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Effect of Bath Temperature on the Cooling Rate of Sesame Seed (*Sesamum indicum*) Oil

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ABSTRACT

The effect of temperature on sesame oil (Sesamum indicum oil) as a quenching medium for medium carbon steel was investigated. Samples were cut and machined for mechanical properties test and cooling curve determination prior to hardening operation. Sesame oil was measured at different volumes such that the final temperature rise of the quenching bath after quenching would be 26 ^oC, 51 ^oC, 66 ^oC, and 81 ^oC. The samples were normalized, and then austenitized at 850 ^oC. They were then soaked for 40 minutes and then quenched in sesame oil (4.88 dm^3, 1.91 dm^3, 1.18 dm^3 and 0.84 dm^3), water, and SAE40 engine oil. Half of the samples quenched were further tempered at 350 ^oC and held for 40 minutes and then air-cooled. Cooling curves for all the quenching media used were developed. Specific heat capacities of the various media used were determined. Hardness and impact strength of the samples was tested. The test result obtained from the quenched samples shows that the highest hardness value (48 HRC) and impact strength (570 kJ/m^2) was obtained from the samples quenched in sesame oil maintained at a temperature rise of 26 and 80 ^oC respectively. Microstructures of the various samples were analyzed using optical microscopy (OM), in all the samples; Martensite, retained austenite and fine pearlite structure were observed. The research shows that sesame oil maintained at a temperature rise of 80 ^oC gives the good combination of impact strength and hardness value. Thus, it is recommended to be used as a quenching medium for medium carbon steel.

1. INTRODUCTION

Certain engineering components require high hardness values so that they may be used successfully for heavy duty processes (Dauda *et al.,* 2015). Hardening as a form of heat treatment has been used to achieve these requirements in metal or alloy components (Kashim, 2010). Hardening of steels involves heating steel to temperatures above the upper critical temperature in order to convert it partially or completely to austenite. This is followed by holding at this temperature for a specified period of time long enough to ensure the desired austenization after which rapid cooling is carried out at a rate equal to or higher than the critical cooling rate (Olson, 2001). The rapid cooling is achieved through quenching. Quenching consists of immersing a hot component in a liquid to lower its temperature rapidly.

Understanding how quenching parameters affect the outcome of the quench is important for control of mechanical properties as well as elimination of distortion and cracking (ASM, 1998). Changes in bath temperature do not usually alter the cooling curve during the vapour blanket phase (stage I); the maximum effect occurs in slow cooling stage (stage III). The higher the bath temperature, the faster the oil and specimen temperatures reach equilibrium. Early equilibrium temperatures reach helps to minimize distortion and cracking (Troell *et al.,* 2014). Thus, this research is aimed at investigating the effect of temperature on the cooling rate of sesame oil (*Sesanum indicum oil*) during quench-hardening heat treatment of medium carbon steel (0.40%C).

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this research work include: medium carbon steel (0.40%C) samples, sesame oil, water, and SAE 40 Engine oil. Other materials include: polishing powder, grinding papers, polishing cloth, nitric acid, ethanol and cotton wool.

2.2. Equipment

The equipment used for the work include: lathe machine, muffle furnace, (electric resistance furnace), polishing machine, thermocouple, optical metallurgical microscope, universal hardness testing machine (Rockwell), and Izod impact testing machine.

2.3. Methods

The samples were prepared for impact, hardness and metallographic examination test. Spectrometric analysis of the steel was carried out to determine its chemical composition. The result is shown in Table 1. The volume of the various quenching media used were determined using the first law of thermodynamics. The volume of each quenching medium was determined using Equation 1.

$$\text{Heat lost by the component} = \text{Heat gained by the quenching medium} \quad (1)$$

For water, using specific heat capacity of 3976.80 Jkg^{-1} K^{-1} as reported by Dodo *et al.* (2016), and maintain 1 ^oC rise in temperature after quenching. The volume required was 2.46 liters of water.
The same was obtained for SAE 40 Engine oil using its specific heat capacity of 1740.21 Jkg^{-1} K^{-1} as reported by Dodo *et al.* (2016). The sesame oil specific heat capacity of sesame oil was determined to be 2381 Jkg^{-1} K^{-1} and the volumes of the bath were:

At 25 ^oC = 4.88 liters
At 50 ^oC = 1.91 liters
At 65 ^oC = 1.18 liters
At 80 ^oC = 0.84 liters

2.4. Heat Treatment Operations

Test samples were grouped under the following:

As-received condition (untreated).
Normalized condition.

