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# STUDY OF MAIZE STARCH SOLUTION AS QUENCHING MEDIA FOR 0.62%C HIGH CARBON STEEL

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**Abstract**: A study of maize starch as a quenching medium for high carbon steel was carried out. Samples of high carbon steel were spheroidized annealed and then machined prior to the Hardening process. Maize starch of three different viscosities was prepared by adding varying amounts of water; such that the ratios of maize starch to water (m-w) were 1:39, 1:27.6 and 1:17.2. The samples were normalized and then austenitized at 800$^{o}$C, soaked for 40 minutes and then quenched in water, engine oil and maize starch solutions (in the ratio mentioned above). Cooling curves of all the quenching media used were developed. Mechanical properties (hardness and impact strength) of the test samples were measured. The test results obtained, sample quenched in the maize starch solution (m-w [1:39]) showed highest hardness and lowest impact strength values. Microstructures of the quenched samples were analyzed using optical microscopy (OM) and scanning electron microscopy (SEM). In all the tests samples, martensite structure was observed. It was also observed that maize starch solutions with mixture ratio m-w (1:27.6) and (1:17.18) had quenching severity lower than that of engine oil. Maize starch solution ms-w (1:39) gives cooling rate close to that of engine oil.
**Keywords**: martensite, quenching, maize starch, engine oil, viscosity, cooling rate, highcarbon steel

## 1. INTRODUCTION

Quenching of steels involves the process of heating a component to austenitizing temperature and holding at this temperature for a specified time followed by rapid cooling in a suitable quenching medium. Quenching prevents the formation of ferrite or pearlite and allows the formation of bainite or martensite [1]. The effectiveness of quenching depends on the cooling characteristics of the quenching medium and the ability of steel to harden. Achieving desired hardness, strength or toughness and minimizing the possibility of occurrence of quenching cracks and warping due to evolution of residual stresses are the principal indicators of successful hardening process [2, 3]. In an attempt to solve problems of distortion, warping and high residual stresses associated with water quenching, mineral oils have been found to be the most suitable quenching media. However, mineral oils are costly and can contribute to air and water pollution. Hence, it is of continued interest to develop a quenchant that is of low cost, environmentally friendly, but effective in inducing the required hardness without the problems of distortion and residual stresses. The most useful methods for assessing the cooling characteristicsof a quenching medium are severity of quenching medium and cooling curve analysis. The severity of quenching or cooling power of a quenching medium is estimated by measuring the thermal response of a heated probe brought in contact with it. It is a measure of the ability of a quenchant to extract heat from a sample during quenching and depends on the viscosity, temperature, contamination and agitation [4]. For starchy liquid, heat transfer coefficient has inverse relationship with the liquid viscosity [5]. The present study, therefore,focuses on the use of maize starch solutions as quenching media for high carbon steel

## 2.MATERIALS AND METHODS

### Methods

High carbon steel samples used in the research were sourced from truck's leaf spring. The average chemical composition of the steel (Table 1) was determined using an atomic absorption spectrometer (AAS) at Dana Steel Ltd, Katsina.

Maize starch of different viscosities was prepared by adding varying amount of water; such that the ratio of starch to water were 1:39, 1:27.6, and 1:17.2.The viscosity of the maize starch solution [m-w (1:27.6)] was equal to that of engine oil. On the other hand, prepared maize starch solutions [m-w (1:39) and m-w (1:17.2)] had viscosities lower and higher than that of engine oil respectively. Viscometer was utilized to measure the respective viscosities. Engine oil served as control.
Normalizing was carried for all the samples.This was achieved by heating the samples to austenitizing temperature of 815°C holding at that temperature for one hour and then cooled in air.
They were later austenitized at 810°C, soaked for 40 minutes and then quenching in all the prepared starch solutions, water and SAE 40 engine oil. Mechanical property tests (Hardness and impact strength) were conducted on the as-quenched samples to evaluate the quenching severity of the maize starch solutions and compared with that of water and engine oil. Metallographic analyses using OM and SEM were carried out. Cooling curves for all the prepared starch solutions, water and engine oil were plotted using high carbon steel probe.

### Hardness Test

Rockwell Hardness tester was used for the hardness measurement. The hardness testsamples were prepared to standard dimensions (15±5mm). The test method adopted was ASTM E18. The samples were made with flat and smooth surface. A diamond indenter was utilized to indent the surface of the test specimen by the application of static load of 150kgf. Following the initial indentation on the test pieces, the displayed hardness value was taken and recorded.The procedure was repeated at two different points on the test piece and the average was recorded.

