

POTENTIAL OF HOT-BAOBAB SEED OIL (*Adonsonia digitata*) BATH AS AN AUSTEMPERING MEDIUM FOR DUCTILE CAST IRON

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ABSTRACT

Despite the report by many researchers on the suitability of polymer solution, hot bitumen, mineral and vegetable oils as quenching medium for austempering of ductile (nodular) cast iron. These findings minimized the need for the 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 baobab seed oil bath as an austempering medium for ductile cast iron. Samples of ductile cast iron were machined to standard dimensions for tensile, impact and microstructural analysis test specimens prior to the austempering process. The samples were normalized and thereafter, austempered in hot baobab seed oil bath at 260°C and 310°C for 1-5hrs from austenitizing temperature of 875°C. Mechanical properties of the test samples were evaluated. The test results obtained showed that samples austempered at 260°C and 310°C for 3hrs exhibited superior mechanical properties than those at 1, 2, 4 and 5hrs. The tensile strength increased from 446 N/mm² for the as-received samples to the maximum value of 1005 N/mm² for the austempered samples with percent elongation of 13.6. Impact strength increased from 57 kJ/m² (as-received) to 128 kJ/m² (austempered). Microstructures of the samples were analyzed using optical microscopy (OM) and scanning electron microscopy (SEM). In all the test samples, ausferrite (bainite) structures which consist of acicular ferrite and carbon enriched austenite were observed. The research showed that, baobab seed oil produced ausferrite (bainite) structures, hence could be recommended for use as an austempering quenching medium for ductile cast iron.

Keywords: Baobab seed oil, austempering, Quenching medium, ausferrite, nodular cast iron

1 INTRODUCTION

Metals and alloys develop requisite properties by heat treatment which plays a critical role in achieving appropriate microstructure that imparts the desired characteristics in a given material. The heat treating of ductile iron by austempering produces the austempered ductile iron (ADI) with outstanding mechanical properties that can be varied over a wide range by changing the heat treatment parameters. Austenitizing and austempering temperatures and time are factors that affect the final properties of ADI [1, 2]. The attractive properties of ADI are due to its distinct and unique microstructure, which consists of fine acicular ferrite with carbon, enriched stabilized austenite (ausferrite) [3]. The final properties of an alloy are not only due to its chemical composition, but also due to its metallurgical history. It's possible to use different treatments so as to change the properties of an alloy; thus, finding the easiest way of heat treatment and optimum treatment conditions is of fundamental importance in achieving the desired properties [4]. Austempered ductile iron (ADI) offers a design engineer the best combinations of low cost, design flexibility, good machinability,

high strength to weight ratio and good toughness, wear resistance and fatigue strength [5]. [6] reported that for some heat treatment operations that requires hardening of components by quenching, those quenching media such as water, brine, oil, etc may sometimes be too drastic, hence resulting to inferior mechanical properties and defects such as cracking and distortion. Such defected components are eventually rejected, resulting to economic waste. Therefore, in order to impart good mechanical properties (especially strength and toughness/ductility) and simultaneously avoid cracking and distortion, many researchers suggested that other heat treatment methods like martempering and austempering in molten salt bath or hot oil bath could be used. But unfortunately, salt bath furnace is known to be very costly. Generally, quenchants are grouped into two categories namely: those maintained at room temperature and those maintained at higher temperatures (250-450°C). The room temperature quenchants are regarded as the most popular, common and conventional or traditional type of quenchants. Few examples include; water, brine, oil (mineral or vegetable), caustic soda solution, etc. Those quenchants maintained at higher temperatures are used for interrupted quenching heat treatment processes such as martempering, austempering, and ausforming [7]. Examples of these types of quenching media are molten salt bath, molten lead bath and hot oil bath. The interrupted quenching procedure employed to the ductile iron which is known as austempering heat treatment, which involves heating the ductile iron to the austenitizing temperature, holding it for some time at that temperature for complete homogenization to take place and then quenching into a molten salt bath maintained at a temperature just above 250°C (i.e. M_s – martensite start temperature) [8]. [9] reported that during austempering, two simple types of bainite are formed: upper and lower bainites. Metallographic observation reveals that upper bainite is feathery and the lower bainite is acicular. The Microstructure of upper bainite consists of ferrite lath with carbides precipitated on the surface of the laths, whereas lower bainite consists of ferrite lath with precipitates of carbide within the laths at an angle to the major axis of the ferrite lath. [10] studied the effect of austempering time on the mechanical properties of ductile iron austempered in rubber seed oil. It was found that rubber seed oil could be used as hot bath for the austempering of ductile cast iron. But because of the toxicity of the oil limit the oil for use in heat treatment processes. [11] reported on the possibility of using Nigerian neem seed oil as an austempering quenchant for locally recycled steels. It was reported that neem seed oil could be used as an austempering medium. The limitation of the neem seed oil for use as an austempering heat treatment is that, it is not always available. Therefore, the present study was carried out to evaluate the potential of hot baobab seed oil bath as an austempering medium for ductile cast iron.

