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Effect of using vegetable oils as quenching media for pure commercial aluminium

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Abstract

This paper presents the effects of rate of heat extraction by groundnut, melon, palm kernel, shea butter and palm oils on the mechanical properties of various samples of pure commercial aluminium heat treated at 200°C, 250°C, 300°C and 350°C. Muffle furnace equipped with digital thermometer and thermocouple was used for the heat treatment. Tensile strength and hardness tests were carried out using Instron Universal Tester and Vickers hardness methods, respectively. Results obtained from the experiment were presented graphically. The results showed that palm kernel oil cools faster at 200°C and 250°C, while palm oil and shea butter oil quench faster at 300°C and 350°C, respectively. Palm kernel oil offers the highest elongation at 200°C, while at 350°C shea butter oil gave the best result. The best among the bio-quenching oils in providing good ductility is shea butter oil at 200°C, while at 300°C and 350°C groundnut oil give the best result. Highest hardness values were obtained from samples quenched in melon oil between 200°C-300°C. However, these values decreased with increased heating temperature probably due to density and viscosity variation with temperature rise. Similar observations were made on most of other samples quenched in other bio-quenching oils used in this experiment. This study shows that these locally available vegetable oils have promising potentials to serve as a possible replacement for non-biodegradable mineral oils in many applications.

Key words: Mineral oils, Vegetable/biodegrable oils, heat treatment, Quenching media, Aluminium, Mechanical Properties.

1. Introduction

Aluminium is widely used in electrical, chemical, food packaging, petrochemical and construction industries on account of its excellent corrosion resistance, high thermal and electrical conductivities and good formability (John, 2007). One major drawback to the use of pure commercial aluminium is its low strength. It has been established that mechanical properties of metals and alloys can be effectively improved through alloying and heat treatment (Krauss, 1990). However, the choice of effective quenching medium after heat treatment is very critical in ensuring the achievement of desired mechanical properties (Feng and Khan, 2008). The most common quenching medium for metals and alloys is mineral oil, and it possesses excellent cooling capacity (Grishin and Churyukin, 1986). However, but they are relatively expensive, toxic and non-biodegradable. There have been considerable studies focused on possibility of reducing or replacing mineral oil with less expensive water-based or polymer-based quenching media (Tolstousov and Bannykh, 1981). Cooling capacity of aqueous solutions of different substances was examined in order to determine their suitability as quenching media, and it was observed that aqueous 6-7 % monosulfite liquor (MSL) with 1 % phenol could serve as a possible replacement for mineral oils (Grishin and Churyukin, 1986). Protsidium et al. 1988) studied the quenching capacity of spent and regenerated minerals oils, and observed that addition of 0.3 % antioxidant lonol to regenerated oils improved their quenching capacity. The effectiveness of polymer based quenching medium, UZSP-1, was examined, and it was found that UZSP-1 of varying concentrations was effective as a quenching medium for only low-carbon ball-bearing steels (Goryushin, et al., 1991) but not well suitable for high-carbon ball-bearing steels. The present study was undertaken with the objective of replacing mineral oils with local biodegradable oils, which are more readily available, relatively cheaper and environmental friendly. These oils also have many other good natural properties, which made them attractive as lubricants and other applications (Xia and Larock, 2010). This was done by examining the mechanical properties of heat-treated pure commercial Al after quenching with several locally available biodegradable oils.

2. Experimental Procedure

Samples of pure commercial Al were obtained from a local aluminium smelting company based in Lagos. The as-received samples were cut into experimental work pieces prior to heat treatment. Heat treatment of the samples was performed at 200ºC, 250ºC, 300ºC and 350ºC, using a muffle furnace. After heat treatment, the samples were soaked for 60 minutes inside the furnace and then quickly transferred into a quenching bath equipped with a digital thermometer and thermocouple. The quenching bath was filled separately with 50 cm^3 of groundnut oil, melon oil, palm oil, palm kernel oil and shea butter oil as quenchants. The heat losses by the heat treated pure commercial aluminium were recorded by the digital thermocouple at various time intervals from 30 s to 300 s.

After quenching, approximately 10 mm long and 9 mm in diameter specimens were cut from the quenched samples. The specimens were ground and polished down to 4000-grit SiC paper and 1 µm diamond paste finish. After polishing, the specimens were cleaned ultrasonically in acetone, followed by alcohol and immediately dried before hardness and other mechanical tests.

