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Mechanical Properties of Heat-treated Medium Carbon Steel in Renewable and Biodegradable Oil

Oluwagbenga T, Johnson[a], Enoch N. Ogunmuyiwa[b]*, Albert U. Ude[c], Norman Gwangwava[c], Richard Addo-Tenkorang[d]

[a]*Department of Mining and Metallurgical Engineering, University of Namibia, Ongwediva Campus, Namibia.*
[b]*Department of Chemical, Materials & Metallurgical Engineering, Botswana International University of Science and Technology, Palapye. Botswana.*
[c]*Department of Mecahnical, Energy & Industrial Engineering, Botswana International University of Science and Technology, Palapye. Botswana.*
[d]*Department of Materials & Production, Aalborg University, Fibigerstræde 16, 9220 Aalborg. Denmark.*

Abstract

The heat treatment of steels under controlled conditions alters their physical and mechanical properties, enabling them to meet the desired engineering applications. In this study, the suitability of a Namibian local oil (marula oil) as an alternative quenchant to SAE40 engine oil (Standard quenchant – a synthetic oil derived from natural or crude oil) for industrial heat treatment of medium carbon steels was investigated. SAE40 engine oil served as the control. The mechanical properties (tensile strength, yield strength, percentage elongation and hardness) of the treated and untreated samples were investigated at the temperatures of 850ºC, 900ºC, 950ºC and 1000ºC. The untreated sample had the highest amount of elongation (40%), while the sample quenched in marula oil had the highest hardness (24.33HRD) and tensile strength (530.32 N/mm^2) values compared with both the untreated and the SAE40 engine oil quenched samples. Hence, marula oil showed high potential as an alternative quenchant to petroleum based SAE40 engine oil for quenching medium carbon steels, without cracking or distortion.

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Keywords: Medium carbon steels; Heat treatment; Marula oil; Mechanical properties.

*Corresponding Author
Email: ogunmuyiwae@biust.ac.bw

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1. Introduction

Medium carbon steels are widely used for many industrial applications and manufacturing on account of their low cost and easy fabrication [1]. Most steel parts such as gears, precision gauges, bearings, tools and dies produced today are heat treated before being put into service. Parts are heat treated to enhance particular properties, such as hardness, toughness and corrosion resistance, and to improve uniformity of properties. The exact heat treatment applied depends on both the type of alloy and the intended service conditions [2]. The main types of heat treatments often used to modify the microstructure and mechanical properties of engineering materials particularly steels are annealing, normalizing, quench hardening and tempering [3].

Quench hardening is one of the most important processes of heat treatment that can greatly improve the performance of steel. It is also one of the major causes of rejected components and production losses due to cracks and distortion in the material. Achieving desired mechanical properties and minimizing the possibility of occurrence of quenching cracks are the key indicators of successful hardening process. Quenching to develop martensitic structures without warping or cracking depends on the hardenability of the steel part, the quenching temperature and the severity of quenching media [4]. Over the years, water, brine and mineral based oils are the most commonly used quenchant in the industries to harden steel because of their availability. However, brine shows the highest severity on the quenched part, while oil is considerably less drastic [4]. Although water quenching is faster and less costly than oil quenching, the degree of distortion that accompanies water quenching can be very high, therefore oil quenching which is less severe than water quenching is generally preferred [5]. Nevertheless, because of environmental concerns and growing regulations over contamination and pollution, associated with petroleum based oils (SAE40 engine oil), it is of continuing interest to identify a safer, renewable and biodegradable alternative quenchant to petroleum based oil. Vegetable oils are currently one of the most commonly identified environmentally friendly renewable, biodegradable and less toxic alternatives [6]. The technical challenge of quenching is to select the quenching medium and process that will minimize the various stresses that develop within the part to reduce cracking and distortion, while at the same time providing heat transfer rates sufficient to yield the desired as-quenched properties.

This study, therefore, intends to explore the suitability of marula oil (locally sourced oil) from the kernels of marula fruit as a quenching medium for carbon steels and compare the tensile properties of the steels quenched in marula oil and SAE40 engine oil.