2 METHODOLOGY

2.1 Materials

The materials used include: Nodular cast iron samples, Baobab seed oil, polishing powder, water, grinding papers, polishing cloth, cotton wool, copper piece, nitric acid and ethanol. The equipment used include: Oil bath, electrically heated muffle furnace, optical Metallurgical Microscope (OM), Scanning Electron Microscope (SEM), lathe machine, polishing machine, Hounsfield tensometer and impact testing machine.

2.2 Methods

The ductile cast irons (rod form) were machined to standard Izod impact samples, tensile test samples and microstructural analysis samples. 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 875°C, soaked for one hour, and thereafter removed and quenched in hot Baobab seed oil bath held at 260°C for 1-5hours. After one hour, the first samples were removed from the hot Baobab seed oil bath and then cooled in air. Other samples were removed after 2, 3, 4 and 5 hours respectively. Similarly, the above process was repeated for samples austempered in hot Baobab oil bath at 310°C.

2.3 Tensile Test measurement

Samples were machined to the standard dimensions prior to the heat treatment operation as specified in ASTM A370 [12]. The test method adopted is ASTM E8. The test sample was mounted at

it ends onto the holding grips of the testing apparatus. The maximum loads were recorded directly from the Hounsfield tensometer. Following the fracture, the two broken ends of the specimens were fitted together and final gauge length was measured. The readings obtained were used to calculate the tensile strength and percentage elongation.

2.4 Impact Test measurement

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 100mm x 10mm x 10mm, a notched about 2mm deep was made at the center. The sample was fixed on vertical position and the hammer struck the sample 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.

2.5 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 1 μ m 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.

3 RESULTS AND DISCUSSION

The chemical composition of the nodular cast iron used is given in Table 1 and Table 2 shows the Physico-chemical properties of the Baobab seed oil used.

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

Element	C	Si	Mn	P	S	Cu	Ni	Mg	Fe
Content (%)	3.61	2.60	0.27	0.06	0.04	0.33	0.22	0.55	Balance

Table 2. Physico-chemical properties of the Baobab Seed oil used

Iodine Value (g/100g)	Acid Value (mgKOH)	Saponif. Value (mgKOH)	Density (g/cm ³)	Viscosity 25.5°C(cp) Before Aust.HT	Viscosity 25.5°C(cp) Before Aust.HT	Smoke Point (°C)	Boiling Point (°C)	Flash Point (°C)
66	0.9	199	0.985	43.2	51	215	>300	>250

