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Assessment of *BALANITE AEGYPTIACA* Oil and its Blend with Used Engine Oil (SAE40) for Heat Treatment of Medium Carbon Steel

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ABSTRACT: Heat treatment is performed usually to enhance the mechanical properties of steel and other non ferrous alloys. Currently, there is increasing interest in the use of vegetable oils (Bioquenchants) because they are eco-friendly, renewable and are readily biodegradable since Mineral oil quenchants are expensive and sometimes involve fire as well as smoke hazard. In this study an attempt was made to investigate the suitability of (BalaniteAegyptiaca) and its blends with used engine oil (SAE40) as quenchant for Medium Carbon Steel (MCS). The steel samples were heated to 860°C, held for 10 minutes at the same temperature and were subsequently quenched in the oil blends samples. The blends were formulated and labeled as E100, B100, E50-B50, E80-B20, E90-B10. The performance of these quenchants was evaluated in terms of the change in the mechanical properties of the as-quenched samples compared with the as-received. The steel samples that were quenched in E50-B50 possessed higher ultimate tensile strength (UTS) of 1820.09 MPa which is almost 2.5 times that obtained from the as received sample (783.9 MPa), whereas samples quenched in E80-B20 showed high hardness value of 602.03 HV which corresponds to (81.96%) expressed in percentage compared to the as-received. Sample quenched in E100% showed 538.3 HV which corresponds to (62.63%) in percentage compared to as-received. The steel sample quenched in E80-B20 indicated an increased in hardness of 19.33% over used engine oil (E100%) when compared with as-received sample.

KEY WORDS: Quenching, *Balaniteaegyptiaca*, Medium carbon steel, Engine oil and Bioquenchants

I.INTRODUCTION

The ever increasing desire to reduce the toxicological effects associated with mineral oils is generating so much interest on the use of bioquenchants[3]. Presently, there is on-going effort to replace petroleum derived oil quenchants because they are expensive, non-biodegradable, and non-renewable [7]. Many vegetable oils such as soy bean, palm kernel and palm oils have been successfully used as quenching media, in heat treatment of steels with very encouraging results [2]. Performance of every quenchant can be evaluated by the ability of the quenchant to extract heat from the part’s surface; alternatively, it can be expressed by direct measurement of the changed in mechanical properties of the quenched part [18]. Heat treatment is a process in which steel is heated to the specified temperature (temperature of austenitization), typically in the range of 750-1100°C, held at this temperature (soaking) and rapidly cooled (quenched) in water, oil, molten salt bath [16]. Steel is an alloy of iron formed by adding certain amount of carbon usually between 0.2 to 2.1%C by weight [17]. It is one of the most important materials in engineering due to its properties, availability and usefulness. Steels, based on their carbon content can be categorized as low carbon steel with carbon contents below 0.25% C, and medium carbon steel with carbon content varying from 0.25% to 0.65%, while high carbon steels usually have carbon content that ranges between 0.65% - 1.5% [12]. Medium carbon steel is the most common form of steel as it provides material properties that are acceptable for many engineering applications as it is neither too brittle nor too ductile due to the amount of carbon content present [10].

II. SIGNIFICANCE OF THE SYSTEM

The paper mainly focuses assessing the suitability of *balaniteaegyptiaca* oil and its blend with used engine oil (SAE40) for heat treatment of Medium carbon steel. The mechanical properties of quenched steel samples that includes; ultimate tensile strength, percentage elongation, hardness and toughness (impact) were measured and compared with that of the as-received. The study of literature survey is presented in section III, Methodology is explained in section IV, section V covers the experimental results of the study, and section VI discusses the future study and Conclusion.

III. LITERATURE SURVEY

Ndaliman (2006) assessed the mechanical properties of medium carbon steel samples quenched in water and palm oil. The study shows that medium carbon steel responds well in terms of tensile strength and percentage elongation when quenched in palm oil than the samples quenched in water and engine oil. Also, the samples quenched in palm oil possessed high toughness upon tempering. Adeyemi and Adedayo (2009) investigated the use of vegetable oils (groundnut oil and palm kernel oil) as quenchants for hardening mediun carbon steel, and the results revealed that steel samples quenched in groundnut oil possessed higher tensile strength and toughness than those quenched in palm kernel oil, but higher wear resistance was achieved with samples quenched in palm kernel oil.