2.1 Mechanical Test

2.1.1 Tensile Testing

Tensile test were carried out on the quenched specimens using Instron Universal Tester. Each of the specimens was loaded till fractured, and the fracture load for each sample was recorded as well as the diameter at the point of fracture and the final gauge length. The initial diameter and initial gauge length for each sample was noted before the application of the uniaxial load. The percentage elongation of each test sample was determined, as well as the tensile strength.

2.1.2 Hardness Test

Vickers hardness method was used for the determination of the hardness of the quenched samples. Each of the test specimens were prepared metallographically after different heating and quenching regimes, and then mounted on the anvil. The specimens were brought in contact with the pyramid indenter and allowed to rest for a dwell time. The hardness of the specimens were indicated by the penetration of the indenter on the test specimens, and displayed by the machine. Average values were recorded after repeating the test for each of the test specimens.

3.0 Results and Discussion

3.1 Cooling Rate

Figures 1-4 show the rate of heat extraction by each of the quenching medium namely; groundnut oil, melon oil, palm oil, palm kernel oil and shea butter oil, from the heat-treated pure aluminium samples after heating at 200°C, 250°C, 300°C and 350°C, respectively. Figure 1 shows that at 200°C, palm kernel oil extracted heat to an elevated temperature of 31.9°C at 160s, while groundnut oil, melon oil, shea butter oil and palm oil extracted heat to 31.6°C at 185s, 31.8°C at 245s, 31.8°C at 205s, and 31.6°C at 265s, respectively. This indicates that palm kernel oil extracted heat and reached equilibrium with the samples faster than the other oils at this heating temperature, while the least heat was extracted by palm oil at this heating temperature. However, the temperature of each of the quenchants remained constant after getting to their elevated temperature during the quenching process. As shown in Figure 2, the temperatures of both palm kernel and melon oils were raised to 32.5°C from 30.8°C at 175s and 250s respectively, during quenching of aluminium samples heated to 250°C, while those of groundnut, shea butter and palm oils were raised to 32.4°C at 165s, 32.2°C at 145s and 31.7°C at 280s, respectively. Thus, showing that palm kernel oil extracted faster than other oils, while palm oil extract least heat at 250°C. However, at 300°C, palm oil cools the heated aluminium faster, as more heat were extracted as shown in Figure 3. Similarly, at 350°C, shea butter oil removed heat and cooled the heated aluminium faster compared with other oils, as shown in Figure 4.

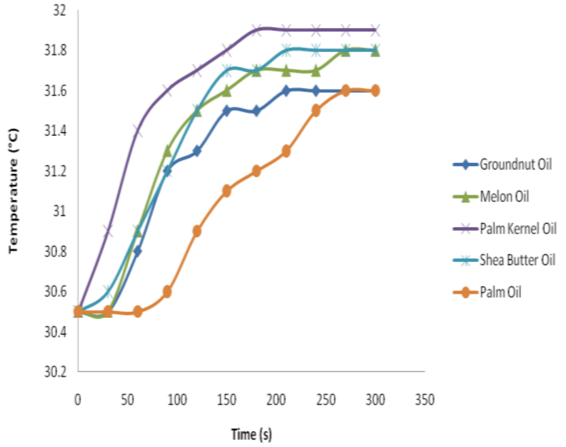

Figure 1. The rate of heat extraction of different bio-quenching oils at 200°C.

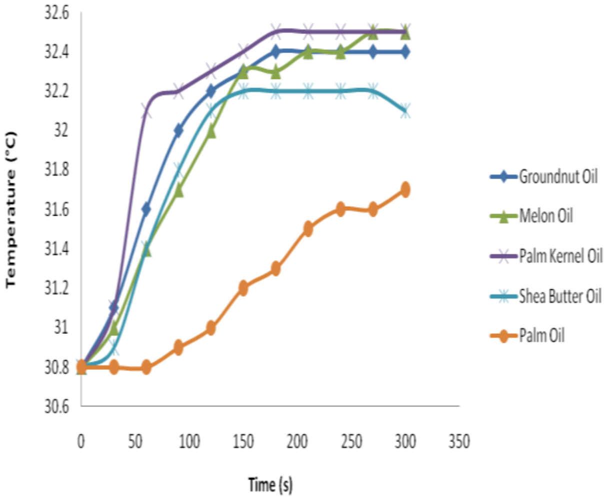

Figure 2. The rate of heat extraction of different bio-quenching oils at 250°C.