3.1 Tensile properties

Figure 1 shows the effect of austempering time on the tensile strength of ductile cast iron samples austempered in hot Baobab oil bath at 260°C and 310°C for 1-5 hours from austenitizing temperature of 875°C. It was observed that as the austempering time increased the tensile strength increased, reaching a peak at 3 hours and then decreased. This increase may be due to formation of stage I austempering reaction which might have caused large fraction of austenite to transform to ausferrite structure. At the austempering times of 4 and 5 hours, slight decrease of tensile strength was observed. This decrease could be attributed to the setting in of stage II austempering reaction. In the stage II reaction, stabilized high carbon enriched austenite transformed to bainitic ferrite plus ϵ -carbide. The brittle ϵ -carbide formed in this stage is responsible for the decrease, of the tensile strength at higher austempering times. This is in agreement with the earlier researches carried out by Shehu [13] and Sani [14]. This is because enlargement of austenite grains at higher austenitizing temperatures improves hardenability [15]. However, the tensile strength values (Figure 1) show a decreasing trend with increasing austempering temperature from 260°C to 310°C. This may be attributed to the progressive decrease in carbon contents in the bainitic ferrite, which is similar to that reported by Laurence [16].

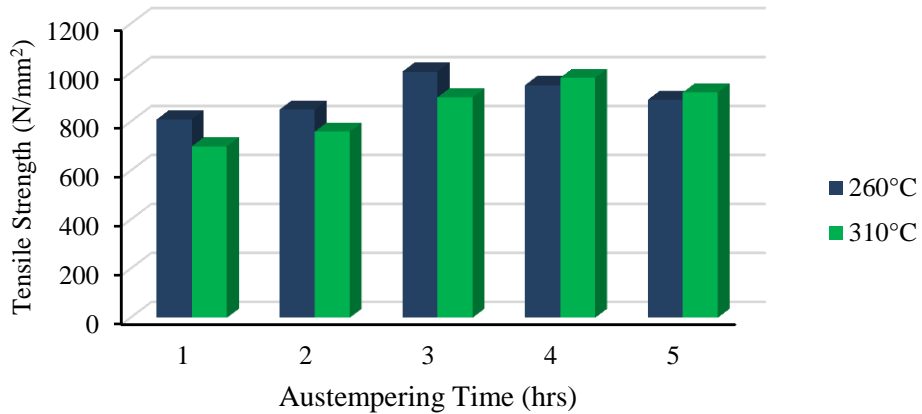


Figure 1. Profile of tensile strength of the ductile cast iron samples austenitized at 875°C and austempered in Baobab oil at 260°C and 310°C.

3.2 Percentage Elongation

Figure 2 represent the effect of austempering time on the percent elongation of ductile cast iron samples austempered in hot Sesame oil bath at 260°C and 310°C from austenitizing temperature of 875°C. 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 in agreement with Shehu [13].