Hassan &Aigbodion (2013) evaluated Khayasenegalensis seed oil (Mahogany oil) as quenchant in the hardening process of plain carbon steel. The results showed increased in hardness and the tensile strength of the steel sample quenched in water, Khayasenegalensis oil, and SAE40 engine oil respectively. Sreeja*et al.* (2016) studied the mechanical properties of steel quenched in a blend of biodegradable (20% groundnut oil and 80%neem oil) with quench accelerators, and greater hardness value and impact resistance were achieved with pure neem oil than groundnut oil and the blend of groundnut oil and neem oil.

Dodo *et al.* (2016) investigated the cooling rate of cane molasses as quenching medium for high carbon steels (0.61%C). They reported that cane molasses could harden high carbon steels without cracks in the same manner as SAE40 engine oil and also the quench severity of the quenchants used was found to be higher with water, followed by prepared molasses, SAE40 engine oil and then raw molasses. Also, the research revealed that quenching of the sample in SAE40 resulted in oil fumes, smoke emission and fire hazard in contrast to cane molasses.

Rajkumar& Dinesh (2013) investigated the influence of petroleum and biodegradable quenchant (soybean oil) on the properties of medium carbon steel. They concluded that soybean oil used as quenchant gave better mechanical properties and microstructure when compared with petroleum base quenchant and suggested that soybean oil is an alternative to petroleum base quenchants.

Maruthi&Sudheer (2016) reported that enhancement of mechanical properties and microstructure of Al-alloy could be achieved using different quenching media (water, distilled water, brine, soybean oil, palm oil, cotton seed oil, olive oil, palm kernel oil, apple juice, polymer quenching, clay and castor oil). The result showed that olive oil, palm kernel oil and cotton seed oil gave hardness values less than that obtained with water and SAE 40 engine oil. While, palm kernel oil, cotton seed oil and olive oil gave higher impact energy values than water.

However, in view of the current industrial demand for more eco-friendly quenching media which necessitates the search for alternative quenchants. This is one of the major reason for the research.

IV. METHODOLOGY

A. Materials

The material used for the research are Medium carbon steel which is sourced from Ahmadu Bello University (ABU),zaria. And its chemical composition is given table 1.Balaniteaegyptiaca oil, Used engine oil (SAE40), Tetraoxosulphate (VI) acid, and silicon Carbide abrasive paper (120, 180, 230, 320, 400 and 600 grades).

Table 1: Chemical composition of Medium carbon steel in %Wt.

C	Mn	Si	P	S	Cr	Ni	Cu	V	Al	Sn	Ti
0.41	0.54	0.15	0.031	0.048	0.19	0.12	0.30	0.003	0.42	0.021	0.001

B.Equipments

Electric furnace (capable of withstanding up to 1200^{0}C), Vickers Hardness testing machine (model no. MV1-PC), Hounsfield Balance Impact testing machine (Charpy), Hounsfield Tensometer, Lathe machine, Tongs, Digital verniercaliper, and Metallurgical microscope (model no. NJF-120A).

C. Methods

- **Blends formulation**

The various blends were formulated by mixing used engine oil (SAE40) with *balaniteaegyptiaca* oil, in the proportion EXBY, where letter E stands for used engine oil (SAE40) and letter B stands for *balaniteaegyptiaca*oil; X and Y represents the percentage of used engine oil and percentage of *balaniteaegyptiaca* in the mixture respectively. The mixing was carried out with the aid of mechanical stirrer. The resulting mixtures were allowed to settle for 20 minutes to check for phase separation before the quenching commenced. The oils blends formulated were labeled as E100% contains 100% used engine oil (SAE40), B100% contains (100%*balanitesaegyptiaca* oil), E50-B50 contains 50% used engine oil and 50% *balaniteaegyptiaca*oil, E80-B20 (80% used engine oil 20% *balaniteaegyptiaca* oil) and E90-B10 (90% used engine oil and 10% *balaniteaegyptiaca*oil).

- **Heating and cooling of the samples**

A total of 48 samples of medium carbon steel were prepared by machining process. The samples were grouped and heated in a furnace at temperature of 860^{o}C and holding for 10min (soaking) at that temperature and then cooled in the various oils according to ASTM standard as reported by Robert, (1980). Plate I shows the prepared samples for the experiment.