Quenched condition.
Tempered condition.

2.4.1. Normalizing

Thirty eight samples were heated to 850 °C and soaked for 1 hr 12 min for the necessary transformation to occur and attainment of homogenization after which the samples were air-cooled (Dodo *et al.*, 2016). This normalizing heat treatment was carried out to remove the effects of unfavorable structures due to casting and machining and also to restore original condition of the structures and induce homogeneity in the structure (Dodo *et al.*, 2016). Thus, the normalized microstructure was used as the starting structure for this work.

2.4.2. Hardening heat treatment

Thirty samples were austenized at 850 °C for 40 min and were then quickly quenched in the sesame oil (4.88 dm^3, 1.91 dm^3, 1.18 dm^3 and 0.84 dm^3), water, and engine oil. The sesame oil was put in different bath with different volume which determined the final temperature of the sesame oil after quenching. The volumes were obtained using first law of thermodynamics (maintaining 1 °C rise in temperature), and the final temperatures of the bath were 50 °C, 65 °C and 80 °C. There were six containers containing sesame oil at different volumes, water, and SAE 40 Engine oil temperatures to quench the sample.

2.4.3. Tempering

Fifteen samples in the as-quenched conditions from all the media were tempered. This involved heating the samples to 350 °C and holding for 40 min after which the samples were air cooled (Dodo, 2015).

2.5. Determination of Cooling Curve

Medium carbon steel sample was machined to 10 mm diameter and 60 mm long for the purpose of plotting the cooling curve. A k-type thermocouple was fitted in a hole that was drilled at the geometric centre of the test piece. The test piece was heated in a furnace to 850 °C for 1 hr and was quenched in the sesame oil, water, and SAE 40 engine oil. On cooling, during quenching the falling temperature and the corresponding time was recorded after which the cooling curves and cooling rate curves were plotted for all the media.

2.6. Mechanical Tests

2.6.1. Hardness test

Samples used for the metallography were subjected to hardness test using the Rockwell hardness test (scale C) method on the Indentec universal hardness testing machine 8187.5 LKV. Each sample was mounted on the machine with the polished surface faced up. Three indentations were made on the surface, and the depth of indentation made was measured by the electronic scale which converts the depth measurement to the corresponding hardness value. The average of the three hardness values was determined and recorded (Dodo, 2015).

2.6.2. Izod impact test

The impact test was carried out according to standard of 11.4 mm diameter circular section with a 2 mm deep V-notch as specified in BSS.131. Before the test, the pendulum was set to a potential energy position of 162.75 J. The test specimen was then gripped vertically in a vice, the trigger was released and the registering pointer of the quadrant scale indicated the energy absorbed in joule by the specimen. The energy

J.O. Gaminana et al. / Nigerian Research Journal of Engineering and Environmental Sciences
4(2) 2019 pp. 715-723

that was absorbed in breaking the samples was recorded and the same was repeated for other test pieces (Dodo, 2015).

2.6.3. Metallography

All the specimens (both untreated and heat treated) was prepared for optical microscopic investigation using the standard metallographic techniques. The specimens were ground on a water lubricated grinding machine with silicon carbide abrasive papers of grades 320, 400, 600, and 800 grit sizes. Polishing was carried out on two 15 cm rotating discs of a METASERV universal polishing machine. Rough polishing was done with synthetic velvet polishing clothes impregnated with I-micro Alumina past: Final polishing was then carried out with 0.5-micron chronic oxide polishing powder. The specimens were etched with 2% nital solution using the swabbing method with cotton wool soaked in the etchant. The microscopic examinations were carried out on M100 optical metallurgical microscope and the microstructures obtained were captured with the aid of in-built camera (Dodo, 2015).