### Impact Test

The impact test was carried out on the high carbon steel specimens subjected to the under listed heat treatment conditions. A 120ft.lb capacity Avery Denison Izod machine with a striking velocity of 5.24m/sec. was used to carry out all the impact tests. The samples were machined to a 100mmx10mmx10mm, a notched about2mm deep was made at the center. The sample was fixed on vertical position and the hammer struck thesample on the notched face. The energy absorbed after fracture is measured and it showed the impact energy of the material. Impact strength was calculated from the data obtained.

### Metallographic examination

Metallographic examination was carried out on the samples that have been subjected to various heat treatment conditions. Standard techniques of sample preparation for the microstructure observation were adopted. The microstructure examination was carried out with anoptical microscope and the microstructures obtained were captured. Scanning electron microscope (SEM) was used as well. SEM images were snapped.

### Determination of Cooling Curve

Cooling curves were generated under non-agitated conditions according to ASTMD6200-01. The test method is based on the 12.5 mm diameter x 60 mm length of high carbon steel sample. A K-type thermocouple was fitted in a hole drilled in thecenter of the test piece. The test piece was heated in the furnace to 800°C, held for 40 minutes, and then quenched in prepared maize starch (1:17.2) solution. On cooling, falling temperatures and the corresponding times were recorded. The data obtained served to plot the cooling curve for the medium. The same method was repeated for the other maize starch solutions [(1:27.6) and (1:39)], water and SAE engine oil.

## 3. RESULTS AND DISCUSSIONS

The average chemical composition of the steel used is given in Table 1.

Table 1: Chemical composition of the as-received high carbon steel

| Element | C | Si | Mn | P | Cr | Mo | Ni | Sn | S |
|---|---|---|---|---|---|---|---|---|---|
| Content (%) | 0.62 | 0.254 | 0.753 | 0.0132 | 0.108 | 0.0278 | 0.130 | 0.0054 | 0.0172 |
| Element | As | Ca | B | Pb | Sb | Al | Co | Cu | Fe |
| Content (%) | 0.0233 | 0.0016 | 0.0010 | 0.0109 | 0.0130 | 0.0103 | 0.0153 | 0.196 | balance |

### Hardness

Figure 1 illustrated hardness results for samples quenched in different media. From the chart, it is clear that a decrease in viscosity of the maize starch caused an increase in hardness value. Sample quenched in maize starch solution (1:39) developed the highest hardness value followed by sample quenched in m-w (1:27.6). Maize starch solution (1:17.2) produced sample with the least hardness value. However, samples from engine oil and maize starch solution (1:39) have hardness of almost the same value. On the other hand, a peak hardness value was achieved by the water quenched sample. A mild dip in hardness was noted when the as-received sample was normalized. This is similar to the report of Dodo et al., [6].

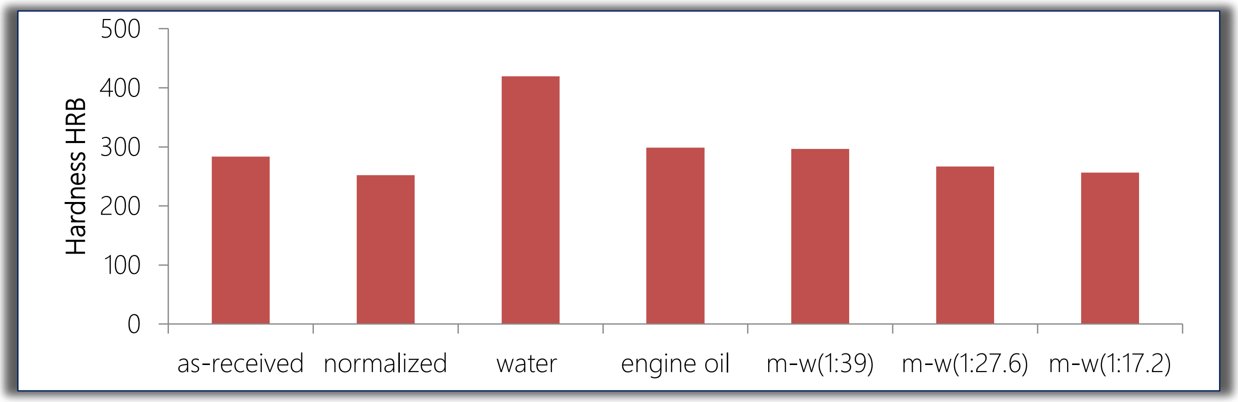


Figure 1: Hardness profile of the high carbon steel samples quenched in different quenching media

