Potential of Hot Sesame Oil *(sesanum indicum oil)* Bath as Quenchant for Austempering of Ductile Cast Iron

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Abstract: ***Potential of sesame oil (sesanum indicum oil) as quenching medium for austempering heat treatment of ductile cast iron has been studied. Samples of ductile iron were machined and then normalized prior to austempering heat treatment. Samples were austenitized at 900°C. They were then soaked for 1 hour and then austempered in hot sesame oil bath held at 300°C for periods of 1,2,3,4 and 5 hours. Mechanical properties (tensile strength, percent elongation, and impact strength) of the test samples were evaluated. The test results obtained showed that the highest value of tensile strength (1029 N/mm²) and percentage elongation (14.6%)were obtained from sample austempered for 3 hours. Maximum impact strength (163 kJ/m²) was also obtained from sample austempered for 4 hours. Microstructures of the samples were analyzed using optical microscopy (OM) and scanning electron microscopy (SEM). The microstructure, which consist of graphite nodules embedded in a matrix of ausferrite (acicular ferrite and carbon enriched austenite) was observed. The research showed that sesame oil was able to cause the formation of ausferrite structure, hence could be recommended to be used as an austempering quenching medium for ductile cast iron.***

Keywords: austempering, Quenching medium, ausferrite, sesame oil

1. Introduction

Since the discovery of ductile (nodular) cast iron in 1948, no other new type of cast iron has been discovered, hence austempered ductile cast iron (ADI) is a relatively new engineering material with exceptional combination of mechanical properties and marked potential for numerous applications [1-5]. The attractive properties of ADI return to its distinct and unique microstructure, which consist of fine acicular ferrite with carbon enriched stabilized austenite (ausferrite) [5]. ADI offers the design engineer the best combinations of low cost, design flexibility, good machinability, high toughness, wear resistance and fatigue strength [6].The isothermal heat treatment of ductile iron produces the ADIwith outstanding mechanical properties that can be varied over a wide range by changing the heat treatment parameters. Isothermal heat treatment is most typically carried out in nitrate/nitrite salt bath, due to the advantages they offer compared to others, although a lot of attention is given today to vegetable oils, minerals oils and polymer solutions [7]. Many researchers reported on the suitability of polymer solution, hot bitumen, mineral and vegetable oils as quenching medium for austempering of ductile cast iron. These findings minimized the need for a molten salt and lead baths. However, the substantial deficiencies with respect to environmental friendliness, high cost, non-availability and toxicity of molten salt and lead baths justify the search for alternative replacement media. Therefore, the present study focus on using hot sesame oil bath as an austempering quenching medium for ductile cast iron.

2. Statement of the Problem

Austempering is known to be one of the quench hardening methods which is applied to ferrous alloys in order to improve toughness and ductility. It is usually carried out in a bath. The three baths used for austempering are: molten salt bath, molten lead bath and hot oil bath.

Molten salt bath is the commonest used for austempering heat treatment but it is very expensive and scarce in developing countries like Nigeria. Its acquisition requires importation and in addition has the following shortcomings: It may cause explosion as a result of instrument failure, it is very hazardous especially during cleaning and in maintaining the bath at elevated temperatures, it can be dangerous as it can produce vapors which are toxic to workers, the running costs are high and the surfaces of samples become corroded if for any reason they are left too long in the bath. Molten lead bath also is expensive and emits fumes which is a health threat to humans and general environment.

Based on the above aforementioned reasons therefore, the present research focused at using hot sesame oil bath as an alternative to molten salt bath for austempering of ductile cast iron. This will go a long way in assisting many local heat treatment industries in the area of austempering.

3. Materials and Methods

3.1 Materials and Equipment

The materials used in this research work include: ductile cast iron samples, Sesame oil *(Sesanum indicum oil)*,polishing powder, water, grinding papers, polishing cloth, cotton wool, copper piece, nitric acid and ethanol. The equipment used include: Thermocouple, Optical Pyrometer, oil bath, electrically heated muffle furnace, optical Metallurgical Microscope (OM), Scanning Electron Microscope (SEM), lathe machine, polishing machine, Hounsfield tensometer, Hounsfield balance impact testing machine.

Methods

The machined samples were initially normalized by heating to a temperature of 900°C and soaked for one hour and then air-cooled. Then the normalized samples were loaded into the furnace, heated to 900°C, soaked for one hour, and thereafter removed and quenched in hot Sesame oil bath held at 300°C. After one hour, the first set of samples (two tensile, two impact and one for metallography)was removed from the hot Sesame oil bath and then cooled in air. Another set of samples was removed after 2, 3, 4 and 5hours respectively.