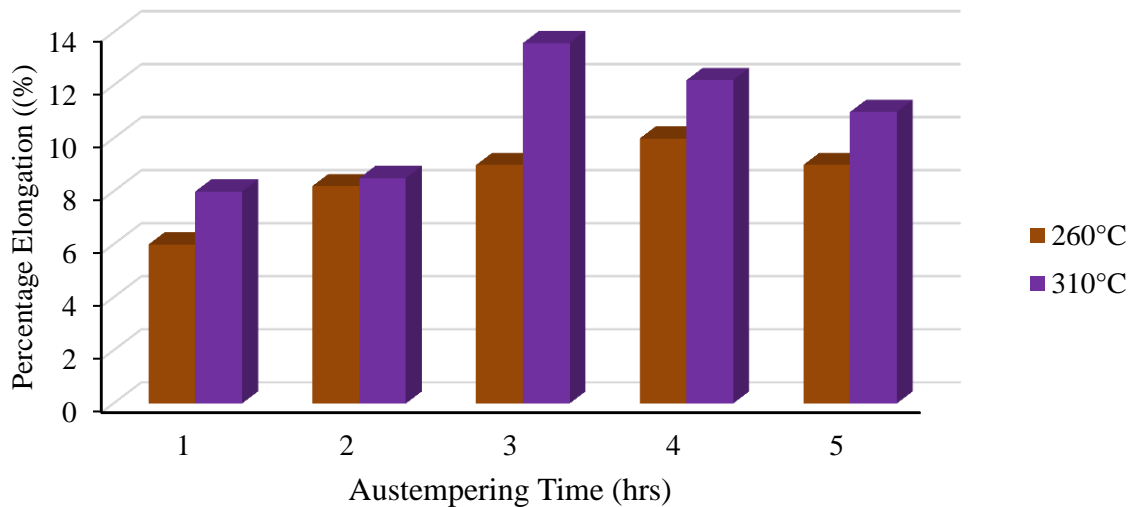


Figure 2. Profile of percent elongation of the ductile cast iron samples austenitized at 875°C and austempered in Baobab oil at 260°C and 310°C.

3.3 Impact Strength

Figures 3 indicate the effect of austempering time on the impact strength of ductile cast iron samples austempered in hot Baobab oil bath at 260°C and 310°C for 1-5hours from austenitizing temperature of 875°C . The results clearly show that, as the austempering time increase, impact strength of the samples increased until it reached 3 hours. The decrease in impact strength by samples austempered at 4 and 5 hours, could be attributed to the brittleness set into the samples because of the start of stage II austempering reaction. These observations are in line with Ause [17].

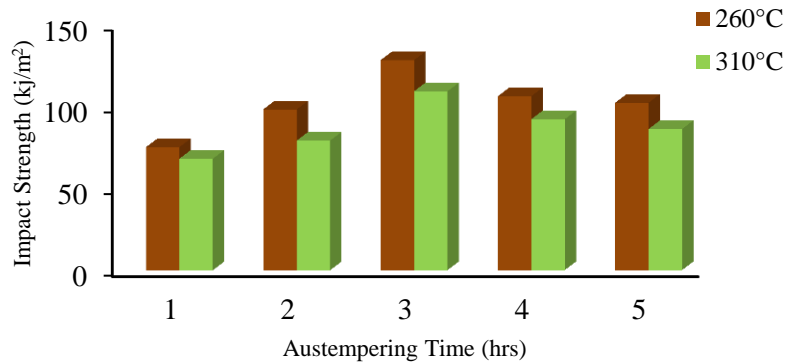


Figure 3. Profile of impact strength of the ductile cast iron samples austenitized at 850°C and austempered in Sesame oil and austempered in Baobab oil at 260°C and 310°C.

3.4 Microstructures

The optical microstructures of the test sample are shown in Plate 1(a); the structure consists of graphite nodules with grain boundary ferrite in pearlite matrix. The normalized structure of the ductile cast iron used is shown in Plate 1(b); the structure consists of graphite nodules in pearlite matrix. All microstructures are associated with retained austenite. This is in line with the findings of Shehu [5].

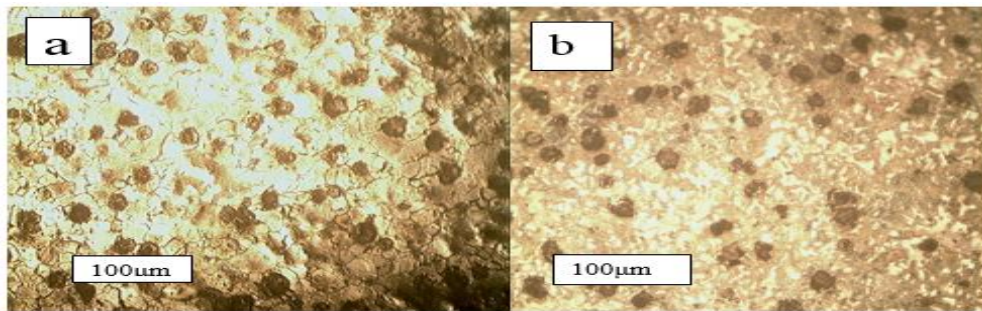


Plate 1. Optical micrograph of ductile cast iron. (a) as-received; the structure consists of graphite nodules with grain boundary ferrite in pearlite matrix; (b) after normalizing; the structure consists of graphite nodules in pearlite matrix, 2% Nital etch. (x100)