## Impact Strength

Figure 2 depicted the impact strength for samples quenched in different media. The least impact energy absorbed before fracture (44.6kJ/m) was issued by the water quenched sample. Also, impact strength of (0.71 kJ/m) was obtained for oil quenched specimen while the. Highest impact strength was exhibited by the sample quenched in maize starch solution of high viscosity [m-w (1:17.2)]. Samples quenched in less viscous maize starch solution [m-w (1:39)] absorbed lower impact energy compared to that quenched in m-w (1:27.6).This trend could be due to the low cooling rate shown by the m-w (1:17.2) (Figure 8). However, in comparison to the impact strength of the oil quenched sample, water quenched sample showed lower impact strength. This is similar to the results of Joseph et al. [7]

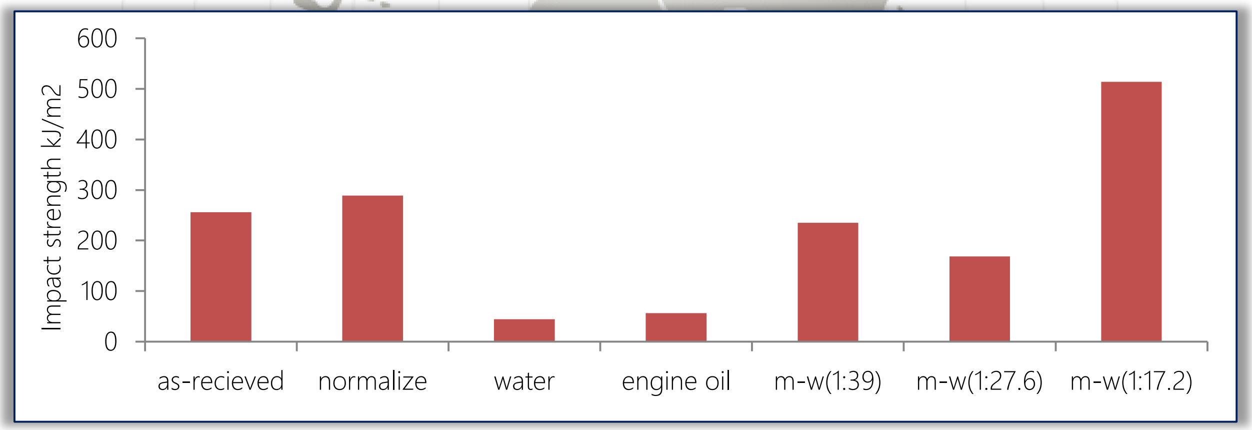


Figure 2: Profile of Impact Strength of the high carbon steel samples quenched in different Quenching media

## Microstructures

The microstructures of the as-received, normalized and quenched samples are given inFigure3 to 6. The structure of the as-received sample (Figure 3a) consists of fine pearlite. The normalized structure is illustrated in Figure 3b; the structure revealed proeutectoid ferrite in pearlite matrix. The microstructures of the samples quenched in water and engine oil are represented in Figure 4. Water quenched sample showed high proportions of martensite (as evident in its hardness value). Oil quenched sample showed martensite proportion lower than that of water quenched sample. The microstructures are associated with retained austenite. This is in line with observations of Vivek et al.[8]. The microstructures of the samples quenched in maize starch solutions (1:39, 1:27.6 and 1:17.2) disclosed martensite and retained austenite in varying proportions. The microstructures of samples quenched in maize starch solutions (1:39 and 1:27.6) showed finer martensitic structure compared to that quenched in maize starch solution (1:17.2).This might be related to the higher quenching severity displayed by maize starch solutions (1:39 and 1:27.6).

SEM images (Figure 7), showed that the martensite grains got finer with decrease in viscosity of maize starch solution. The reason could be assigned for the fact that the cooling rate decreased as the viscosity was increased. This trend explains clearly the high hardness obtained for samples quenched in a less viscous solution. The observations are in line with what is obtained in the literature [6]