3. RESULTS AND DISCUSSION

The cooling curves for the various media; mechanical properties result and microstructures for the as-received, normalized, as-quenched, and tempered medium carbon steel samples are shown in the following sections.

3.1. Chemical Properties

The results indicated in Table 1 show that the steel used possess a carbon content of 0.4 %. The steel composition meets the minimum carbon content required for it to be materially affected by hardening heat treatment, since it has 40 % carbon which is higher than the required 25% (Durowoju *et al.,* 2013). Similarly, the physiochemical and thermal properties of the sesame oil used is depicted in Table 2. The pH and specific gravity of the oil were found to be 6.4 and 0.9126 respectively. Additionally, the oil has a considerably higher specific heat capacity than the SAE40. The flash point obtained was 380 ^oC. The flash point met the ASTM minimum requirement of 90 ^oC above room temperature (Mackenzie, 2009).

Table 1: Chemical composition of medium carbon steel

Element	C	Si	Mn	P	S	Al	Cu
Composition	0.40	0.19	0.76	0.052	0.056	0.08	0.28

Table 2: Physiochemical and thermal properties of sesame oil

Physical properties	pH Value	Pour point (^oC)	Flash-point (^oC)	Specific gravity	Specific heat capacity (J/kg)
Sesame oil	6.4	7	380	0.9126	2381

Table 3: Physiochemical and thermal properties of SAE40 Engine oil (Dodo, 2015)

Viscosity at 25 ^oC (cp)	Viscosity at 100 ^oC (cp)	Viscosity Index	Flash-point (^oC)	Specific gravity	Specific heat capacity (J/kg)
40	5.03	105	260	0.868	1740.21

Table 4: Viscosity, specific gravity, and specific heat capacity of water used (Dodo, 2015)

Viscosity at room temp. (cp)	Specific gravity	SHC ($Jkg^{-1}K^{-1}$)
1	1	3976.80

3.2. Cooling Curve

Figure 1, shows the cooling curves of the various quenching media used. The assumption used was that the temperature of the medium will be varied (50ºC, 65 ºC, and 80ºC) throughout the cooling operation. Water proved to have the shortest stage I (vapor blanket stage); which is estimated to last for less than a second. Whereas stage II is estimated to last for 8 seconds; this corresponds to the literature obtained from Skidmore (1986). SAE 40 engine oil presents prolonged vapor blanket and boiling stage. This is what makes it to have a lower cooling rate than water. This is in line with what was reported by Komatsu *et al.* (2009). However sesame oil at temperature of 50 ºC have vapor blanket stage very close to that of water which last for 2 sec, and the nucleate boiling stage last for 10 secs this is due to the fact that at 50 ºC the volume of sesame oil is much and the heat extraction ability of the oil is relatively high (Olson, 2001). However, the other media at 65 ºC, and 80 ºC, have less volume compared to that at 50 ºC because as the temperature increases the volume decreases, therefore they will have more prolonged nucleate boiling stage.

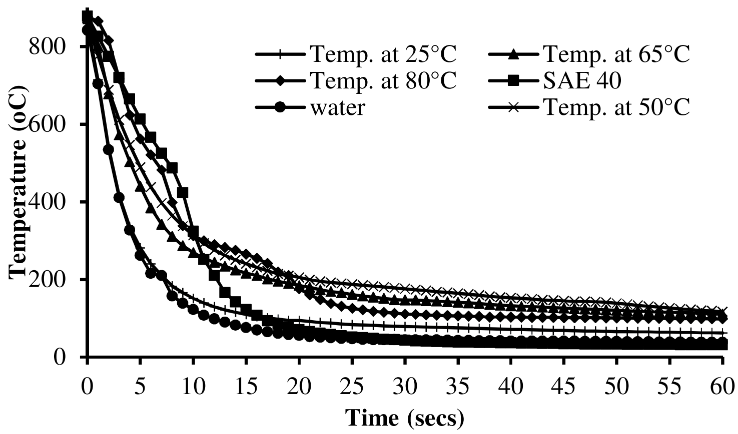

Figure 1: Cooling curves result for the as-received, normalized, quenched, and tempered in different quenching media

