HARDENING CHARACTERISTICS OF MEDIUM CARBON STEEL USING AGITATED CASSAVA LIQUID EXTRACT AS QUENCHANT

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ABSTRACT
The possibility of using cassava liquid extracts agitated condition as quenching media for plain carbon steel has been investigated. Agitated liquid extract from cassava were used in fresh and fermented condition for hardening 0.35%C plain carbon steel. The mechanical properties of the quenched samples and the cooling rate curves were used to determine the quench severity. The microstructures of the quenched samples were also examined. Steel samples quenched in agitated cassava liquid extract showed an improvement in their mechanical properties. The cooling rate curve shows that the fermented cassava liquid extract has a higher cooling rate compared to oil but lower than water. The microstructure of the samples quenched in the cassava liquid extract revealed the formation of martensite. Hence the cassava liquid extracts can be used as quenchant in hardening process steels.
Keywords: Hardening characteristics, Medium Carbon Steel, Cassava Liquid Extract and Quenchant.

1.0 INTRODUCTION

Quenching is a crucial process within the broader field of heat treatment. It constitutes an important manufacturing technology in nearly every market sector. These include: railway, automotive, aerospace and others. Quenching is used to induce hardness in steel so that it may perform as required in service [1]. It involves heating steel to some temperature above the upper critical temperature, in order to convert it partially or completely to austenite, holding it long enough to ensure the desire austenization, after which cooling is carried out at a rate equal to or faster than the critical cooling rate[2]. The two primary functions of a liquid quenchant is to facilitate the hardening of steel by controlling heat transfer during quenching and also to minimize the formation of undesirable thermal and transformation gradients which may lead to increase in distortion and cracking[3].

The commonly used quenchants are water, oil, brine, and synthetic solutions. Water though abundant and low cost has the drawback of inducing crack or dimensional changes on the quenched component due to its high cooling rate and oil has the problem of not inducing enough hardness. Polymer quenchant, though it can provide severity between those of water and oil, has the problem of varying concentration during the quenching process and it is also more expensive. Brine produces more quenching severity than water; it also has a problem of corrosive attack on the components and the equipment used for the quenching[4-5].

The technical challenge of quenching that has since been known is the choice of a quenching medium that will yield the desired as-quenched properties, such as hardness with minimum induced distortion. There is need therefore for the development of a quenching medium with good economics like water, but having less severity of quench and yet producing appreciable hardening. This work is aimed at investigating the suitability of using cassava liquid extract in agitated condition as a quenching medium for hardening steels.

A rough estimate of about 10million tonnes of cassava is processed into garri annually in Nigeria alone[6]. With the ongoing aggressive and positive campaign by the Nigerian government to popularize the cultivation of cassava by Nigerian farmers, and also the introduction of improved cassava varieties by the International Institute of Tropical Agriculture, IITA, Ibadan, Nigeria there may be further increase in the country's annual cassava production. During the traditional processing of cassava starch storage root for garri production in Africa, the fermented liquid juice squeezed off from the mesh, which is normally discarded as waste, and do constitute environmental or health hazard. Therefore, there is need to take advantage of this abundance and availability of cassava, sustain the development, and stop wastage of the extract by harnessing its economic value.

2.0 EXPERIMENTAL PROCEDURE

2.1 Materials.

Materials used in this study are; medium carbon steel from Bamford International, Jos, Sweet Cassava extract, water and SAE 40 engine oil as quenching media. The chemical composition of the steel is shown in Table 1.

Table 1: Chemical composition of the medium carbon steel[9].

%C	%Si	%S	%P	%Mn
0.35	0.95	0.05	0.026	0.6

2.2 Equipment

The equipment used in this research includes: Lathe machine, Heat-treatment Furnace, Hand grinding deck of abrasive papers and rotary wheel for polishing; Metallurgical Microscope, Hounsfield Tensile testing machine; Izod impact test; Digital hardness machine; Tanks, k-type thermocouple and Arrow 600 variable speed impeller type agitator unit.