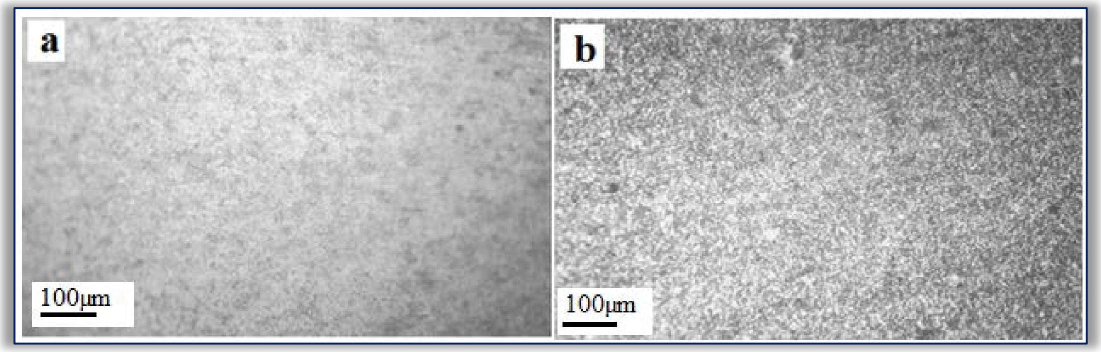


Figure 3. Optical micrograph of high carbon steel. (a) as-received; the structure consistsof fine pearlite; (b) after normalizing; showing regions of ferrite (white) and pearlite (black) structure. 2% Nital etch. (x100)100µm

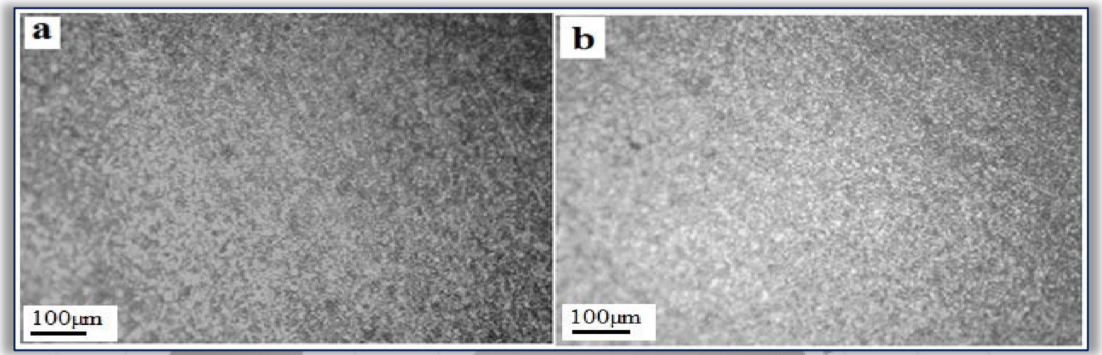


Figure 4: Optical micrograph of the high carbon steel quenched (a) in water; a structure of martensite (dark) and retained austenite (light-colored areas), (b) in SAE 40 Engine oil; a structure of martensite (dark) and retained austenite (light color areas). 2% Nital etch.(x100)

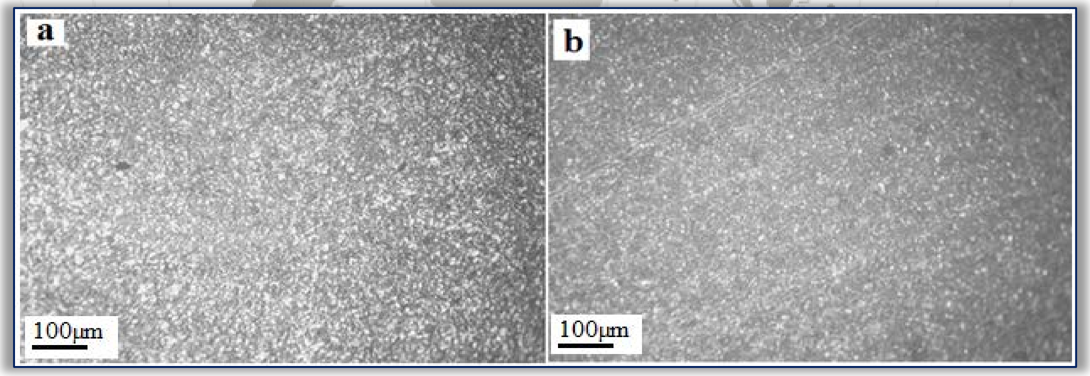


Figure 5: Optical micrograph of high carbon steel quenched (a) in maize starch solution (1:17.2); a structure of martensite (dark) and retained austenite (light-colored areas), (b) in maize starch solution (1:27.6); a structure of martensite (dark) and retained austenite (light-colored areas). 2% Nital etched. (x100)

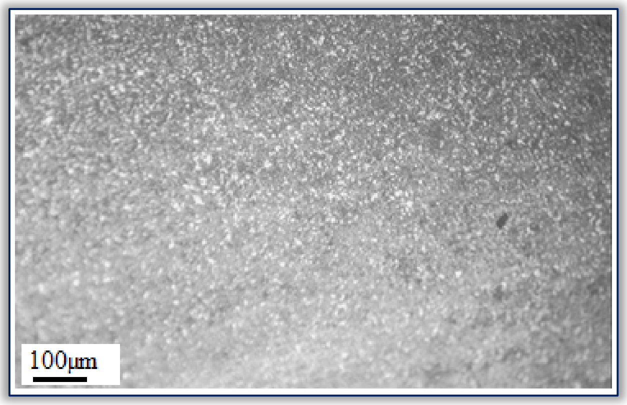


Figure 6: Optical micrograph of the high carbon steel quenched in maize starch solution (1:39); a structure of martensite (dark) and retained austenite (light-colored areas). 2% Nital etched. (x100)