Plate 1: prepared samples.

- **Mechanical test**

a).Hardness test

The Vickers hardness method was used to determine the hardness of the quenched as well as the as-received samples. The hardness of the specimen is its ability to resist indentation by an applied force. The Vickers machine model of micro hardness tester MV1-PC was used. The six (6) samples (5-treated and 1-untreated) of 10 mm diameter each were grinded to a smooth mirror-like surface with quartz paper. The surfaces of the prepared samples were indented with the Vickers diamond indenter at a dwelling time of 10 seconds. The hardness value of each of the samples was read and recorded by the machine. The hardness value of the materials was determined with the following test parameters; an applied load of 0.3 kgf and maximum hardness limit of 650 HV asreportedby [13].

b). Impact Test

The impact strength is the measure of the energy absorbed by the specimen. The impact test was carried out on the Hounsfield impact machine. The sample was inserted horizontally into the slot of the inner tup of the machine, by pulling the notch register (NR) backward; when the V-notch section was actually engaged the notch register was released. The hammers were then thrown over elegantly; the inner tup was lifted to the right, while the outer one was moved upward to the left. The pawl release lever was pushed up and the hammers were moved out of position to strike the samples with a relative speed of 22 ft/sec. causing the samples under test to break. The readings were taken by observing the new position of the pointer on the dial. The impact energy was calculated using the following equation.Impact strength = Impact energy (J) / Cross sectional area (mm^2) = E_{im} / A_{im} - - - (1)

Impact area (A_{im}) is given by $A_{im} = \frac{\pi d_{nc(av)}^2}{4}$

Where d_{nc} = notch diameter

c).Tensile strength test

The tensile strength tests for the eighteen (18) (15-treated and 3-untreated) steel specimens were carried out on a 20kN Hounsfield Tensometer connected to a data logger. The test pieces were firmly held in the chucks of the machine, Load was gradually applied manually while the load-extension curve was traced on a graph attached to the drum of the machine. The ultimate tensile strength, the strain, percentage elongation and modulus of elasticity were calculated based on the stress-strain curve obtained with the following equations (Equations 2-5). The averages of the applied loads and corresponding extensions of all the samples were tabulated. Then the ultimate tensile strength (UTS) was computed using equation [6] and strain, percentage elongation and modulus of elasticity were found using equations (3), (4) and (5) respectively [5].

Ultimate tensile strength (UTS) is $\sigma_t = \frac{F_{\max}}{A_t}$ - - - (2)

Where σ_t is the ultimate tensile strength in (kN/mm^2), $F_{max}$is the maximum load at fractute in (kN) and A_t is the original cross sectional area in (mm^2).

$$A_t = \frac{\pi d_{av}^2}{4},$$

Where l_{av} is average gauge lengths and $l_{(o)av}$ is the average of the original gauge lengths

Strain $\varepsilon = \Delta l_{av(m)} / l_{av}$ - - - (3)

% elongation = $\Delta l_{av(m)} / l_{(o)av}$ x 100 - - - (4)

Modulus of elasticity $E = \sigma_t / \varepsilon$ - - - (5)

Where σ_t is the ultimate tensile strength in (kN/mm^2), ε is the strain.

V. EXPERIMENTAL RESULTS

Table 2. Contains the various mechanical properties obtained from the as-received sample as well as that of the samples quenched in the oils and their blends.

Table 2: Results for the tensile test

Sample	Average Impact Energy, E_{im} (J)	Average Hardness (HV)	UTS, σ (MPa)	Strain , Ɛ	%Ɛ elongation	Modulus of Elasticity (MPa)

As-received	20.32	331.0	738.90	0.0912	9.12	8101.97
E-100%	4.43	538.3	1329.00	0.0612	6.12	21715.00
B-100%	8.72	379.3	1252.04	0.054	5.40	23185.93
E50-B50	6.33	352.0	1820.06	0.076	7.60	23948.16
E80-B20	5.33	602.3	1248.51	0.063	6.30	20389.05
E90-B10	8.00	525.7	1259.09	0.062	6.20	20307.90

d).Hardness of the steel samples

Figure 1 depicts the hardness of the steel samples (quenched and as received). and the sample quenched in E80-B20 has the highest hardness number of 602.3 HV in comparison with the as received sample, followed by sample quenched in E-100 (538.3 HV), then followed by sample quenched in E90-B10 with hardness values of (525.7 HV).

