Effect of Isothermal Transformation on the Mechanical Properties of Austempered Grey Cast Iron

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Abstract
Influence of isothermal transformation on the mechanical properties of austempered grey cast iron was investigated in this study. Austempering heat treatment was carried out at 400°C for 60, 90 and 120 minutes after austenizing at 900°C for 120 minutes. Measurement of ultimate tensile strength, % elongation, hardness and toughness are presented as a function of austempering time. The results show sensitivity of elongation, ultimate tensile strength, hardness and toughness to austempering time. The highest values of UTS (605MPa), % elongation (2.8), hardness (515BHN) and impact (55J) were obtained from samples austenitized at 900°C and austempered at 400°C for 90 minutes.

Keywords: grey cast iron, isothermal transformation, austempering, mechanical properties

INTRODUCTION
Grey cast iron is an alloy of iron, carbon and silicon that has been melted and poured into a mould to form a shape. If molten iron is allowed to cool normally the carbon comes out of solution and forms flakes of graphite which run through the ferrite/pearlite matrix (Harvey and Noble, 2007). Grey cast iron has more carbon present than can be retained in solid solution in austenite at the eutectic temperature (John, 1994; Saliu, and Bolarinwa, 2013). Major constituents of gray cast irons are carbon in the range of 1.7-4.5% and silicon in the range of 1-3%. The carbon precipitates as either graphite flake or carbide during solidification; the free graphite expands on solidifying, giving sharp, well defined castings, hence enhances maximum machinability, but reduces the strength of the grey cast iron. Also, graphite acts as a lubricant, improving wear resistance. On the other hand, the presence of carbide in grey cast iron results in hardness and extreme brittleness (Onsoien, and Skaland, 2001).

Although there are currently new advanced materials, cast irons are still the most used casting alloy for its considerable reduction in their cost of production. Their popularity stems from an ability to cast complex shapes at relatively low cost and the wide range of properties that can be achieved by careful control over composition and cooling rate. All grey cast irons contain flake graphite dispersed in iron matrix including silicon. The properties of the grey cast iron depend on the size, amount and distribution of the graphite flakes and the matrix structure (Kim, Kim and Jung, 2002; Bates, 1984; Leube and Arnberg, 1999; Ramadan, Takita and Nomura, 2006).

Grey cast iron is good under compression loading and has good corrosion resistance when compared to mild steel (John,1994). It works well under continual heating and cooling cycles, and has a range of tensile strength and hardness to suit different applications. Therefore, it is well suited for the production of low, medium and high quality castings, and are widely use in the production of spare parts and consumables in forges and rolling mills, brake disks and drums particularly where castings are subject to repeated heating and cooling cycles, valve and pump applications, motor housings, gearboxes, engine blocks and machinery components, architectural, decorative and sculptural castings. Apart from the properties of grey cast iron stated in(Harvey and Noble,2007), its preferred choice for those applications relative to other alternative materials is as a result of its lower cost (Chisamera et al. 2008).

The aim of this research is to evaluate the effect of variation of austempering parameters on the mechanical properties of grey cast iron. During the services of grey cast iron spare parts, it faces a variety of stresses, corrosion, temperature and wear. Improvements of mechanical properties for wide range of application are the main goals for this research to obtain high performance grey cast iron through control of their microstructure, especially graphite morphology by isothermal heat treatment.

MATERIALS AND METHODS
Materials use in this study is grey cast iron. Chemical composition analysis was done spectrometrically and the result of the analysis is shown in Table 1.
Table 1. Chemical compositions of Gray cast iron (Mukoro 2012).

<table>
<thead>
<tr>
<th>Elements</th>
<th>% C</th>
<th>% Si</th>
<th>% P</th>
<th>% S</th>
<th>% Mn</th>
<th>% Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray cast iron</td>
<td>4.01</td>
<td>2.09</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
<td>93.8</td>
</tr>
</tbody>
</table>

Heat Treatment
The austempering kinetics, austempered microstructure, and mechanical properties are controlled by heat treatment parameters (austenitizing temperature, austenitizing time, austempering temperature and austempering time and the rate of cooling between austenitizing and austempering temperatures). Each parameter play a role in producing the mechanical properties required to satisfy the required specification. The selection of austempering time is the most critical of the five parameters. The austempering time was selected to optimize the mechanical properties for a particular austenitizing and austempering temperature. Each machined specimen was austenitized at 900°C for 120 minutes using carbolite furnace. To avoid cracking of specimen which might result from rapid heating to the austenitizing temperature, the entire specimens were first homogenized at 400°C for about 30 minutes before austenitizing. This was followed by rapid quenching in a salt bath for subsequent austempering. Austempering was carried out at 400°C for 60, 90 and 120 minutes and then air-cooled. To prevent oxidation during austempering, salt bath containing Cassel TS 220 (K, NaNO₃) was used.