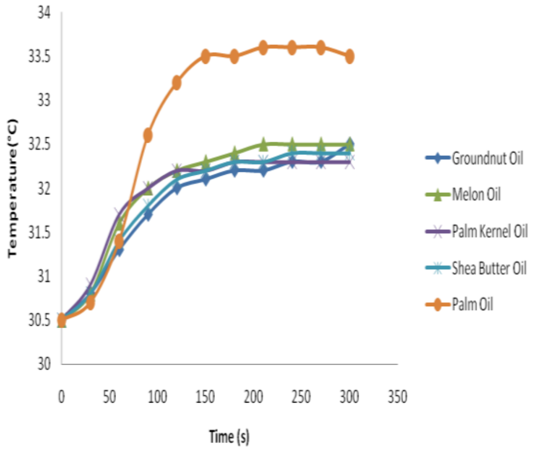

Figure 3: The rate of heat extraction of different bio-quenching oils at 300°C.

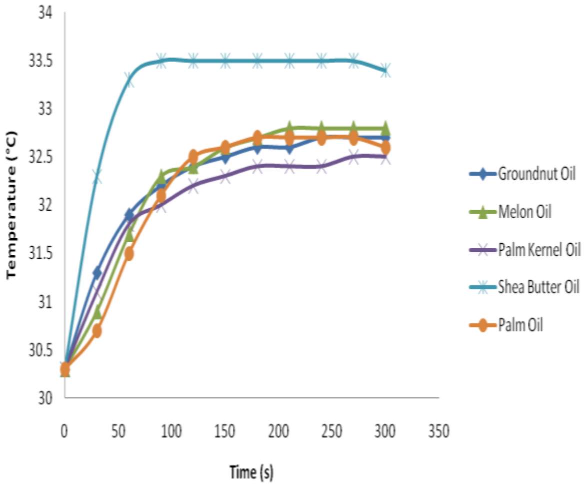

Figure 4: The rate of heat extraction of different bio-quenching oils at 350°C.

3.2 Mechanical Properties

3.2.1 Elongation of the quenched samples

Figure 5 shows the elongation of the investigated samples after quenching in various bio-quenching oils at different exposure temperatures. Comparing the value of elongation of the quenched samples at different heating temperatures with the as-received sample of 14.09 mm, it was evident that in most cases the elongation of the quenched samples increased with increasing heating temperature, as shown in Figure 5. This indicates possible improvement in the ductility of the quenched samples at higher heating temperatures. The least elongation value of 6.92 mm was obtained after quenching in groundnut oil at 250°C, while shea butter oil produces samples with highest ductility at 350°C. As shown in the Figure, all the samples heated at 200°C and 250°C and quenched in the various oils are brittle, except those quenched in shea butter oil at 200°C, which are slightly ductile. Samples heated at 300°C and quenched in groundnut and shea butter oils are also ductile, while those quenched in other oils are brittle. However, at 350°C, all the quenched samples exhibited ductility, with highest elongation of 22.25 mm was displayed by those quenched in shea butter oil.

3.2.2 Tensile strength of the quenched samples

The tensile strength of the as-received commercial Al sample is 60.04 MPa, which is higher than those obtained from the quenched samples at some of the heating temperatures (Figure 6). At 200°C, samples quenched quenched in groundnut and melon oils displayed lower tensile strenght compared with that of the as-received sample, while shea butter oil exhibited highest tensile strength value of 67.38 MPa. This value is higher than 65.62 MPa and 61.21MPa of palm kernel and palm oils, respectively. At 250°C, all the quenched samples gave lower tensile strength value compared with that of as-received sample, with sample quenched in groundnut oil showing lowest tensile strength value. However, at 300°C and 350°C, heat treated samples quenched in groundnut oil displayed highest tensile strength value, followed by those quenched in shea butter oil, with the least value obtained from samples quenched in melon oil at 300°C, and in palm oil at 350°C. Thus, quenching in groundnut oil after heating at 350°C, resulted in sample with best tensile strength.