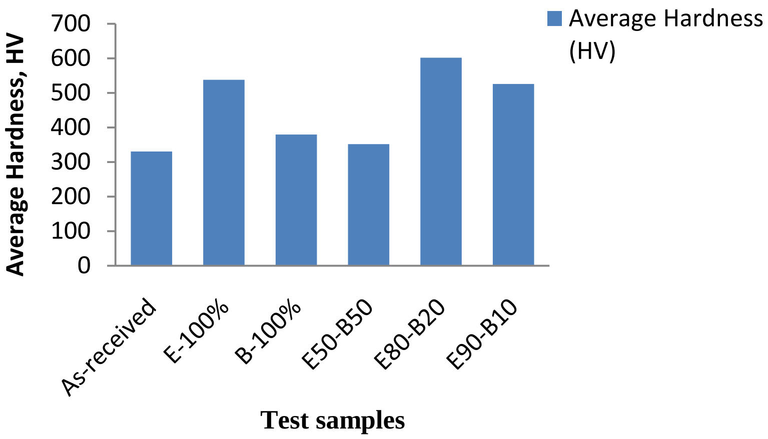

Figure 1: Average hardness values of the steel samples.

e).Ultimate tensile strength

Figure 2 shows the ultimate tensile strength (UTS) for various steel samples quenched in the oils and their blends and that of the as-received sample. The results indicated that the samples quenched E50-B50 has the highest UTS value of 1820.06 MPa, which is almost 2.5 times the UTS of the as-received sample. This is in agreement with what was reported by [4].

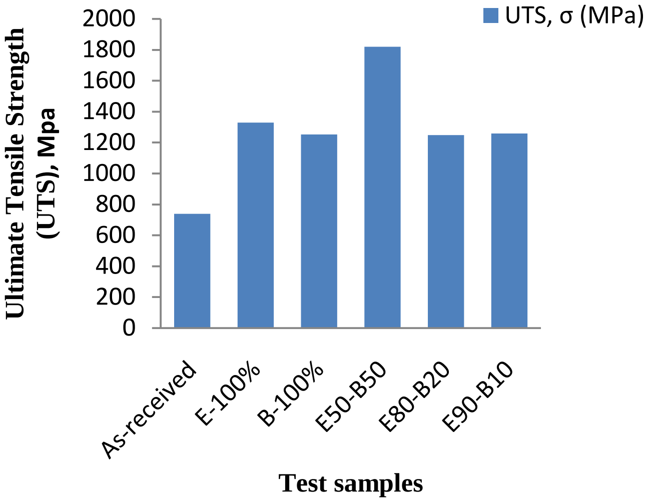

Figure 2: Ultimate tensile strengths of the steel samples

f). Percentage elongation

This is the materials ability to deform plastically. Figure 3 indicates percentage elongation of the steel samples against the respective quenchants. The as-received sample shows the highest percentage elongation of 9.12%. This high value of elongation of the as-received sample is evident since it has not been heat treated. The sample quenched in E50-B50 has the highest elongation (7.6%) among all the quenched samples.

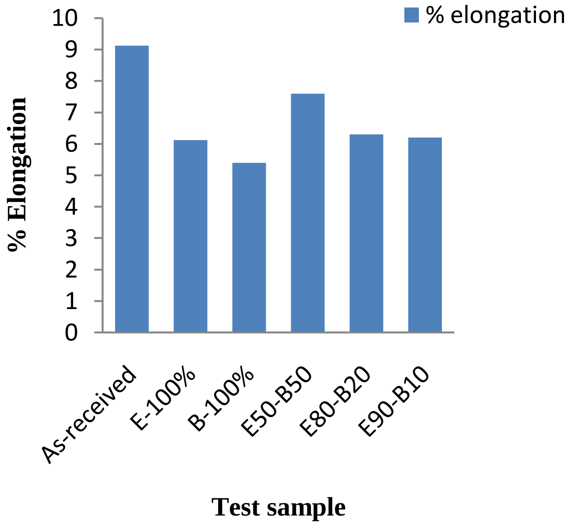

Figure 3: % elongation of the steel samples

g).Modulus of elasticity

The modulus of elasticity indicates the materials stiffness or its resistance to elastic deformation. Figure 4 represents the modulus of elasticity of the steel samples tested. It can be seen that samples quenched in E50-B50 has the highest value of 23948.16 MPa among all quenched samples.