Microstructural Examination
Specimens for microscopy studies were mounted on thermosetting material known as Bakelite in order to make them convenient for handling. Thereafter, the surfaces of the specimens were then flattened by filing and grinding using laboratory grinding and polishing machines with a set of emery papers of 240, 320, 400, 600, 1000 and 1200 microns. As each specimen was changed from one emery papers to the other, it was turned through an angle of 90° to remove the scratches sustained from the previous grinding. After grinding, the specimens were polished and etched in stead’s reagent and later in 2% nital solution, thereafter their surfaces were rinsed with methylated spirit and dried in warm current of air using an electric dryer. The microstructures were then examined using Scanning Electron Microscopy (SEM).

Determination of Tensile Strengths
Tensile test were carried out on a tensile testing machine at room temperature in an ambient atmosphere. Loads and displacements plot were obtained on X-Y diagrams; ultimate tensile strength and percentage elongation values were calculated. The average values from the test samples are reported. Tensile test of samples (37 min long with gauged length of 25 mm and 8 mm diameter) were performed as per ASTM A8970-90 standard.

Hardness Value Determination
The hardness values of the specimen were determined using the Brinell hardness tester. The testing machine consists of a 10 mm diameter steel ball indenter. A load of 3000 kgf was applied for 15 sec. The Brinell hardness number (BHN) is expressed as:

\[
BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}
\]

Where,  
- \( P \) = load applied (kgf)  
- \( D \) = Diameter of the ball (mm)  
- \( d \) = Diameter of indentation (mm)

Impact Test Determination
Charpy impact testing machine was used to determine the impact toughness of each of the sample heated-treated. The test pieces were 10 mm² cross section, 55 mm long with a 2 mm deep V-notch in accordance with ISO 148.

RESULTS AND DISCUSSION
Effect of Austempering Time on the Mechanical Properties
The result of variations in UTS, % elongation, hardness and impact toughness for samples austenitized at 900°C and austempered at 400°C for 60, 90 and 120 minutes are shown in figures 1a-d.
The effects of austenitizing temperature and austempering time on the ultimate tensile strength and % elongation increases from 60 to 90 minutes and decreases at 120 minutes, and was found to have a higher value at 90 minutes (Figures 1a and b). It is seen that % elongation and ultimate tensile strength of austempered samples increases with increasing austempering time indicating the formation of less distorted bainitic α-phase and higher amount of retained austenite at high temperature. It is evident that austempered samples has higher UTS value than as received sample.

Figure 1c shows the effect of austempering time and Austernizing temperature 900°C on hardness values of the samples. It is evident that the hardness value of austempered samples increases at 90 minutes during short times of austempering as during the subsequent cooling from austempering temperature to room temperature, the formation of martensite cannot be prevented. As austempering time increases the carbon content of the austenite increases resulting in a decrease in Martensitic start (Ms) and Martensitic finish (Mf) temperatures. With somewhat longer austempering time the amount of retained austenite increases which results in decrease in hardness at 120 minutes and have a maximum value at 90 minutes. The austempered samples have higher hardness values (341, 515, and 477 BHN) than the as-received samples (260 BHN) values.

Figure 1d shows the effect of heat treatment on the impact of the samples, from the result obtained the impact strength was found to increase with increasing austempering time up to 90 minutes which may be due to increase in the amount of retained austenite with austempering time and less martensite on subsequent cooling to room temperature. Beyond 90 minutes a decrease in impact strength was seen in some samples due to start of the Stage II of austempering reaction when retained austenite decomposes to bainitic ferrite and carbide. Comparing the present work to the conventional gray cast iron (3J), the heat treated samples was found to have a higher impact values (49, 55, and 51 J).

Effect of Austempering time on the Specimens’ Microstructures
The observed SEM microstructures are shown in Figures 2a-d. The as-received and heat treated samples shows similar microstructures. Microstructure of both the as-received and heat treated samples with flakes graphite of type A which are uniformly and completely distributed in cementite-rich ferrite-matrix as seen in Figures 2a-d respectively, may have resulted from austenitizing time of one hour. More time is required for decomposition of graphite.
CONCLUSIONS
From the study on the effect of isothermal transformation on the mechanical properties of austempered gray cast iron the following conclusions could be drawn:

1. Austempering significantly enhances the tensile strength of gray cast iron.
2. Strength and ductility increase with increasing austempering time from 60 till 90 minutes but decreases at 120 minutes.
3. Toughness of gray cast iron increases with increasing austenizing time from 60 to 90 minutes but decreases at 120 minutes and was found to have the highest value at 90 minutes.
4. The microstructure of as-received and austempered samples were found to be similar due to less holding time.

REFERENCES