2.3 Method

2.3.1 Hardening process

Tensile test samples of 5mm gauge diameter and 27mm in length, 11.47mm in diameter and 71mm length for the impact strength determination, machined from the medium carbon steel was used The steel samples were initially normalized, followed by austenitizing at 860^{o}C for 15 minutes and then quenching in both agitated fresh and fermented cassava juice, Water and SAE 40 engine oil respectively[7]. Mechanical property tests were carried out on the as-quenched samples to determine the severity of the cassava juice as quenchant and compared with water and oil. The cooling rates of all the selected quenching media were determined. Metallographic analysis was carried out for each as-quenched sample in the selected media.

2.3.2 Determination of Cooling Curve.

A separate sample from the steel was machined to 10mm diameter and 30mm of length for the purpose of plotting the cooling curve. A k-type thermocouple was fitted in a hole drilled at the geometric centre of the test piece. The test piece was heated in the furnace to 850^{o}C and quenched in the agitated fresh cassava extract, agitated fermented cassava extract with impeller at a speed of 200 RPM, water and SAE 40 engine oil quenchants respectively[9]. The temperature and the corresponding time of the cooling test sample in each quenching medium were recorded and the cooling curves were plotted for all the quenching media.

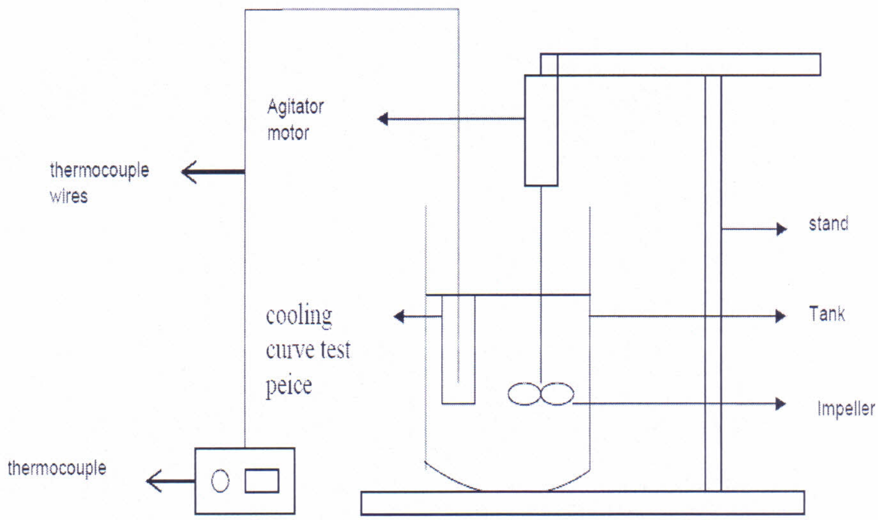


Fig. 1 The Schematic Diagram of the Quench Tank set up.

2.3.3 Metallographic Examination

The as-quenched specimens in the various selected quenching media were mounted on Bakelite powder before grinding. Grinding of the samples was carried out manually on a water lubricated grinding machine using silicon carbide abrasive paper of grades 180, 240, 400 and 600 grit sizes. The ground samples were then polished to completely remove the fine scratches and make the surface smoother. Polishing was carried out on a rotating disc covered with polishing cloth impregnated with 1μ alumina solution. The disc rotated at a speed of 100-400rpm. The sample is rotated slightly against the surface of the impregnated polishing disc so that it skids over the paste without touching the fibers of the polishing cloth. The final polishing was carried out with 0.5 micron alumina polishing solution until the surface of the samples became scratch free and mirror like. The specimens were then etched with 0.5%HF solution. After etching, the samples were washed in running water and alcohol and then dried in hot air. The etched samples were then placed on the sample stage of a metallurgical microscope and the microstructures obtained were recorded with the aid of the in built camera.

2.3.4 Tensile Strength Determination

The tensile test samples were mounted, one after the other on the tensometer as recommended. A small load was initially applied to set the specimen in the grips and then the load was increased until failure occurred. The load extension relationship was plotted simultaneously. The breaking and the maximum tensile loads of the quenched samples were obtained. The ultimate tensile strength (UTS) was determined from the relationship given below: [8]

$$UTS = \frac{P\max}{A_0} \quad \text{-- (1)}$$

Where, P_{max} = maximum load, A_o = original cross sectional area of the test sample.