3.3. Hardness Profile

From the hardness result, shown in Figure 2, it was observed that the samples have lower hardness value in the as-received, normalized, and tempered condition than in the as-quenched condition. Medium carbon steel developed a highest hardness value of 54.5 HRC when quenched in water and the lowest hardness value of 15 HRC when normalized. The hardness value of 47.47 HRC was developed by the medium carbon steel when quenched in sesame oil at temperature of 50 ºC, while when tempered it gave a lower hardness value of 42.3 HRC. When quenched in sesame oil at temperature of 65 ºC gave a hardness value of 46.3 HRC, while when tempered, it gave a lower hardness value of 38.97 HRC. When quenched in sesame oil at temperature of 80 ºC gave a hardness value of 44.63 HRC, while when tempered it gave the lowest hardness value of 37.93 HRC. The hardness value of the samples quenched in sesame oil developed hardness value close to that of SAE 40 Engine oil. However, high hardness obtained from these results could be attributed to the various microstructure obtained [see plate 2-4]. This shows that the quenching severity of sesame oil increases with decreasing temperature and this is in line with what was reported by Saska (2005).

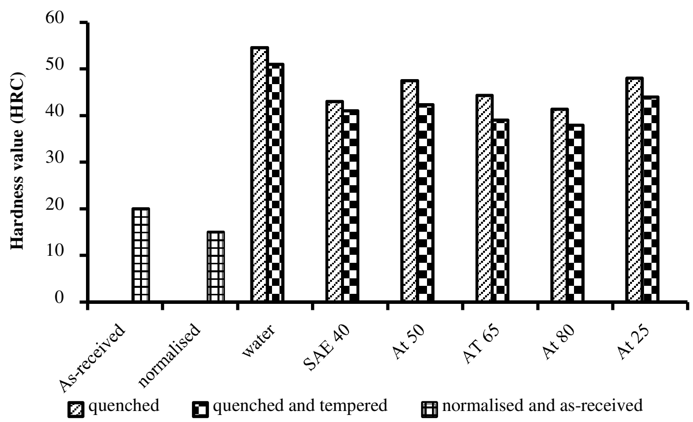

Figure 2: Hardness value result for the as-received, normalized, quenched, and tempered in different quenching media for medium carbon steel

3.4. Impact Strength

Figure 3 shows the impact strength (energy absorbed per unit area under the notch) for the samples quenched and tempered in different media. It can be seen that the highest energy absorbed before fracture (570 kJ/m^2) was obtained from the sample quenched in sesame oil at a temperature of 80^{o}C. Similarly, 670 kJ/m^2 was obtained from the sample quenched and tempered in sesame oil at a temperature of 80^{o}C. This is attributable to the fastest equilibrium reach of the oil and sample temperatures. The least impact strength (90 kJ/m^2) was obtained from the sample quenched in water. The samples quenched in sesame oil at temperatures of 65 ^{o}C and 50 ^{o}C have an intermediate impact strength value. The trend showed by the impact strength values in relation to the quenching severity of the sesame oil is similar to that observed in polymer solutions (Muhammad, 2007).

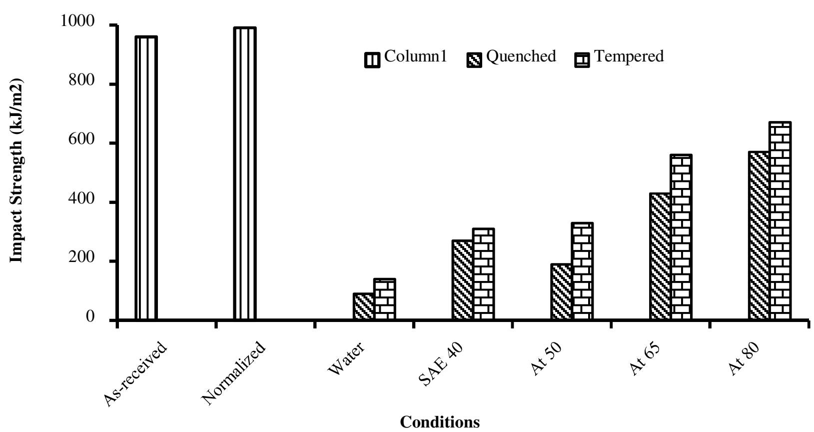

Figure 3: Impact strength test result for the as-received, normalized, quenched, and tempered in different quenching media for medium carbon steel