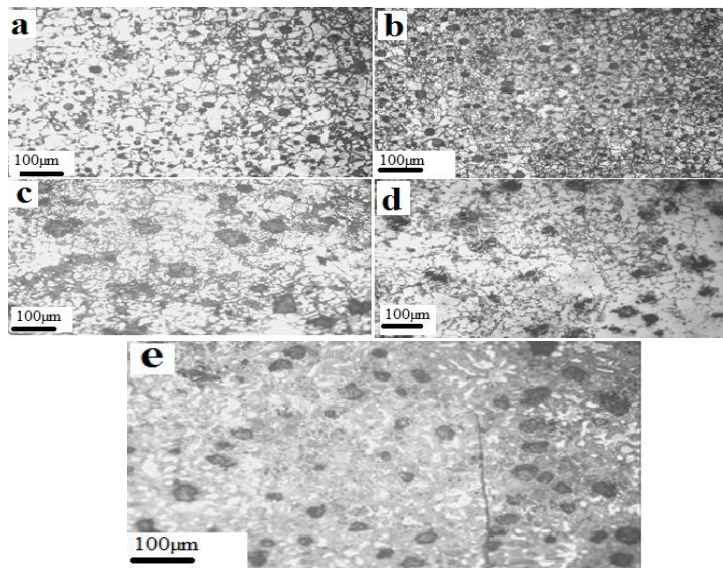


Plate 2. Optical micrograph of ductile cast iron austenitized at 875°C, austempered at 260°C in Baobab Seed oil and etched in 2% Nital for (a) 1 hour, (b) 2 hours, (c) 3 hours, (d) 4 hours, (e) 5 hours. The structure consists of graphite nodules (dark balls) and retained austenite in ausferrite (x100).

