# EFFECTS OF USING VEGETABLE OILS AS AUSTEMPERING QUENCHANTS ON THE MICROSTRUCTE AND MECHANICAL PROPERTIES OF LOW ALLOYED ST STEEL

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## ABSTRACT

The effect of using local vegetable oils as quenching media in the austempring process of low alloyed cast steel was investigated. Cottonseed, groundnut and shear butter oils were used as quenching media instead of traditional molten salt bath for austempering process. Specimens were austenitized at $950^0$C and austempered in the selected hot vegetable oils at 250°C for 1-5hrs. Optical microscopy was used to study the morphology of structures formed at different austempering time. Mechanical properties were determined by testing standard tensile, hardness and impact specimens. The results showed clear disparity in mechanical properties between these oils. Samples austempered in shear butter oil recorded the highest tensile strength value of 954N/mm$^2$ and impact strength value of 36J at 5hrs. The lowest tensile strength and impact strength values were reported for the austempered samples in hot groundnut oil as 444N/mm$^2$ and 16J respectively at 1hr.However, austempered sample in hot groundnut oil recorded the highest hardness value of 298HV at 1hr. The results showed that austempered samples were able to form a mixture of bainite, martensite and retained austenite at different time.

**Keywords:** Austempering, Bainite, Low alloyed cast steel, tensile strength, Microstructure, Vegetable Oil.

## 1.0 INTRODUCTION

Low alloyed cast steel with medium carbon content of (C=0.492) is normally used in a quenched and tempered condition (ASM 1979). Low alloyed cast steels are generally used for extreme heat, corrosion and abrasion conditions (Higgins, 1995). The low production cost, high corrosion resistance, heat resistance and low alloy content makes it a widely used material for many industrial applications, like chemical industry. However, in many applications a suitable combination of strength and toughness is needed. Because of limited ductility of the quenched and tempered cast steel, the improvement of ductility without reduction of strength is necessary to increase the application field. This can be achieved by different methods such as modification of chemical composition, utilizing and removing of brittle phases and austempering heat treatment. It was shown by some researchers that the replacement of tempered martensite with bainite in some steels increases ductility while retaining the same level of strength (Tomita et al, 1990). Different morphologies of bainite in steel that form at different austempering time and temperature lead to different mechanical properties.

Tomita et al (1990) used a continuous cooling process to obtain various banitic structures in AISI 4130 steel. They showed that the best combination of mechanical properties of steel can be achieved when nodular bainite form.

In this research work, three (3) different types of vegetable oils were used as quenchants for austempering of steel instead of traditional molten salt. This is because molten salt bath heat treating is very hazardous, especially during cleaning and in maintaining the bath at elevated temperature. Therefore, a similar heat treatment but using different safer quenchants, vegetable oils were investigated to provide similar properties. There are benefits of using vegetable oils which includes: they are biodegradable; can be manufactured from plant source and produce less harmful by-product (Keith, 2004). These oils are available in Nigeria and are cheaper to use than molten salt bath.

## 2.0 EXPERIMENTATION

Low alloyed cast steel with chemical composition given in table 1. was used in this work. The steel was produced at the National Metallurgical Development Centre, Jos, Nigeria. The tensile and impact samples were prepared from rod of 30mm based on ASTM, E8 standard. Vegetable oils were individually pre-heated in a stove to achieved austempering temperature of 250°C. Specimens were austenitized at 950°C for 1hr in a controlled atmosphere furnace. The specimens were isothermally austempered at 250°C for different period of time (1-5hrs). The selection of heat treatment temperature was based on the calculated martensite start (Ms) temperature as explained in the Metals Handbook,(ASM, 1964).