3.5. Microstructures

Plate 1a shows the microstructure of the as-received sample consisting of fine pearlite in ferrite. Plate 1b depicts the microstructure of the normalized sample consisting of a pro-eutectoid ferrite in pearlite matrix. However, a fine martensitic structure with retained austenite and tempered martensite was observed in the water quenched and quenched-tempered sample respectively (Plate 1c and d). High hardness obtained for water quenched sample is connected to the high proportion of martensite in the structure (Agboola *et al.*, 2015). Plate 3a is the structure obtained from SAE40 engine oil as-quenched sample containing a lower amount of martensite structure compared to that of water and it is also associated with retained austenite. Plate 3b is the result of quenched and tempered in SAE40 engine oil containing structure of tempered martensite. This is similar to the observation made by Vivek *et al.* (2014). Similarly, it is seen from Plates 2a, 3c, 4a, and 4c that more of austenite transformed to martensite at low temperature rise after quenching and this might have accounted for the high hardness induced in the samples (samples quenched in the oil with low temperature rise) (Alabi *et al.,* 2012). Plates 2b, 3d, 4b, 4d illustrated tempered martensite. The structure of the samples quenched and tempered have increased precipitation of cementite in fine supersaturated ferrite and lower bainite due to decomposition of martensite and retained austenite. This is alike to the results reported by Hassan *et al.* (2009). The decomposition of martensite and retained austenite, account for the reduction in hardness and strength after tempering. This is expected and is in line with the result of Hassan and Aigbodion (2013).

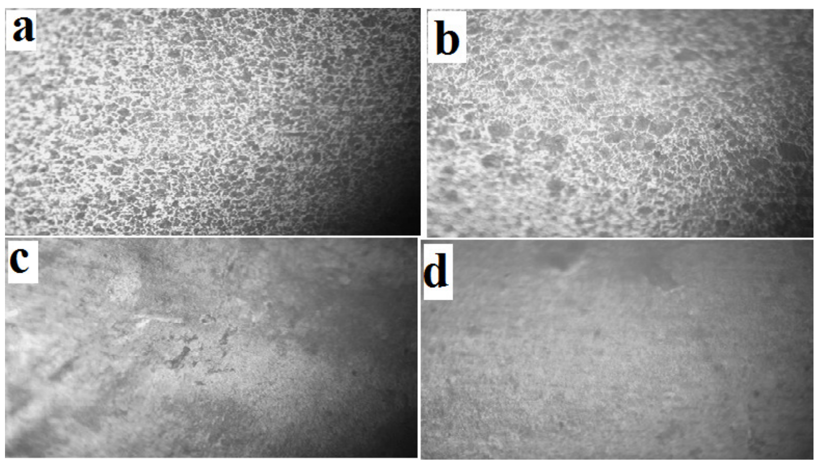

Plate 1: Micrograph of medium carbon steel sample (a) in as-received condition (b) in normalized condition; (c) quenched in water; (d) quenched in water and tempered at 350 ºC. Etched 2% Nital. (x200)

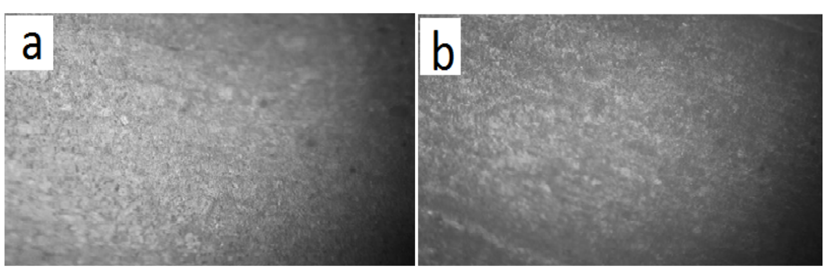

Plate 2: Micrograph of medium carbon steel sample (a) quenched in sesame oil maintained at a temperature rise of 26 ºC; (b) quenched in sesame oil maintained at a temperature rise of 26 ºC and tempered at 350 ºC. Etched 2% Nital. (x200)