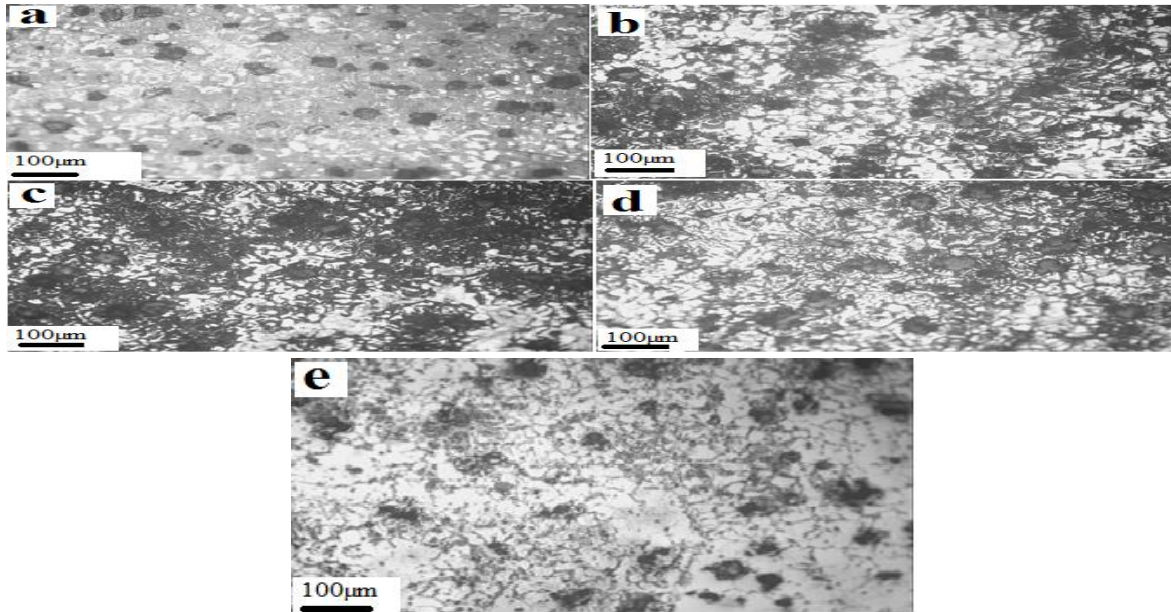


Plate 3. Optical micrograph of ductile cast iron austenitized at 875°C, austempered at 310°C in Sesame oil and etched in 2% Nital for (a) 1 hour, (b) 2 hours, (c) 3 hours, (d) 4 hours, (e) 5 hours. The structure consists of graphite nodules (dark balls) and retained austenite in ausferrite (x100).

The optical microstructures of the samples austempered in hot Baobab oil bath at 260°C and 310°C for 1-5hours from austenitizing temperatures of 875°C are shown in Plates 4 and 5. As austempering time was increased progressively, ausferrite structure (Bainite) was formed. The structures are associated with retained austenite. This resulted from the early stage of austempering reaction. Complete ausferrite (bainite) structure was observed for austempered samples for 3hours. This is in agreement with what was reported by Ause [17].

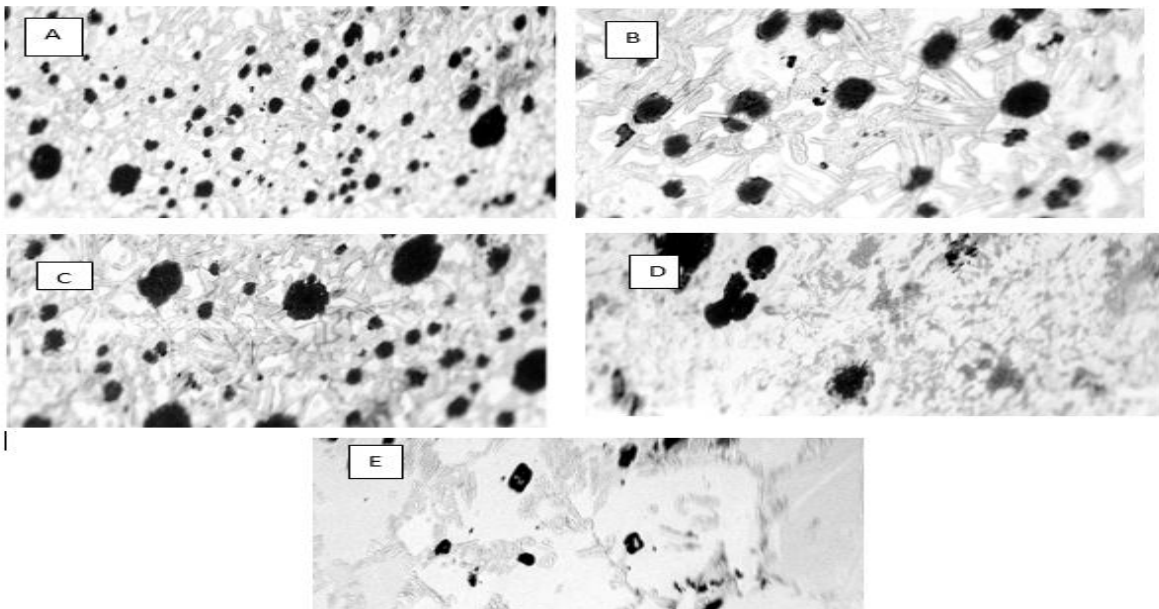


Plate 4. SEM images of ductile cast iron samples austenitized at 875°C and austempered in Baobab oil at 260°C for (A) 1hour, (B) 2hours, (C) 3hours, (D) 4hours and (E) 5hours. The structures show ausferrite structures (Bainite) and retained austenite

