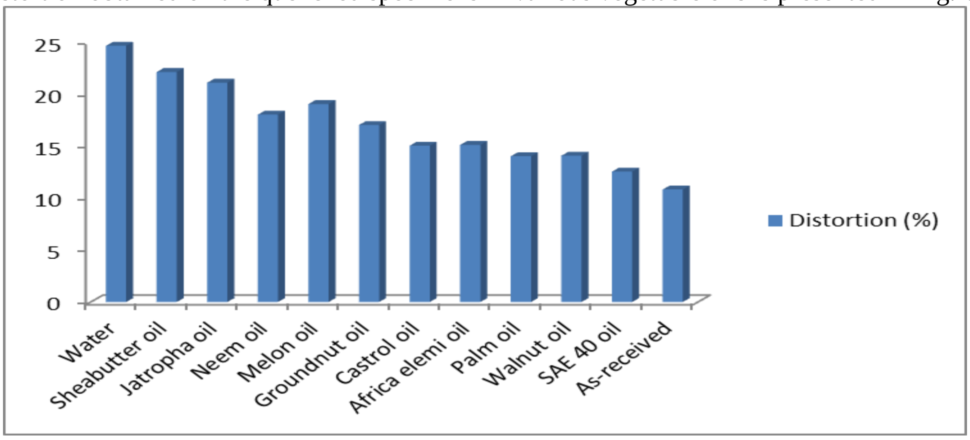


Fig. 6. Average Percentage Distortion of specimen in Quenchants.

Sheabutter seed oil exhibited the highest percentage distortion of 22.109 % among the non-edible oils while melon oil shows highest distortion value of 19.032 % among edible oils. This was closely followed by jatropha, neem, groundnut and Africa elemi oils with distortion values of 21.081, 18.010, 17.011 and 15.102 %

respectively. Castrol, walnut and palm oil exhibits least percentage distortion of 15.002, 14.061 and 14.008 % respectively.

3.6 Physiochemical Properties versus Distortion

The degree of distortion is a function of composition of quenchants and viscosity. Distortion increases with corresponding increase in viscosity and acid values but decrease in iodine value. Increase in viscosity result in a corresponding decrease in percentage distortion, since rate of heat transfer increases with lower viscosity and decreases with increasing viscosity. Lower viscosity, high heat transfer is observed which results to rapid quenching/cooling of temperature distribution in the material and in turn high distortion value [8]. According to santos et al., 2005, noted that for most vegetable oils, viscosity increases with fatty acid. The above results confirm this statement.

Higher iodine value denotes high degree of unsaturation in oil. This results to low resistance to rancidity (highly prone to oxidation) in turn lowering of viscosity value [13] and higher distortion value. In this study, higher distortion was found to greatly influence by iodine values.

Non-edible vegetable oils quenchants with higher distortion values shows least desirable than the edible vegetable oil quenchants when distortion is a major concern, walnut oil and palm oil are most desirable among the selected vegetable oil with minimum distortion values. For each distortion obtained on the specimens quenched in vegetable oils and petroleum-based oils were comparable, water exhibits the highest distortion value due to its ability to extract heat rapidly from the heated specimen than other quenchants used.

III. CONCLUSIONS

On the basis of the results of the study,the following conclusions were deduced:

- Distortion results of the study confirm that quenching with the types of vegetable oils used was successful.
- Specimen quenched in non-edible vegetable oils exhibits higher quench severity, heat coefficients and distortion when compared to specimens quenched in edible vegetable oils.
- The rate of distortion, cooling rate was found to be strongly dependent on the viscosity and its physiochemical properties of the oils.
- Based on the critical heat flow parameters, edible vegetable oils used in the study and SAE 40 oil can be used as slow quenching media. Non-edible vegetable oils and water may be used as fast quenching media.
- Specimens quenched in the vegetable oils show significant improvement in hardness values compared with the as-received samples and petroluem-based oil (SAE 40 oil).
- Hardness value increases with increasing distortion values which are a function of rate of heat extraction from the materials.
- Edible vegetable oils show the most desirable quenchants for quenching carbon-steel with minimum or least distortion values.
- Non-edible vegetable oils show the least desirable quenchants for quenching carbon steel with high distortion values.

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