**Table 1**: Chemical composition of steel used

| C | Si | Cr | P | S | Cu | Ni | Ti | Al | Mo | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.492 | 0.07 | 0.26 | 0.137 | 0.018 | 0.139 | 0.043 | 0.005 | 0.006 | 0.014 | Bal |

Tensile test was carried out using a 20KN Hounsfield Tensiometer at a constant extention rate of 3.8mm/sec. Charpy test on notched specimens were carried out with a 300J Charpy test machine at room temperature. The hardness was measured using a Vickers Hensold Wetlar Machine. Optical microscopy was used to characterize the etched microstructures. Specimens were ground, polished and etched using Nital solution prior to metallography test. The structure obtained was photographically recorded using an optical microscope with build in camera (see Micrographs 1-9).

**Table 2: Properties of local oils used**

| Types of Oil | Properties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Free fatty acid % | Saponi-fication value | Iodine value | Viscosity at 38°C mm²/sec | Flash point °C | Specific heat, J/kg k | Phosphor content mg/kg |
| Groundnut | 0.24 | 230.30 | 114.53 | 22.5 | 271 | 0.3 | 0.067 |
| Cottonseed | 0.32 | 227.84 | 121.35 | 33.5 | 264 | 0.3 | 0.105 |
| Shear butter | 0.09 | 177.7 | 68.7 | 25.7 | 281 | 0.3 | 0.07 |

**SOURCE:** Ajala (1982) and Keith (2004)

## 3.0 RESULTS AND DISCUSSION

### 3.1 Results

Table 3 shows the values of mechanical properties of austempered low alloyed cast steel. Figures 1-3 showed the graphs of austempering time versus tensile strength, hardness and impact strength of austempered low alloyed cast steel. Micrographs 1-9 are the microstructures of austempered low alloyed cast steel samples in groundnut, cottonseed and shear butter oils.

### 3.2 Discussion

Figure 1 shows the effect of austempering time on the tensile strength of low alloyed cast steel samples austempered at 250°C in various vegetable oils. Using load-extension curve, the values of tensile properties of this material were determined and listed in Table 3.It shows that the tensile strength and yield strength increases with increased austempering time in both oils. As observed, austempered specimene in hot shear butter oil recorded the highest tensile strength and yield strength values of 954N/mm² and 696N/mm² at 5hrs respectively. While the lowest tensile strength value of 444N/mm² was observed for sample austempered in groundnut oil at 1hr. The variation of tensile properties can be explained by means of specimen's microstructure. The higher tensile strength values obtained between 4-5hrs is attributed to the formation of bainite structure which is fine and more homogeneous. The oils properties (iodine value, viscosity, free fatty acid, etc) also contributed in the disparity of mechanical properties.

Table 3 shows the hardness values of the austempered low alloyed cast steel samples in various vegetable oils. The hardness decreases with increased of austempering time. This is attributed to the increase in the formation of bainite structure. The higher hardness values obtained in using both oils at 1hr may be due to the insufficient time for the austempering reaction to taken place and this transformed austenite to martensite and retained austenite after cooling to room temperature. Figure 2 shows the hardness versus austempering time. It shows that austempered sample in hot groundnut oil obtains the maximum hardness value of 298HV, w austempered sample in hot cottonseed oil recorded the lowest value of 279HV at 1hr.

The values of impact strength of austempered samples in oils under investigation are shown in Table 3 observed, the impact strength values increased with increased of austempering time. Sample austempered in shear butter oil had the highest impact strength value of 36J, while austempered sample in hot groundnu recorded the least value of 25J at 5hrs. At 1hr, the impact strength value of austempered specimen groundnut, cottonseed and shear butter oils were 16J, 24J and 22J respectively. The presence of carbide form elements such as Cr and Mo contributed to lower impact strength values of this material. The formatior carbides during bainitic transformation can be detrimental to toughness of the material (Higgins, 1995). T confirms the reason of low percentage elongation and impact strength values obtained from this work (see Ta 3).