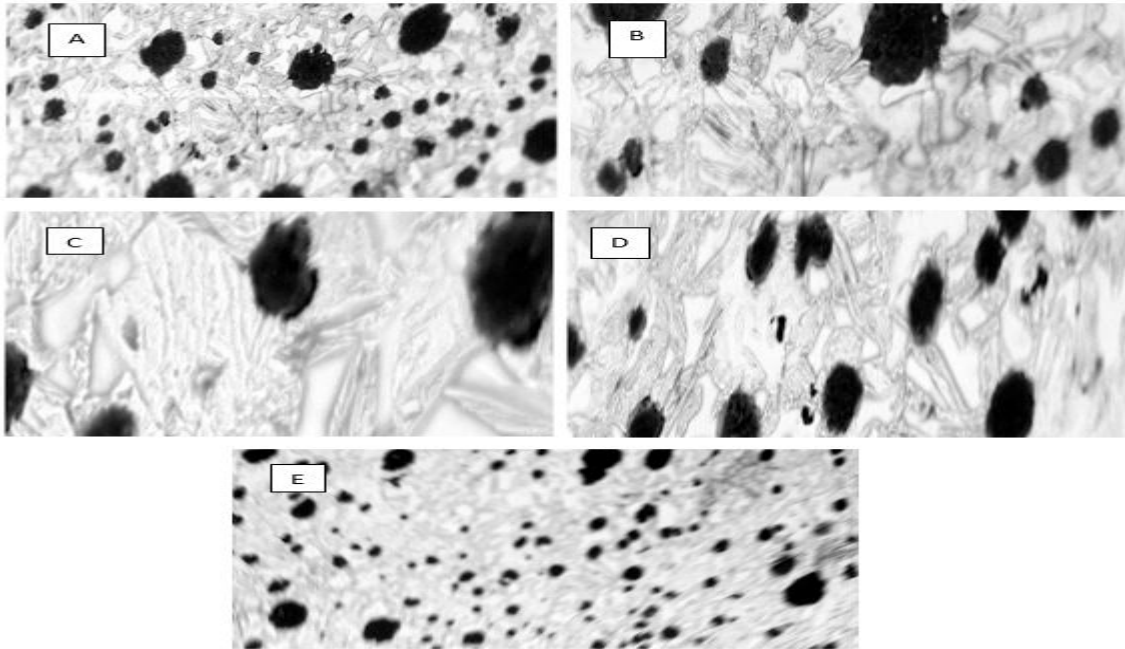


Plate 5. SEM images of ductile cast iron samples austenitized at 875°C and austempered in Baobab oil at 260°C for (A) 1 hour, (B) 2 hours, (C) 3 hours, (D) 4 hours and (E) 5 hours. The structures show ausferrite structures (Bainite) and retained austenite.

The SEM images (Plates 2 to 5) show that the proportion of ausferrite structures (Bainite) increase with increase in austempering time. This could be attributed to the progressive setting in of stage I austempering reaction. This trend clearly explained the high strength and toughness obtained for samples austempered up to 3 hours. However, samples austempered at 4 and 5 hours proved to show relatively coarser ausferrite lath with fine precipitates of brittle carbides. The brittle carbide formed as a result of second stage austempering reaction. This caused the inferior mechanical properties in samples austempered at 4 and 5 hours. These SEM images are similar to those obtained from samples austempered in molten salt bath by Tun and Lwin [18].

4 CONCLUSIONS

Based on the results obtained, the following conclusions can be drawn: The smoke, boiling and flash points of the oil were found to be 215°C >300°C and >250°C respectively. Austempering in hot Baobab oil bath gave microstructures that consist of ausferrite structure (Bainite) and retained austenite. As the holding time for austempering increase, the tensile strength, impact strength and percentage elongation initially increase progressively to a maximum at 3 hours and then slightly decreased at 4 and 5 hours.