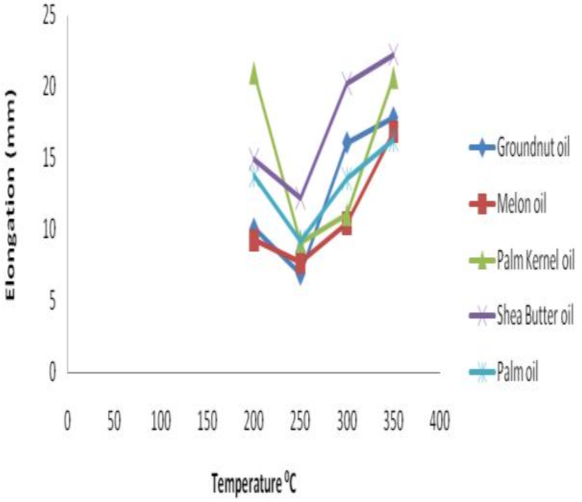

Figure 5. Elongation of Pure Commercial Aluminium in Different Bio-Quenching Oils at Different Heating Temperatures.

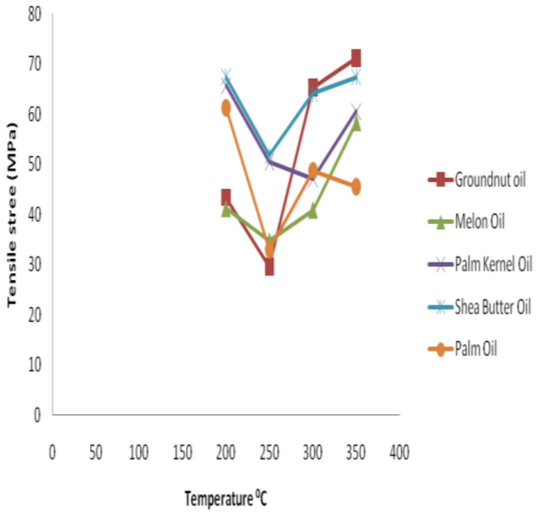

Figure 6. Tensile Strength of Pure Commercial Aluminium in Different Bio-Quenching Oils at Different Heating Temperatures.

3.2.3 Variation of the hardness of the quenched samples

The highest Vickers hardness value of the samples quenched in the various quenching oils were obtained at 200°C, with peak value from the sample quenched in melon oil, as shown in Figure 7. However, at 250°C, the hardness values of all the quenched samples decreased, with those quenched in melon, palm kernel and shea butter oils became lower than that of the as-received sample, which is 30.9 Hv. The hardness values of all the samples increased at

300°C above that of the as-received, but later decreased when quenched after heating up to 350°C, except that of the sample quenched in melon oil. This indicates that the best heating temperature to obtain highest hardness value will be 200°C, with melon oil as the quenching medium.

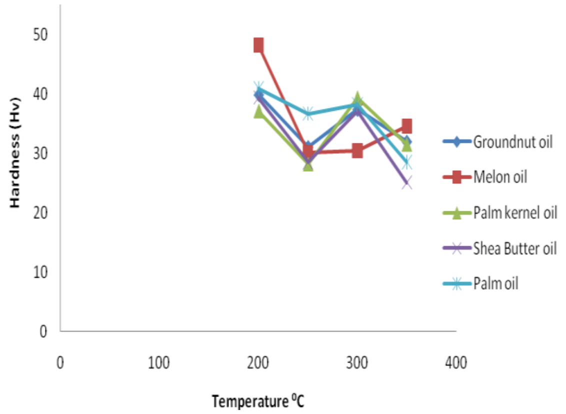

Figure 7. Vickers Hardness of Pure Commercial Aluminium in Different Bio-Quenching Oils at Different Heating Temperatures.

4. Conclusions

We established the possibility of using some of the bio-quenching oils for quenching pure commercial aluminium, in order to improve its mechanical properties. Quenching with Shea butter oil was found to produce pure commercial aluminium with best ductility after heating at 350°C, while groundnut oil can be used for quenching to improve the tensile strength at 350°C. The best bio-quenching oil in providing a high hardness value for the aluminium sample after quenching at 200°C is melon oil. However, use of any of the bio-quenching oils to quench the aluminium samples heating up to 250°C was found to be detrimental to both the hardness and tensile strength properties of the samples.

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