2.3.5 Hardness Value Determination.

The hardness values of the samples were determined using a digital Vickers Hardness (HVN) testing machine due to its high accuracy [1]. The samples were mounted in bakelite, for better handling and proper flatness. The surfaces were thoroughly polished before samples were tested. The various hardness values were recorded in HVN.

2.3.6 Impact Strength Determination.

The notched impact samples quenched in the selected media were subjected to impact test from the weighted pendulum load on the Izod type impact testing machine. Sample of 110.47 x 12mm with a 2mm deep notch of angle of 45^o was used [1].

3.0 Results and Discussion

The results of cooling curves and cooling rate of the quenching media investigated are shown in Figures 2 and 3.

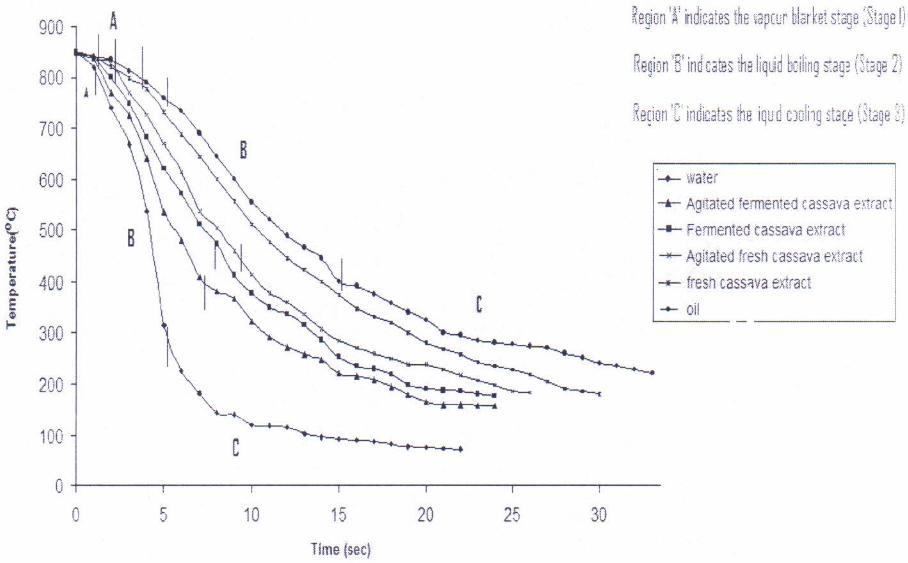


Figure 2: The Cooling Curves of the Quenching Media Investigated

From the cooling curves shown in Figure 2, water produced a very small vapour blanket stage (region A) and showed a more prolonged boiling stage (region B) as compared to the fermented cassava liquid extract. However, the fermented cassava liquid extract showed a more stable boiling stage (region B) compared to the fresh cassava extract. This stage is responsible for extraction of a large amount of the heat. Both the fresh and the fermented cassava liquid extracts gave a longer liquid boiling stage compared to SAE40 engine oil.

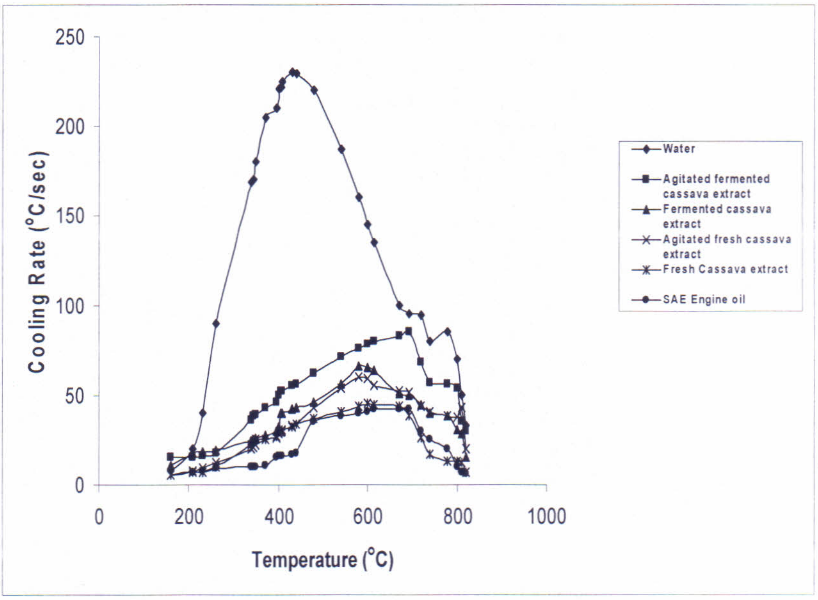
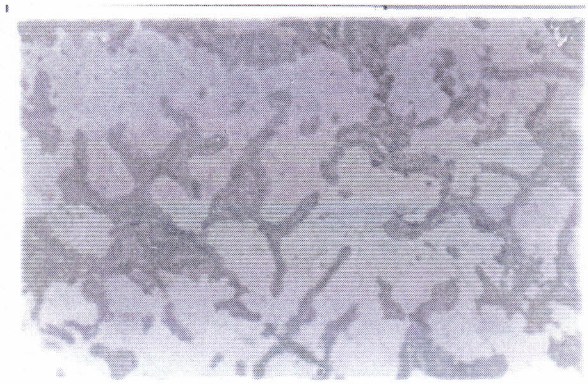