**Table 3:** Mechanical properties of low alloyed cast steel samples austenitized at 950°C and austempered at 250°C

| Medium | Austempering time (Hrs) | Hardness (HV) | Tensile Strength ($N/mm^2$) | Proof Stress ($N/mm^2$) | % Elongation (%) | % reduction in area (%) | I E |
|---|---|---|---|---|---|---|---|
| Groundnut Oil | 1 | 298 | 444 | 260 | 0.0 | 0.0 | 16 |
| | 2 | 264 | 556 | 354 | 0.0 | 0.0 | 21 |
| | 3 | 242 | 648 | 436 | 0.15 | 0.1 | 22 |
| | 4 | 167 | 688 | 495 | 0.2 | 0.1 | 23 |
| | 5 | 161 | 893 | 652 | 0.2 | 0.15 | 25 |
| Cotton seed Oil | 1 | 279 | 597 | 352 | 0.1 | 0.1 | 24 |
| | 2 | 271 | 735 | 472 | 0.1 | 0.2 | 24 |
| | 3 | 265 | 791 | 525 | 0.2 | 0.2 | 26 |
| | 4 | 260 | 821 | 547 | 0.2 | 0.2 | 26 |
| | 5 | 241 | 852 | 568 | 0.3 | 0.2 | 27 |
| Shear Butter Oil | 1 | 287 | 954 | 696 | 0.1 | 0.1 | 22 |
| | 2 | 282 | 699 | 489 | 0.2 | 0.1 | 22 |
| | 3 | 246 | 658 | 448 | 0.2 | 0.2 | 25 |
| | 4 | 221 | 643 | 436 | 0.2 | 0.2 | 25 |
| | 5 | 213 | 516 | 312 | 0.4 | 0.2 | 36 |

Micrographs 1-9 are the microstructures formed from low alloyed cast steel using vegetable oils as quenchin media at different time (1-5hrs). Micrographs 1-4 are the morphology of bainite plus martensite and retaine austenite formed from austempered samples in hot cottonseed oil at 1-5hrs. Micrograph 1 shows th morphology of bainite plus martensite, and retained austenite while micrographs 2 and 3 revealed bainiti structure and martensite . Micrographs5-6 are the morphology of austempered specimens in hot shear butter oil Micrograph 5 shows a mixture of martensite and bainite structure while micrograph 6 reveals network of bainite and martensite. Micrographs 7-9 are the morphology of austempered samples in hot groundnut oil . Micrograpl 7 shows Widmanstatten plates while micrograph 8 shows network of martensite. Micrograph 9 reveals mixture of mrtensite and bainite. The result of the microstructural study shows that austempering time and differen types of quenchants have a major effect on the bainite formation.

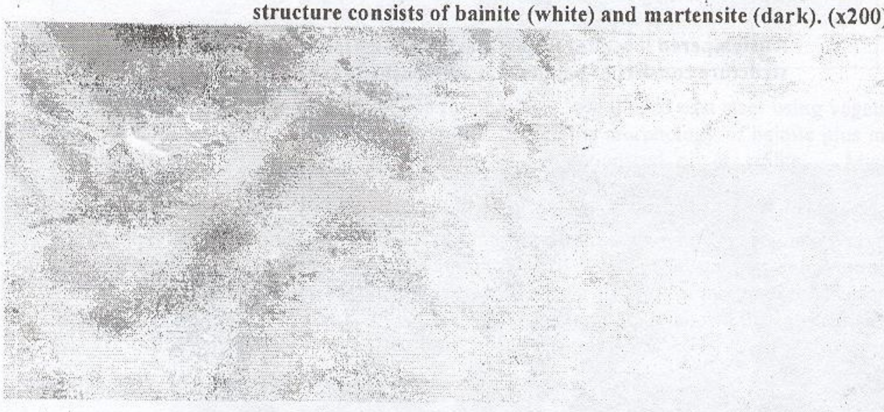
Micrograph 1: Austempered low alloyed cast steel in hot cotton seed oil at 250°C for 1hr. The structure shows on set of bainite (white) and martensite (dark). (x200)

*Micrograph 2: Austempered low alloyed cast steel in hot cotton seed oil at 250°C for 3hrs. The structure consists of bainite and martensite (dark) structure. (x200)*

rograph 3: Austempered low alloyed cast steel in hot cotton seed oil at 250°C for 4hrs. The structure shows more bainite . (x200)