2. Experimental Procedure

Medium carbon steels were sourced at Nic Engineering in Ongwediva, Namibia. Tensile samples of 6 mm diameter and 30 mm gauge length were machined on the lathe. The samples were charged into the muffle furnace in pairs and austenitized at temperatures of 850°C, 900°C, 950°C and 1000°C. The samples were then soaked at these temperatures for 45 and 90 minutes. After soaking, the samples were then separately quenched in marula oil and SAE40 engine oil. Table I summarizes the experimental parameters used for the heat treatment of the medium carbon steels. Tensile test was carried out at ambient temperature on the Gunt Hamburg Universal Testing Machine following the ASTM E18 standard procedures. 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 were noted before the application of the uniaxial load. The elongation percentage and reduction of each sample were determined and the ultimate tensile strength and yield strength were obtained from the data generated. Load-elongation data were recorded and converted into stress-strain graphs. Yield strength (Y), ultimate (tensile) strength (U), and ductility (% elongation) were determined from these graphs, while reported values were average of three readings.

Table I: Summary of experimental parameters

Factor	Levels	Descriptions
Temperature (° C)	4	850; 900; 950; 1000

Soaking time (mins)	2	45, 90
Quenchant	2	SAE 40 engine oil, marula oil
Replications	3	
Total number of experiments	**48**	

Additionally, some cylindrical samples were heat treated, ground and polished for hardness measurements. Rockwell hardness tester (Qness model Q150) with Rockwell D scale was used to measure the hardness of the treated and untreated medium carbon steel samples. Figure 1 shows the outline of the experimental procedures used for this study.

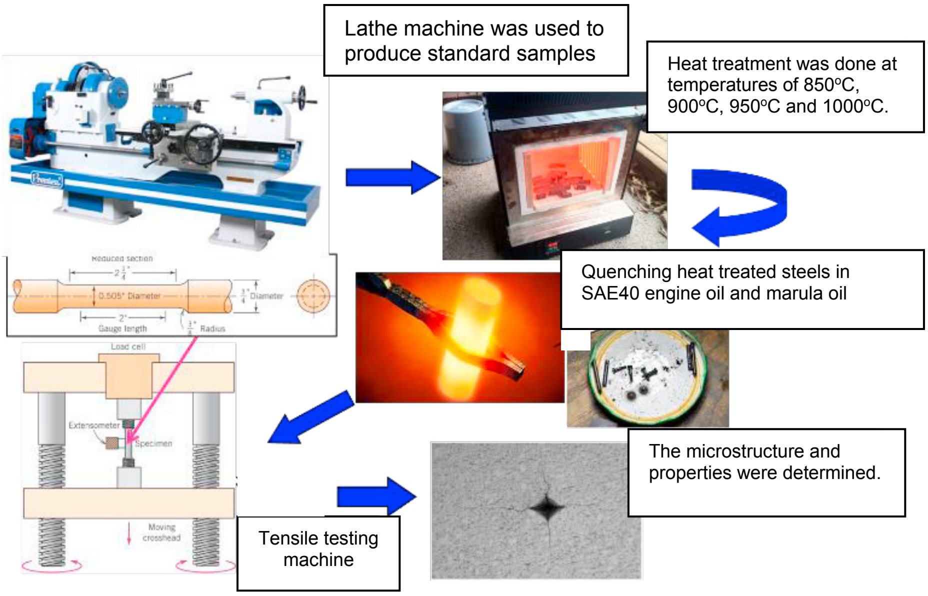

Fig. 1. Outline of the experimental procedures used for this study.

3. Results

The tensile strength of the untreated specimen was 391.86 N/mm^2 and the hardness value of 13.9 HRD, the elongation 40% and the yield strength 207.87 N/mm^2. Table II summarizes the mechanical properties of the samples quenched in SAE40 engine oil. It was observed that there was an increase in the hardness of the quenched samples compared to the untreated sample. This was expected due to the formation of martensitic structure in the samples quenched in SAE40 engine oil and supported by studies done by Odusote et. al [7].

Table II: Mechanical properties of samples quenched in SAE40 engine oil

Temp. (°C)	Soaking Time (mins)	Hardness Rockwell (HRD)	Yield Strength (N/mm^2)	Tensile strength (N/mm^2)	% Elongation
850	45	16.27	245.05	379.43	24
850	90	19.28	264.14	407.58	32
900	45	17.67	225.49	483.53	32
900	90	18.83	253.29	458.44	35
950	45	18.88	238.15	468.42	33
950	90	18.05	246.17	449.28	32

1000	45	18.43	271.94	483.87	32
1000	90	22.11	272.96	457.08	31

Table III summarizes the mechanical properties of the samples quenched in marula oil. The values of the hardness, the yield strength and the tensile strength were higher than those obtained for the untreated medium carbon steel. These results show that the marula oil acted as a quenchant for the medium carbon steel.