Tensile test measurement

Hounsfield tensometer was used for tensile test measurement. The tensile test samples were machined to standard dimension as specified in ASTM A37O [8].The test method adopted was ASTM E8. The test sample was mounted by its ends onto the holding grips of the testing apparatus. The maximum loads were recorded directly from the Hounsfield tensometer. The readings obtained were used to calculate the tensile strength and percentage elongation.

Impact test measurement

Hounsfield balance impact testing machine was used for impact test measurement. The impact test sample were machined to standard dimensions as specified in ASTM A370 [8].The test method adopted was ASTM E23.The samples were machined to 8mm diameter and 45mm length with a 1mm deep V-notch. Before the test, the pendulum was set to a potential energy position of 162.75J. The test specimen was griped vertically in a vice, the trigger was released and the registering pointer of the quadrant scale indicated the energy absorbed in Joules to break the specimen. The energy absorbed in breaking the sample was recorded and the same was repeated for other test samples.

Microstructural examinations

All the specimens (both untreated and heat-treated) were prepared for optical microscopic examination. The specimens were ground on a water lubricated silicon carbide abrasive papers of 180, 240, 320, 400 and 600 grit sizes. Polishing was carried out on 15cm rotating discs of a Metaserv universal polishing machine with synthetic velvet polishing clothes impregnated with 1µm Alumina paste. The specimens were then etched with 2% Nital solution using the swabbing method with cotton wool soaked in the etchant. The microscopic examinations were carried out on M100 optical metallurgical microscope and the microstructures obtained were captured with in-built camera. SEM was carried out as well for the quenched samples.

4. Results and Discussion

The chemical composition of the ductile cast iron used is given in Table 1.The Physico-chemical properties of the Sesame oil used is shown in Table 2.

Table 1: Chemical composition of the as-received ductile cast iron

Element	C	Si	Mn	P	S	Cu	Ni	Mo	Mg	Fe
Content (%)	3.81	2.70	0.26	0.06	0.042	0.32	1.85	0.2	0.04	balance

Table 2: Physico-chemical properties of the Sesame oil used

Oil	Iodine Value (g/100g)	Acid value (mg KOH)	Peroxide value (m_{eq} KOH/g)	Saponification value (mg KOH)	Density (g/cm^3)	Viscosity at 25.5°C (cp)	Smoke point(°C)	Boiling point(°C)	Flash point (°C)
Sesame Oil	113.2	0.5	7.7	189	0.914	40.2	223304391		

Tensile Strength

Figure 1 shows the results obtained from tensile tests of ductile cast iron samples austenitized at 900°C and austempered in hot Sesame oil bath (300°C) for the period of 1-5hrs.

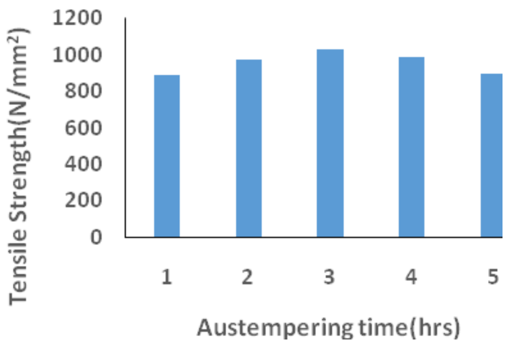

Figure 1: Variation of austempering time on the tensile strength of ductile cast iron samples austenitized at 900°C and austempered in hot Sesame oil bath at 300°C.

Figure 1 shows the effect of austempering time on the tensile strength of ductile cast iron samples austempered in hot Sesame oil bath at 300°C from the austenitizing temperature of 900°C. It was observed that as the austempering time increased the tensile strength increased, reached a maximum at 3 hours then decreased. This increase may be due to formation of stage 1 austempering reaction which might have caused considerable quantity of austenite to transform to ausferrite structure. At the austempering times of 4 and 5 hours, slight decreased of tensile strength was observed. This decrease could be attributed to the setting in of stage II austempering reaction. In the stage II reaction, austenite transformed to ferriteplus cementite, the ausferrite structure (which is responsible for high tensile strength values in ADI) breaks down into bainitic structure containing cementite. The cementite formed in this stage was responsible for the decreased of the tensile strength at higher austempering times. This is in agreement with the earlier researches carried out by Sandeep and Sani [9-10].