Micrograph 4: Austempered low alloyed cast steel in hot cotton seed oil at 250°C for 5hrs. The structure consists of massive bainite and martensite structure. (x200)

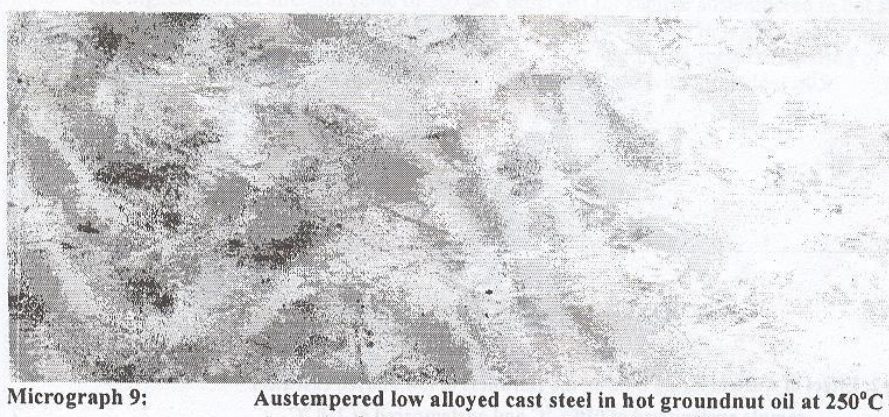
Micrograph 5: Austempered low alloyed cast steel in hot shea butter oil at 250°C for 2hrs. The structure consists of bainite (white) and martensite (dark). (x200)



Micrograph 6: Austempered low alloyed cast steel in hot shea butter oil at 250°C for 4hrs. The structure shows a network of bainite (white) and martensite (dark). (x200)

**Micrograph 7:** **Austempered low alloyed cast steel in hot groundnut oil at 250°C for 1hr. The structure shows Widmanstatten plates (white). (x200**

**Micrograph 8:** **Austempered low alloyed cast steel in hot groundnut oil at 250°C for 2hrs. The structure consists of neteork of martensite. (x200)**



**Micrograph 9:** **Austempered low alloyed cast steel in hot groundnut oil at 250°C for 4hrs. The structure shows massive network of bainite (white) and martensite (dack). (x200)**

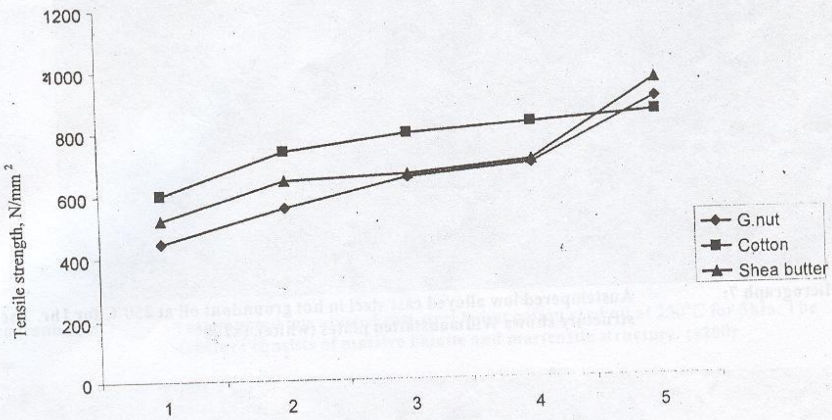



**Fig 1.: Effect of Austempering time on the tensile strength of low alloyed cast steel sample austenitized at 950 °C and austempered at 250 °C**