J.O. Gaminana et al. / Nigerian Research Journal of Engineering and Environmental Sciences
4(2) 2019 pp. 715-723

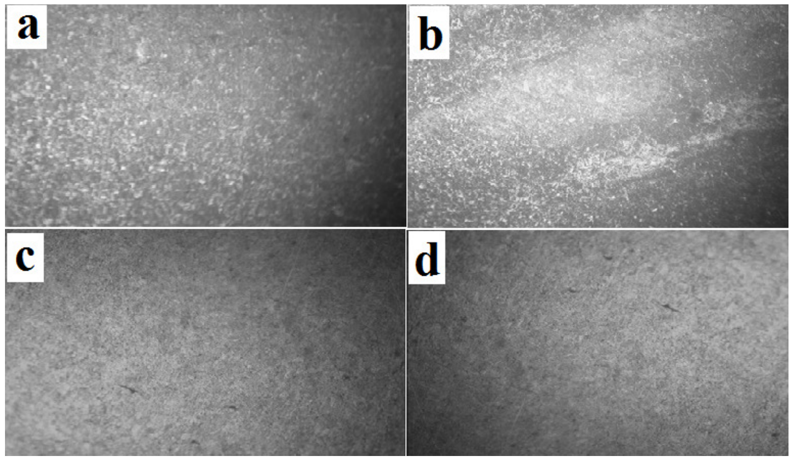

Plate 3: Micrograph of medium carbon steel sample (a) quenched in SAE40 engine oil (b) quenched in SAE40 and tempered at 350 ºC (c) quenched in sesame oil maintained at a temperature rise of 50ºC (d) quenched in sesame oil maintained at a temperature rise of 50 ºC and tempered at 350 ºC. Etched 2% Nital. (x200)

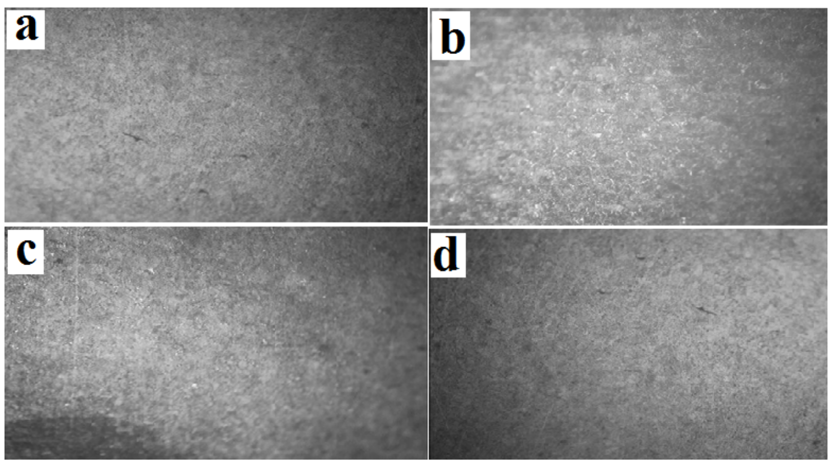

Plate 4: Micrograph of medium carbon steel sample (a) quenched in sesame oil maintained at a temperature rise of 65 ºC (b) quenched in sesame oil maintained at a temperature rise of 65 ºC and tempered at 350 ºC (c) quenched in sesame oil maintained at a temperature rise of 80 ºC (d) quenched in sesame oil maintained at a temperature rise of 80 ºC and tempered at 350 ºC. Etched 2% Nital. (x200)

4. CONCLUSION

The following conclusions were drawn from the results of this study.

- Medium carbon steel could be hardened when quenched in sesame oil.
- Based on the hardness profiles, impact strengths and microstructures obtained, sesame oil could be recommended to be used as quenching medium for medium carbon steels.
- Sesame oil maintained at a temperature rise of 50ºC gives a good combination of impact strength and hardness value. Thus, it is recommended to be used as a quenching medium for medium carbon steel.
- The quench severities of the quenching media used depicts the following descending order: water > 25 ºC > 50ºC > 65 ºC > 80 ºC > SAE40 oil.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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