Percentage Elongation

Figure 2 shows the results of percent elongation obtained for ductile cast iron samples austenitized at 900°C and austempered in hot Sesame oil bath (300°C) for the period of 1-5hrs.

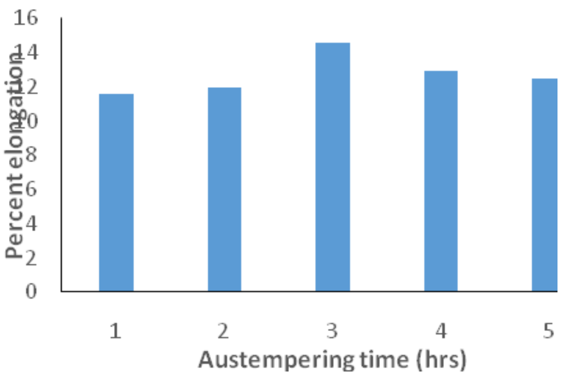

Figure 2: Variation of austempering time on the percent elongation of ductile cast iron samples austenitized at 900°C and austempered in hot Sesame oil bath at 300°C.

Figure2 shows the effect of austempering time on the percent elongation of ductile cast iron samples austempered in hot Sesame oil bath at 300°C from the austenitizing temperature of 900°C. The percentage elongation increased as the austempering time increases, reached a maximum at 3 hours then decreased. This increase may be due to progression of stage 1 austempering reaction which might have causedconsiderable quantity of austenite to transform to ausferrite structure. At the austempering times of 4 and 5 hours, the percent elongation decreased. This decrease could be attributed to the setting in of stage II austempering reaction. This is inagreement with what was established by Bisht [11].

Impact Strength

Figure 3 shows the results obtained from impact tests of ductile cast iron samples austenitized at 900°C and austempered in hot Sesame oil bath (300°C) for the period 0f 1-5hrs

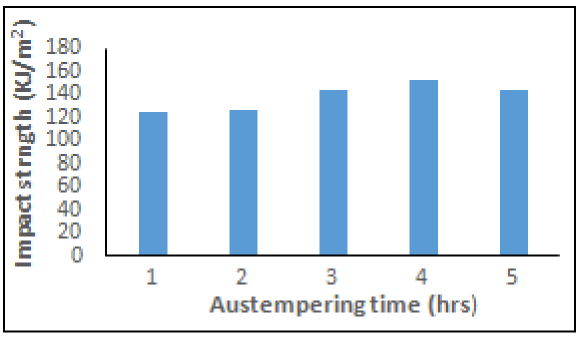

Figure 3: Variation of austempering time on the Impact strength of ductile cast iron samples austenitized at 900°C and austempered in hot Sesame oil bath at 300°C.

Figure 3 shows the effect of austempering time on the impact strength of ductile cast iron samples austempered in hot Sesame oil bath at 300°C from the austenitizing temperature of 900°C. The impact strength increased as the austempering time increases, reached a maximum at 4 hours then decreased. This increase may be due to progression of stage 1 austempering reaction which might have causedconsiderable quantity of austenite to transform to ausferrite structure. At the austempering times of 5 hours, the impact energy decreased. This decrease could be attributed to the setting in of stage II austempering reaction. In the stage II reaction, austenite transformed to ferriteplus cementite$(\gamma_{hc} \rightarrow \alpha + Fe_3C)$, the ausferrite structure (which is responsible for high impact energy values in ADI) breaks down into bainitic structure containing cementite. The cementite formed in this stage was responsible for the decreased of impact energy at higher austempering time. These observations are in line with what Ause [12] established.

Microstructures

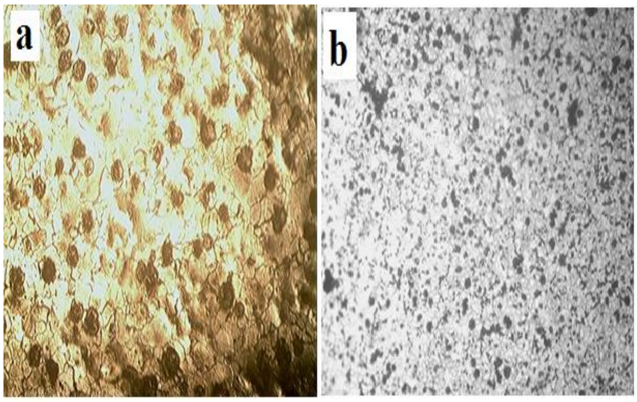

Plate 1: Optical micrograph of ductile cast iron. (a) as-received; the structure consists of graphite nodules with ferrite grain boundary in pearlite matrix; (b) after normalizing; the structure consists of graphite nodules in pearlite matrix. . 2% Nital etch. (x100)