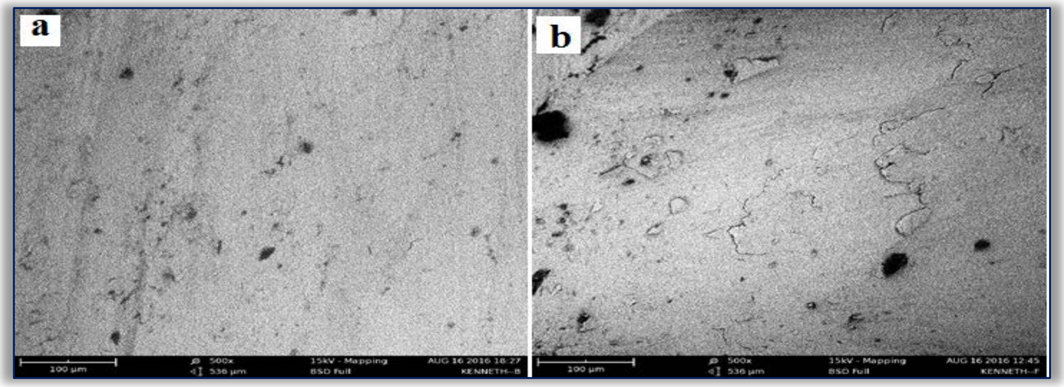


Figure 7. SEM micrograph of high carbon steel quenched (a) in maize starch m-w (1:17.2) (b) in maize starch m-w (1:39); the structure of martensite (dark) and retained austenite (light-colored areas).

**Cooling curve**

Figure 8 showed the cooling curves of the various quenching media used. The assumption used to arrive at it was that the temperature of the medium remained constant throughout the cooling operation. Water proved to have the shortest stage I (vapour blanket stage); which is expected to last for less than a second, whereas stage II is estimated to last for 9 seconds. This agrees with what is obtained in the literature [9]. SAE 40 engine oil displayed a prolonged vapor blanket and boiling stage enabling it to have a lower cooling rate than water. This is consistent with what was established by William [10] and Komatsu et al.,[11].However, m-w (1:39) depicted similar cooling curve to that of water. A more prolonged nucleate boiling stage was observed with maize starch solutions m-w (1:27.6) and (1:17.2).This confirmed the intermediate quenching severity of the two solutions.

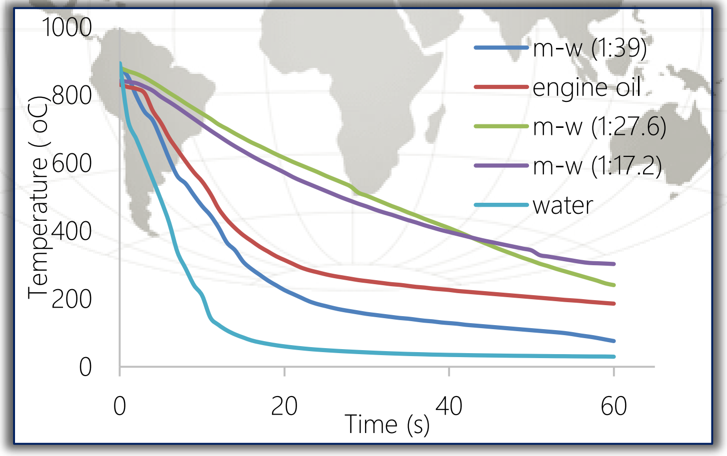


Figure 8: Cooling curves of the quenching media used using high carbon steel probe

## 4. CONCLUSIONS

A study of maize starch as a quenching medium in the hardening process of high carbon steel has carried out. Based on the results obtained, high carbon steel could be successfully hardened when quenched in maize starch solutions. It appeared from the cooling curves that viscosity plays a key role in the heat extraction ability of the maize starch. Thus, the lower the viscosity the higher the heat extraction ability. It was also noticed that the sample quenched in m-w (1:39) developed hardness value similar to that obtained using engine oil. Therefore, maize starch diluted with water in the ratio (1:39) could act as an alternative quenching medium to engine oil.

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