Table III: Mechanical properties of samples quenched in marula oil

Temp. (°C)	Soaking Time (mins)	Hardness Rockwell (HRD)	Yield Strength (N/mm^2)	Tensile strength (N/mm^2)	% Elongation
850	45	16.10	281.11	440.47	15
850	90	17.61	287.66	434.36	21
900	45	20.38	282.95	502.18	28
900	90	20.37	266.86	479.47	30
950	45	20.12	244.48	494.38	26
950	90	23.29	288.22	413.68	28
1000	45	21.59	287.54	530.32	27
1000	90	24.33	290.93	482.85	33

Fig. 2 shows a representative stress-elongation graphs of untreated medium carbon steel and samples treated in marula oil and SAE40 engine oil respestively.

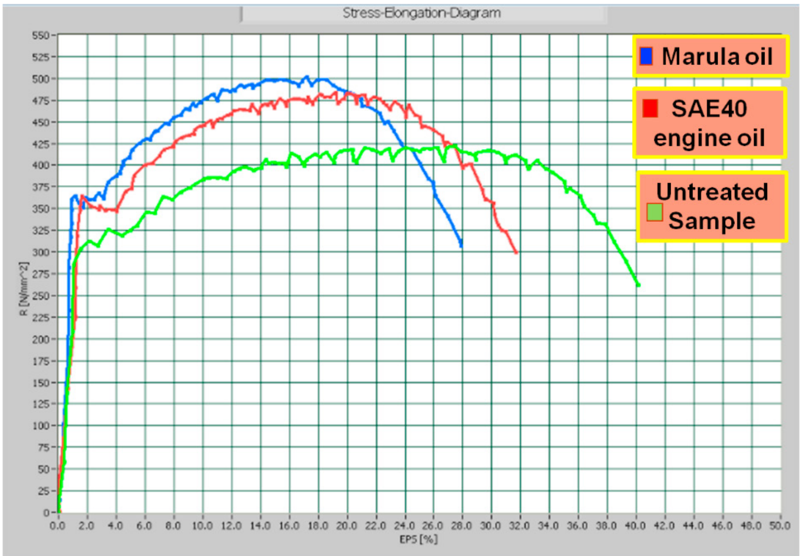

Fig 2. Stress-elongation curves of marula oil, SAE40 engine oil and untreated specimens at 900°C for 45 minutes.

4. Discussion

The variability in tensile strength, yield strength and hardness of treated and untreated medium carbon steel are shown in Figure 3 to 5 respectively. The mechanical properties (the tensile strength, the yield strength, the hardness and the percentage elongation) of the marula oil samples were found to be 440.47 N/mm^2, 281.11 N/mm^2, 16.1 HRD and 15 % at the temperature of 850^{o}C. The increase in tensile strength and hardness as compared to the untreated and the SAE40 engine oil treated sample was due to proper austenizing temperature above 900^{o}C and higher cooling rate, which resulted in decrease in elongation, which was lower than those obtained for untreated and SAE40 engine oil samples due to pearlite matrix structure obtained during the quenching of medium carbon steel.