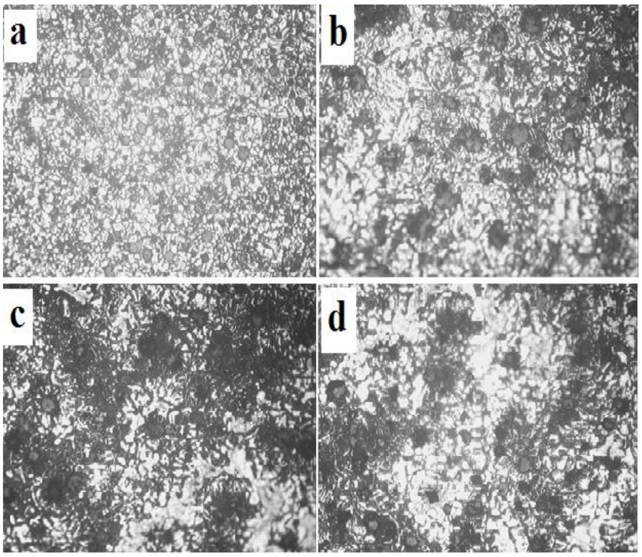

Plate 2: Optical micrograph of ductile cast iron austenitized at 900°C, austempered at 300°C in Sesame oil and for (a) 1 hour; (b) 2 hours; (c) 3 hours: (d) 4 hours. The structure consists of graphite nodules (dark balls) and retained austenite (white) in ausferrite. Etchant 2% Nital (x100).

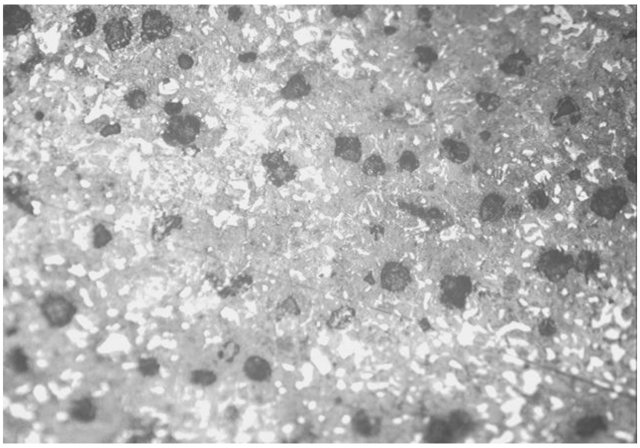

Plate 3: Optical micrograph of ductile cast iron austenitized at 900^{o}C, austempered at 300^{o}C in Sesame oil for 5 hours: The structure shows ausferrite with fine precipitates of cementite. Etchant 2% Nital (x100).

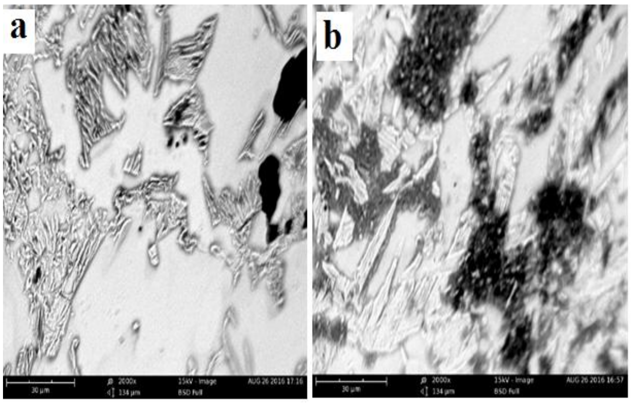

Plate 4: SEM micrograph of ductile cast iron austenitized at 900^{o}C, austempered at 300^{o}C in Sesame oil for (a) 1 hour: (b) 2 hours. The structure consists of graphite nodules (dark balls) and retained austenite (white) in lath of ausferrite. Etchant 2% Nital