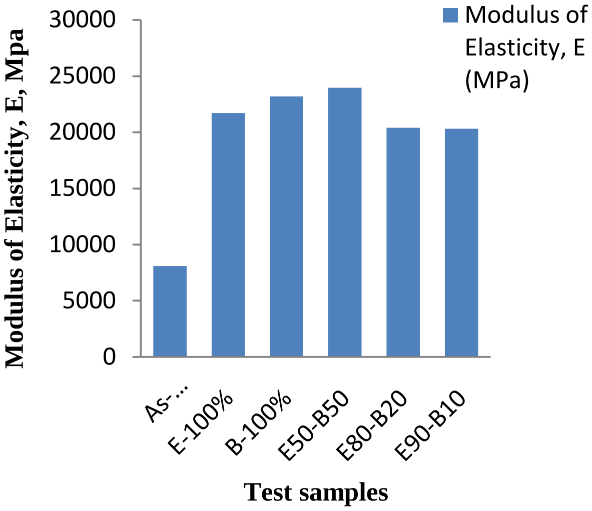

Figure 4: Modulus of elasticity of the steel samples

h).Impact energy of the steel samples

The impact energy in J of the steel samples is shown in figure 5. The as-received sample shows the highest impact energy of 20.32 J. This is also an evidence that the as-received sample absorbs much impact energy than the heat-treated samples. Among the heat treated samples, the sample quenched in B-100 has the highest impact energy of 8.72 J whereas samples quenched in E80-B20 exhibited the least impact energy of 5.33 J.

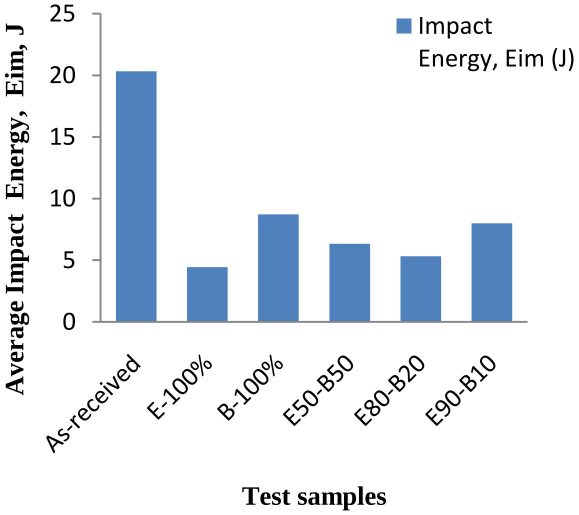

Figure 5: Average impact energy of the steel samples.

VI.CONCLUSION AND FUTURE WORK

In this work, medium carbon steel samples were heat-treated at 860^{o}C and held at 10 min. The samples were quenched in the used engine oil (SAE40) which was treated and its blends was formulated with *Balaniteaegytiaca* (desert dates) oil. After heating and cooling of the samples, the mechanical properties of both the heat treated and un-heat treated samples was tested.

The steel sample that was quenched in E50-B50 possessed the highest values of the ultimate tensile strength (UTS), and modulus of elasticity of 1820.06 MPa and 23948.16 MPa respectively. The results also showed a higher value of percentage elongation of 7.60% compared to the quenched samples.

Sample quenched in E80-B20 showed the highest hardness value of 602.3 HV, corresponding to 81.96% expressed in terms of percentage compared to the as received sample, then followed by sample quenched in E100 that has value of 538.3 HV corresponding to 62.63% when compared to as received. Sample quenched in E80-B20 has an increased hardness of 19.33% over E100% when compared to the as received sample.

Samples quenched in B100 have the highest impact energy value of 8.72 J among the quenched samples. Future work should be carried out to improve on the properties of balaniteaegyptiaca oil by introducing some additives to it.

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