REFERENCES

1. Nofal, A.A. and Jakova, L. (2009). Novel Processing Techniques and Application of Austempered Ductile Iron. *Journal of the University of Chemical Technology and Metallurgy*, vol. 44, no. 3, pp. 213-228.
2. Tun, T. and Lwin, K. (2009). Optimizing the Microstructure and Mechanical properties of Austempered Ductile iron. *Journal of Metals, Materials and Minerals*, vol. 18, no. 2, pp. 199-205.
3. Sandeep, K.S. (2012). Effect of austempering temperature, time and copper addition on Mechanical Properties of austempered ductile iron. *Thesis, Department of Metallurgical and Materials Engineering, National Institute of Technology, Rourkela India*, pp. 5-13.
4. Fracasso, F. (2010). Influence of Quench Rate on the Hardness Obtained After Artificial Ageing of Al-Si-Mg Alloy. *A thesis work performed at Jonkoping institute of Technology Tekniska Hogskolan*, pp. 24-37.

5. Aigbodion, V.S., Yaro, S.A. and Abdulrahman, A.S. (2005). Evaluated the use of engine oil as austempering medium for the austempering of ductile iron for the production of agricultural machines and farm implements. *Journal of Science and Industrial Studies*, vol. 3, no. 4, pp. 51-54.
6. Dodo, R.M. (2015). Potential of Cane Molasses as Quenching Medium for (0.61% C) High Carbon Steel. *MSc Dissertation, Department of Metallurgical and Material Engineering, Zaria: Ahmadu Bello University*, pp. 17-39.
7. Khanna, O.P. (2002). Material Science and Metallurgy. *Dhan Pat Rai Publication Ltd*, pp. 60-70.
8. Adewuyi, B.O. and Afonja, A.A. (2000). Austempering ductile Iron – a viable alternative to steel. *Nigerian Journal of Engineering Management*, vol. 1, no. 1, pp. 6-13.
9. Branka, B. and Branko, R. (2004). Effect of Alloying Elements and Austempering temperature on Austempering Kinetics of Ni-Mo alloy ductile iron. *Material in Technology*, vol. 38, no. 6, pp. 307-312.
10. Akor, T. and Tuleum, L.T. (2014). Effect of austempering time on the mechanical properties of ductile iron, austempered in Rubber seed oil. *International Journal Engineering Research and development*, vol. 10, no. 8, pp. 31-34.
11. Ademoh, N.A. (2015). Effect of Nigerian Neem Seed oil as an austempering quenchant for locally recycled steel. *Middle-East Journal of Scientific Research*, vol. 23, no. 1, pp. 110-118.
12. ASTM (2007). Standard Test Method and definition for mechanical testing, pp. 11-15.
13. Shehu, A. (2017). Potential of hot sesame oil bath as quenchant for Austempering of ductile cast iron. *International Journal of Science and Research*, pp. 2314-2318.
14. Sani, S.A. (2008). Potentials of using some vegetable oils as quenchants for Austempering of steel and cast irons. *PhD Thesis, Department of Metallurgical and Materials Engineering, Ahmadu Bello University Zaria Nigeria*, pp. 69-97.
15. Totten, G.E. (2006). Steel Heat Treating Metallurgy and Technologies. *Oregon, USA: Taylor and Francis Group LLC*, pp. 81-97.
16. Lawrence, I.A. (2011). Evaluation of Khaya Senegalensis Seed Oil as a Quenching medium in Austempering process of Ductile Iron. *PhD Thesis, Department of Metallurgical and Material Engineering, Zaria: Ahmadu Bello University*, pp. 72-92.
17. Ause, T. (2008). Evaluation of Hot Bitumen Bath as a Quenching Medium for Austempering of Steel and Ductile Cast Iron. *Unpublished PhD Thesis, Department of Metallurgical and Material Engineering, Zaria: Ahmadu Bello University*, pp. 47-68.
18. Tun, T. and Lwin, K. (2009). Optimizing the Microstructure and Mechanical properties of Austempered Ductile iron. *Journal of metals, Materials and Minerals*, vol. 18, no. 2, pp. 34-39.