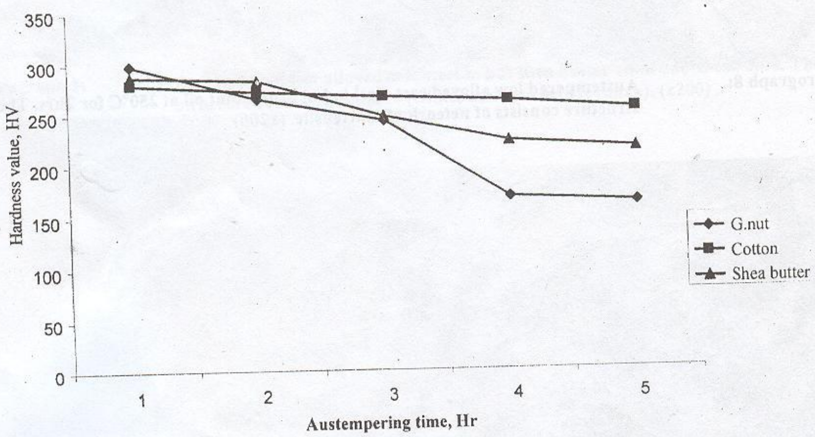



**Fig 2. Effect of Austempering time on the Hardness of low alloyed cast steel sample austenitized at 950 °C and austempered at 250 °C**

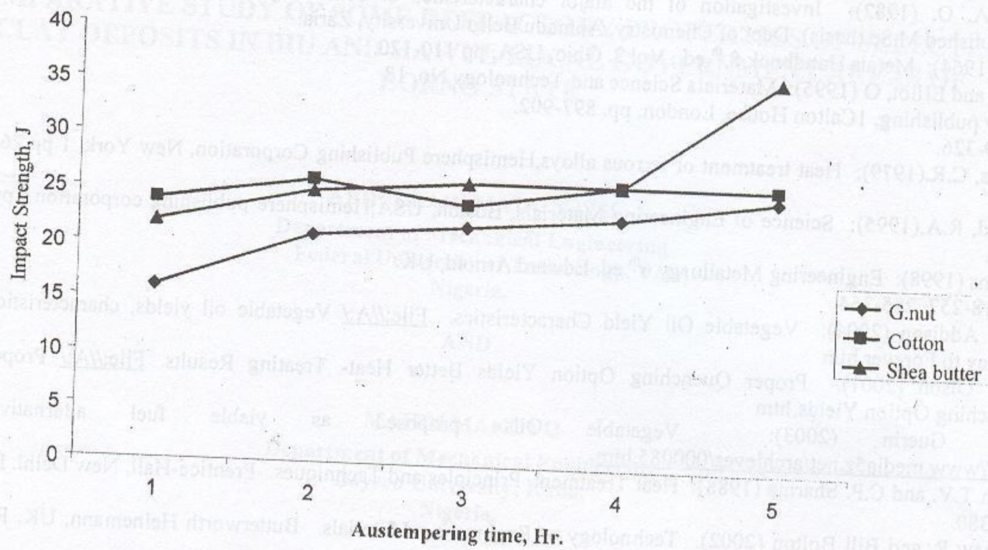



**Fig .3 Effect of Austempering time on the Impact strength of low alloyed cast steel sample austenitized at 950 °C and austempered at 250 °C**

## 4.0 CONCLUSIONS

**Based on this study, it may be concluded that:**

1. The austempered specimen in hot shear butter oil had the highest tensile strength value of 954N/mm$^2$ at 5hrs and the lowest tensile strength value of 444N/mm$^2$ at 1hr using groundnut oil as quenchant.
2. Austempered sample in hot groundnut oil recorded the highest hardness value of 298HV at 1hr while austempered sample in hot cottonseed oil obtained the lowest hardness value of 279HV at 1hr. This higher hardness at 1hr was attributed to insufficient time for austempering reaction to have taken place and as a result, austenite transformed to martensite which is a hard structure.
3. The highest impact strength value of 36J was observed for sample austempered in hot shear butter oil at 5hrs and the least impact value of 16J was on austempered sample in hot groundnut oil at 1hr.
4. The effect of shea butter and cotton seed oils as quenching media for austempering of low alloyed cast steel show improvement on mechanical properties compared with groundnut oil.

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