Figure 3: Graph showing the cooling rate of the quenching media

From the cooling rate curve in Figure 3, it was shown that water gave the highest cooling rate of 230°C/sec at 430°C. The fermented cassava liquid extract showed a higher cooling rate than the fresh cassava liquid extracts in the un-agitated condition, with the highest cooling rate of 60°C/Sec at 578 °C and the fresh cassava liquid extract produced its maximum cooling rate of 45 °C /sec at 600 °C. The SAE40 engine oil has the lowest cooling rate among all the quenchants investigated, with the maximum cooling rate of 42°C/sec at 615°C.

The agitation of the cassava liquid extracts increased the cooling rates of the quenchants. This conforms with the fact that agitation enhances the cooling ability of a medium [9]. The maximum cooling rate of the fresh cassava liquid extracts increased to 58°C/Sec at 600 °C and that of the fermented cassava liquid extract also increased to 85°C/Sec at 578°C. This could be attributed to the fact that agitation increases the uniformity of the quenching media and the rate at which the heat is extracted from the samples and dissipated to the atmosphere. For the fresh cassava liquid extract, the agitation caused the continuous breakage of the gelatinous starchy coating formed around the samples during the quenching.

The microstructure of the as-cast medium carbon steel revealed the presence of pearlite and ferrite structure (see Micrograph 1). The microstructure of the quenched samples in water, the structure consists of high proportion of martensite with retain austenite. (see Micrograph 2). Microstructure of steel sample quenched in oil, revealed martensite structure and retained austenite. (See Micrograph 3).

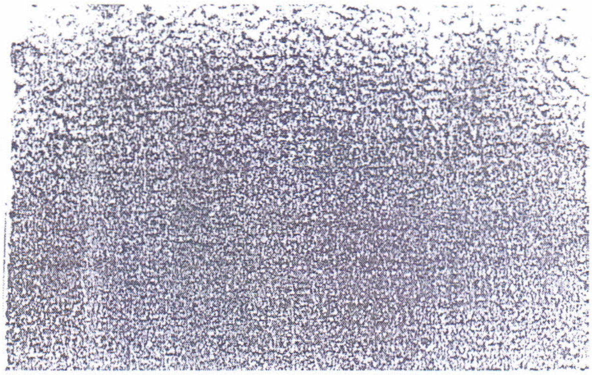


Micrograph 1: The structure of As-cast medium carbon steels showing ferrite (light) and pearlite matrix (dark). (X150)

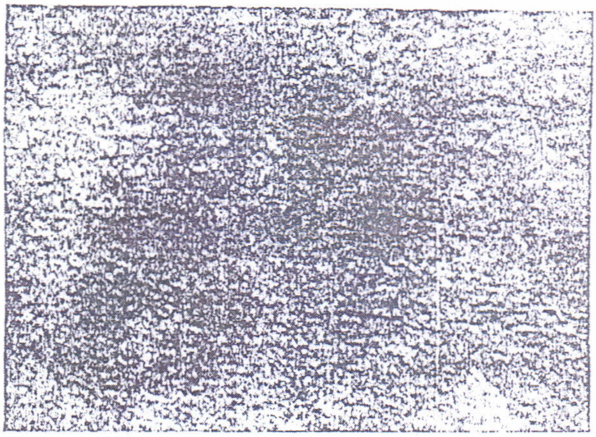
Micrograph 2: The structure of medium carbon steel quenched in water. Consisting of full martensite structure. (X150)