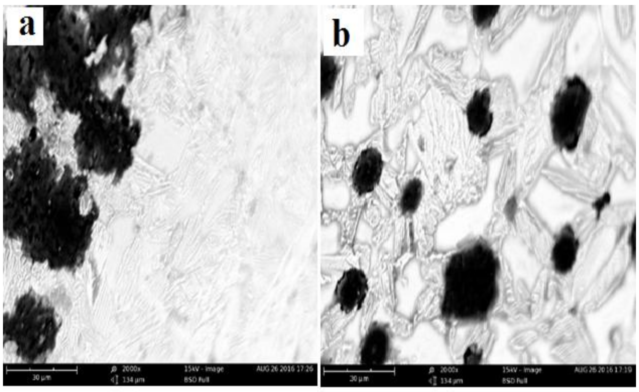

Plate 5: SEM micrograph of ductile cast iron austenitized at 900^{o}C, austempered at 300^{o}C in Sesame oil for (a) 3 hours: (b) 4 hours. The structure shows nodules in plate of ausferrite. Etchant 2% Nital

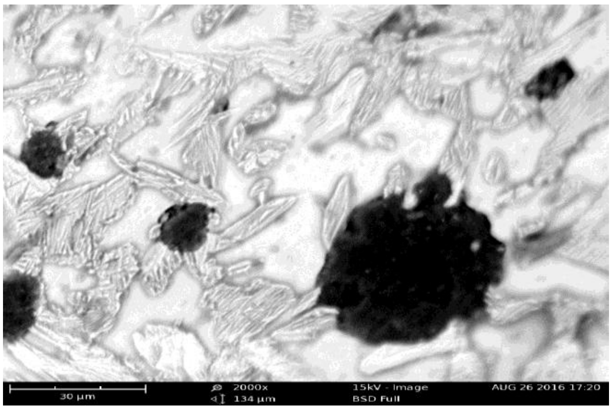

Plate 6: SEM micrograph of ductile cast iron austenitized at 900^{o}C, austempered at 300^{o}C in Sesame oil and etched in 2% Nital for 5 hours. The structure shows ausferrite lath and nodules of graphite. Etchant 2% Nital

The microstructures of the as-received, normalized and austempered samples are shown in Plate 1-6. The as-received structure of the test sample is shown in Plate 1(a); the graphite nodules are present in ferrite and pearlite matrix. The normalized structure of ductile cast iron used is shown in Plate 1(b); the structure consists of graphite nodules in pearlite matrix. The optical micrographs (Plate 2 and3) show structures of ductile cast iron austempered at 300^{o}C for 1, 2, 3, 4 and 5 hours respectively. At the initial period of austempering, a mixture of ausferrite and retained austenite was observed. However, as austempering time was increased progressively, ausferrite structure (Bainite) formed and more quantity of retained austenite. In which at the austempering time of 3 hours, the microstructure composed of more ausferrite and retained austenite as compared to those at 1 and 2 hours. At 4 and 5 hours austempering time there was decrease in the amount of retained austenite and fine precipitates of cementite was observed. The austempering time has impact on the amount of ausferrite (Bainite) and austenite produced during the transformation. These observations are in line with what Laurence [13] reported.

The SEM images (Plate 4, 5 and 6) showed that the ausferrite (bainite lath) got finer and increased with increase in austempering time. The reason could be attributed to the fact that, the progression of stage 1 austempering reaction which might have caused considerable quantity of austenite to transform to ausferrite structure [Plate 4(a, b), 5(a, b), 6].This trend clearly explained the high tensile strength, impact strength and percentage elongation obtained for samples austempered in hot Sesame oil bath for 3 and 4 hrs. This observations are in agreement with what was established by Amar *et al* [11].

5. Conclusions

Based on the results of this study, the following conclusions may be drawn:

- Hot Sesame oil bath at 300˚C was able to cause the formation of “ausferrite structure” in the samples, thus could be used as an austempering quenching medium.
- As the holding time for austempering increases, the tensile strength, impact strength and percentage elongation initially increases and then slightly decreases.

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- At 3- 4 hours of austempering time, a full austempered microstructure (a mixture of fine acicular ferrite and high carbon stabilized austenite, in which at 4hours there is some precipitates of cementite) were found adequate to develop the necessary enhanced mechanical properties in ductile cast iron samples in hot Sesame oil bath.
- Sesame oil is cheaper and environmentally friendly compared to molten salt and lead bath, therefore should be added to the list of existing austempering quenching media.

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