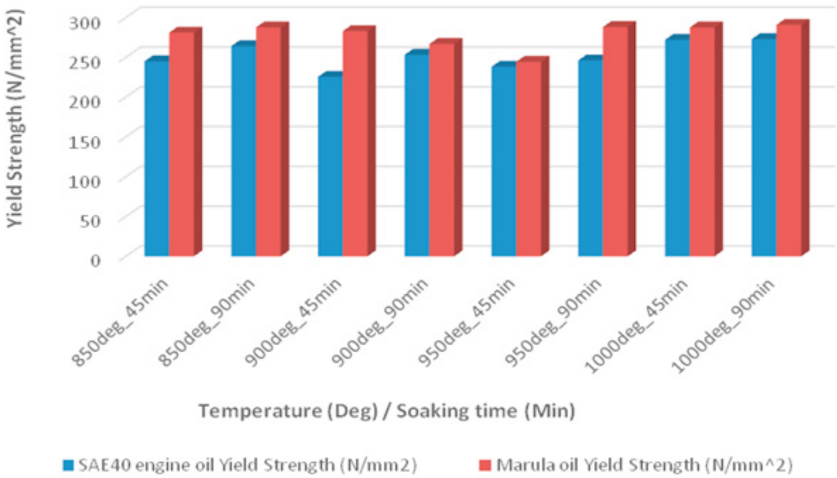

Fig. 3: Yield strengths of samples quenched in SAE40 engine and marula oil

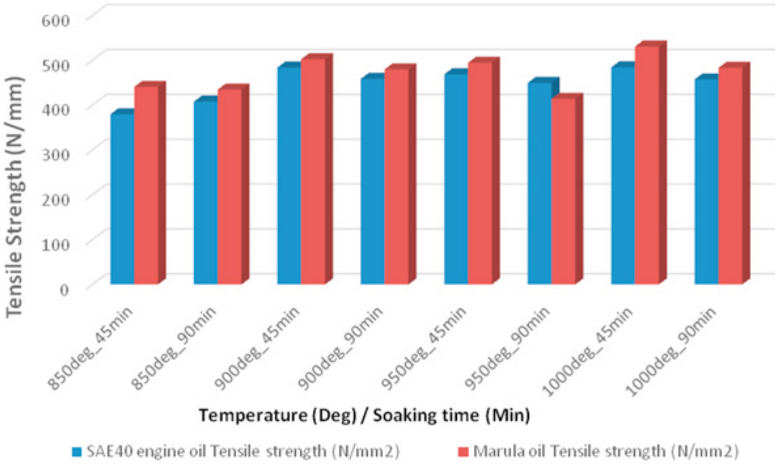

Fig. 4: Tensile strengths of samples quenched in SAE40 engine and marula oil

The mechanical properties obtained at quenching from 1000^{o}C in marula oil showed that the tensile strength, yield strength, hardness and percentage elongation were 530.32 N/mm^2, 290.93 N/mm^2, 24.33 HRD and 27.00%, respectively. Comparing the mechanical properties of marula oil samples quenched from 1000^{o}C with those of SAE40 sample, it was found that at this temperature the best results for the tensile strength, the yield strength and the hardness were achieved although percentage elongation still decreased which can be associated to the lack of graphitization of the precipitated carbides that resulted in the low formation of ferrite at quenching temperature of 1000^{o}C. This showed that quenching in marula oil at the temperature of 1000^{o}C improved the degree of the martensite formation and decreased its resistance of plastic deformation. However, the test results showed that quenching in SAE40 engine oil gave an elongation superior to all of those that were produced in the marula oil samples studied.

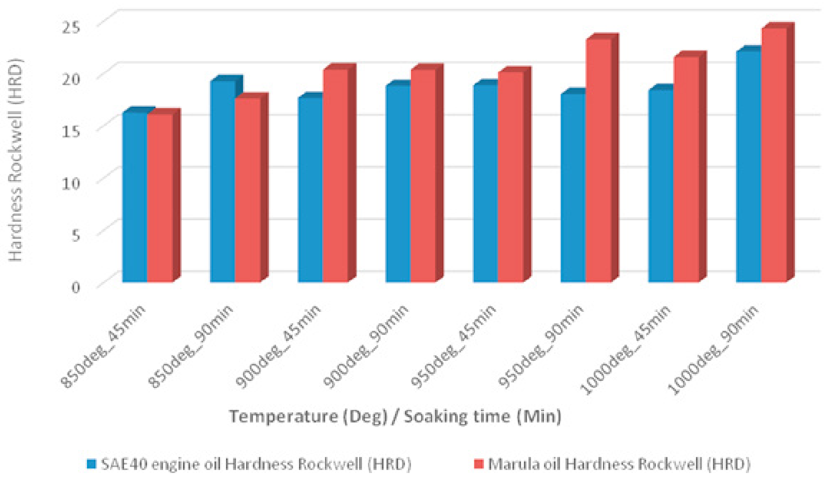

Fig. 5: Hardness rockwell (HRD) of samples quenched in SAE40 engine and marula oil.

The elongation in the untreated specimen remained superior and above all the quenched samples and this is due to the little martensitic structure that is found in this untreated steel but whose ultimate tensile strength is very low as compared to any of the other samples quenched in either SAE40 engine oil or marula oil.

Conclusion

From the results of this investigation, the following conclusions were made:

- Quenching in marula oil led to improve tensile strength, yield strength and hardness of medium carbon steel increased with plastic deformation while ductility decreased due to strain hardening effect.
- From the results obtained from this study it is safe to say marula oil would do wonders in the heat treatment industry as it would produce great results in its use for quenching medium carbon steel to enhance its strength and hardness for purposes of high performance components such as those already manufactured from this steel.

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