Micrograph 3: The structure of medium carbon steel quenched in oil. This reveals Structure of martensite and retained austenite. (X150)

The microstructure of sample quenched in the agitated fresh and fermented cassava extracts reveal the formation of martensite and more amount of austenite has been transformed to martensite and that there is less retained austenite(see micrographs 4-5). All microstructures developed are in line with the earlier observation of [1, 2, 9-10].



Micrograph 4: Plain carbon steel quenched in agitated fresh cassava extract. A structure of martensite (light) and some retained austenite (dark). (X150)



Micrograph 5: Plain carbon steel quenched in agitated fermented cassava extract. A structure of martensite formed. (X150)

From Figure 4, the tensile strength value of the medium carbon steel samples increased after quenching in all the media. The quenched steel samples in the agitated cassava liquid extracts have a lower tensile strength as compared to water. This is attributable to the fact that water has a higher cooling rate than the cassava liquid extract (see Figure 3).

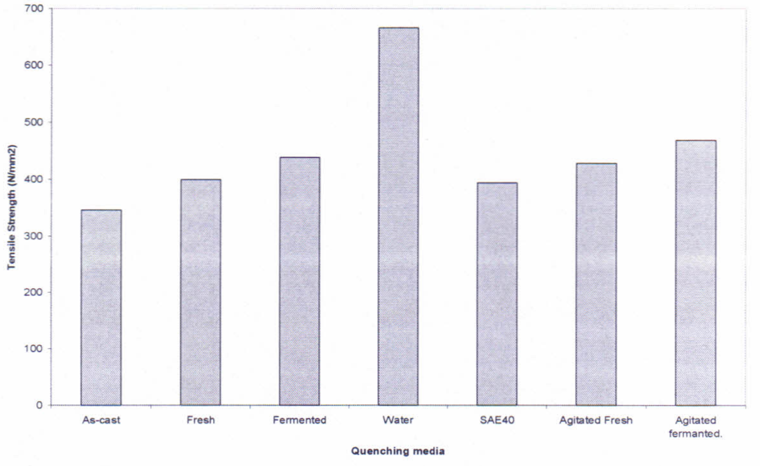


Figure 4: Bar Chart of the tensile strength of the medium carbon steel quenched in media

Sample quenched in agitated fresh cassava liquid extract gave lower tensile strength values than the sample quenched in the agitated fermented cassava liquid extract (Figures 4). This could be as a result of the presence of starch suspension in the cassava liquid extract, which formed gelatinous coating around the surface of the test piece when it was immersed in the fresh cassava liquid quenching medium; hence this impaired rapid extraction of the heat from the sample. The suspension has decomposed and was decanted off after settling in the fermented medium. The reason could also be attributed to the fact that the fermented cassava liquid extract may have more moisture content than the fresh cassava extract.

The tensile strength values of the samples quenched in both agitated fresh and fermented cassava liquid extract are higher than that of SAE40 engine oil, e.g. Tensile strengths of 345.83, 428.03, 468.79, 665.23 and 393.69N/mm^2 were obtained for the as-cast condition, agitated fresh and fermented cassava liquid extract, water and SAE 40 engine oil respectively. The cooling rate curve and the tensile strength values of the as - quenched samples for the plain carbon steel obtain showed that the fermented cassava extract has a better cooling capability than SAE40 engine oil.

The hardness values of the quenched steel samples showed a similar trend with the tensile strength values obtained (see Figure 5). For all the media, the hardness values of the quenched steels increased after quenching. The hardness values of the as-cast condition, agitated fresh and fermented cassava liquid extract, water and SAE 40 engine oil quenched are 143.9, 163.9, 182, 253.4 and 155.8HVN respectively (see Figure 5). Water quenched produced the highest hardness value and SAE 40 engine oil produced the least after quenching. The hardness and tensile strength of the samples quenched in the agitated cassava liquid extracts showed that agitation improved the severity of quench of the fresh and fermented cassava liquid extracts. The high hardness values and strength obtained in these results can be attributed to the various cooling rate and microstructures obtained.

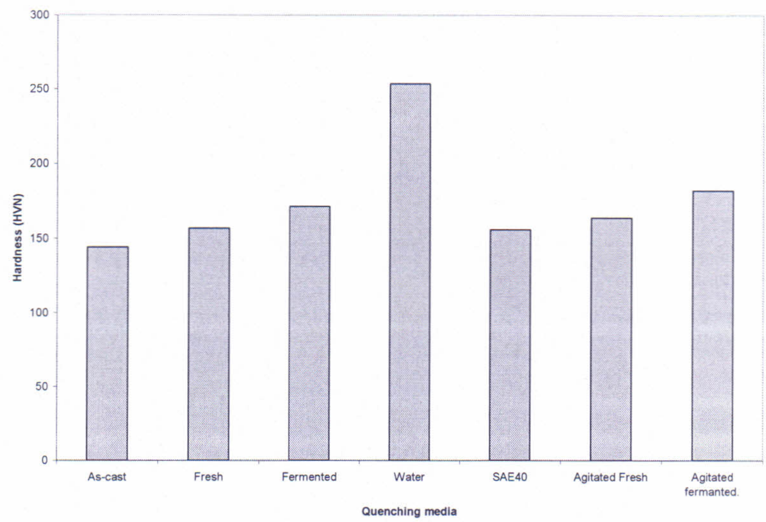


Figure 5: Bar Chart of the hardness values of the medium carbon steel quenched in media.

The hardening process by quenching in all the liquid media reduced the impact energy (see Figure 6). The as-received steel sample gave the highest impact strength value and water gave the least impact strength. The impact strength of the steel samples is 29.8, 20.2, 15, 5.0 and 23.1Joule for as-cast condition, agitated fresh and fermented Cassava liquid extract, water and SAE 40 engine oil respectively. The decreased in the impart energy value as the hardness increases are in agreement with the earlier research of [1, 9-10], after quenching steel in various media.

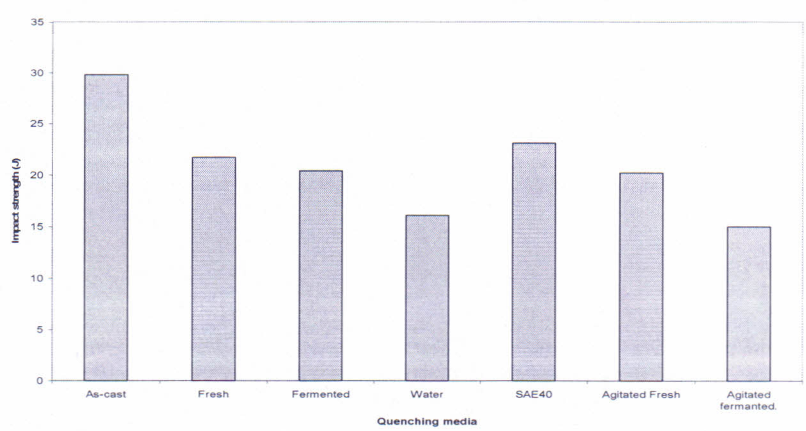


Figure 6: Bar Chart of Impact energy of the medium carbon steels quenched in media.

It has been shown from these results that the higher the cooling rate of the quenching medium, the higher the hardness and tensile strength imparted on the steels. The impact energy value of the metal reduces as the hardness increases. This agrees with the trend of the result obtained by[9, 10], after quenching steel in various media.

4.0 Conclusions

From the results obtained in this study the following conclusions can be drawn;

1. The mechanical properties of the quenched medium carbon steel samples and the cooling rate curves showed that the cooling rate of the cassava liquid extract is less than that of water but higher than that of SAE40 engine oil. Hence, cassava liquid extract can be used where cooling severity less than water but greater than SAE 40 engine oil is required for hardening of plain steel.
2. Fermented Cassava liquid extract in the agitated condition produced a higher cooling rate and enhanced mechanical properties than that of fresh cassava extract.
3. The hitherto wasted cassava juice can be utilized as quenching medium, as a replacement for water and oil in hardening process for plain carbon steels.

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