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# Adhesive Wear Behavior of Heat Treated Spheroidal Graphite **Cast Iron**

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**Abstract.** Spheroidal graphite cast iron is one of the most favorable materials in cast iron family due to its wide range of mechanical and tribological properties. In the current research priority is given towards the investigation of wear system response of spheroidal graphite cast iron subjected to various heat treatment conditions. Pearlitic/ferritic and upper bainitic matrix was obtained through normalizing and austempering treatment for an austenitizing temperature of 1000°C. Dry sliding wear test was performed at 10N, 20N, 30N for a sliding distance of 7.54m. With increase in load weight loss was observed for as-cast specimen whereas normalized specimen showed very less weight loss with increasing load. On the other hand the austempered specimen observed to lose weight when operated at 10N, whereas at 20N and 30N drastic gain in weight was observed.

Keywords: SG cast iron, heat treatment, dry sliding wear, microstructure, hardness

#### I. Introduction

Spheroidal graphite cast iron has gained its reputation in structural, automotive, agriculture and many other industries due to its good mechanical and tribological properties. Although it posses good mechanical properties in as-cast condition for any desired application, they can be improved through proper heat treatment application. Austempered ductile iron (ADI) has excellent mechanical properties such as high strength [1,2] toughness and good wear resistance [3,4] in addition to excellent fatigue strength [5,6] and good fracture toughness [7,8].

Tribological investigation carried out in past are mainly focused on austempered ductile iron subjected to various austempering time and temperature. Boutorabi et.al [9] performed dry sliding wear test on SG iron austempered at different temperature and time. The increase in austempering temperature and time leads to decomposition of carbon into the austenite surrounding and eliminates the formation of martensite and carbide which decreases the hardness and increase the wear rate. Haseeb et.al [10] studied the wear system response of austempered and quenched and tempered ductile iron with same hardness level. The bainitic ferrite matrix was more resistant to dry sliding wear at higher loads and the hardness below the wear surface was also increased. The wear rate in both the specimen was also found to be increasing with increase in sliding distance. It was also reported in their result that one of the major constituent of the austempered iron, i.e., bainitic ferrite, which is less prone to thermal instability than martensite, might undergo strain hardening during wear resulting in an increased hardness. Tempering treatment on ductile iron with boron increased the wear resistance but with increasing boriding time wear rate of boro-tempered ductile iron decreased [11]. Not only alloying element or heat treatment but also graphite nodule size and distribution affect the wear

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properties of SG iron. According to a study by Sugishita and Fujiyoshi [12] and Zimba et.al [13] presence of large size graphite nodules reduces the wear rate by acting as lubricating agent.

The past results reported are mainly leaned towards austempered ductile iron and the studies were focused on the effect of austempering time and temperature on wear behavior. Hence the present investigation is concentrated to study the wear behavior of as-cast pearlitic/ferritic ductile iron compared with higher amounts of pearlite in normalized and upper bainitic austempered ductile iron subjected to dry sliding condition.

#### **II. Experimental details**

#### 2.1: Specimen Preparation

In order to investigate the structure-property relationship, ductile iron test blocks with different alloying elements were brought from LandT Kansbahal, India. The chemical composition test block by weight percentage is presented in Table 1. In order to carry out the experiment specimens of  $25 \times 10 \times 5$  mm<sup>3</sup> were machined from the test block and then austenitized at 1000°C for 90 minutes followed by air cooling to room temperature for normalizing heat treatment. On the other hand specimens after austenitization were quenched in KNO<sub>3</sub> + NaNO<sub>3</sub> (1:1 ratio) maintained at 500°C and kept there for 240 minutes in order to get complete transformation of bainitic matrix, followed by air cooling to room temperature for austempering heat treatment process. After heat treatment oxide layer from each of the specimen was removed by conventional filing and emery paper polishing method.

Elements	Wt. %
С	3.45
Si	2.07
Mn	0.15
S	0.008
Р	0.024
Cr	0.02
Ni	0.15
Mg	0.043
Fe	Balance

Table 1: Chemical composition of specimens in wt. %

#### 2.2: Vickers hardness and wear testing

Vickers hardness was measured by applying a load of 20Kg and dwell time being 10seconds on each heat treated and as-cast specimen. Ducom TR-208-M1 Ball-on-Plate (diamond tip) type wear tester was used in order to investigate the wear system response of the as-cast heat treated specimens. Test was conducted at 10N, 20N, 30N loads for a sliding distance of 7.54m at linear velocity of 0.063m/s. The weight loss for corresponding specimens was measured with the help of electronic balance of 0.1mg accuracy, prior to the weight measurement specimens was cleaned ultrasonically with acetone before and after the wear took place. Ball on plate type wear monitor [14-17] with specimen as flat plate and a spherical tipped diamond cone of 120° angle 0.4mm tip diameter was used in order to investigate the wear system response of the as-cast heat treated specimens. The mechanism of Ball on plate wear test is very much similar to that of Pin on disc wear tester. However the minor difference is that in pin-on-disc specimen is in the form of cylindrical pin, held stationary in specimen holder and disc is the counter body which rotates against the pin, whereas in case of Ball on plate wear test instead of pin specimen is a flat one rotates against a counter ball which is fixed. Also, in pin on disc

machine only the disc rotates whereas in Ball on plate mechanism both the specimen and indenter rotate at same relative speed. The Ducom TR-208-M1 Ball on plate type wear monitor along with schematic diagram of pin on disc wear monitor is presented in Fig. 1 (a) and Fig. 1 (b) respectively.



Fig. 1: (a) Ducom TR-208-M1 Ball on plate type wear monitor



Fig. 1: (b) Schematic diagram of pin on disc wear test machine [18]

### 2.3: Microstructural and wear morphology investigation

In order to correlate the wear response with matrix structure standard metallographic technique was followed for microstructural investigation. Specimens were first polished with belt polisher followed by 1/0, 2/0, 3/0, 4/0 grades of emery paper and finally cloth polishing was done with alumina slurry followed by diamond polishing. Metallographic images were taken with the help of computer integrated optical microscope at 100X magnification. The worn surfaces of each specimen under various loading conditions were observed under optical microscope at 200X.

#### **III. Results and Discussion**

#### 3.1: Morphological Study

The microstructures of respective specimens were shown in Fig. 2. The as-cast matrix Fig. 2 (a) was bull's eye ferritic/pearlitic one with graphite nodules surrounded by ferrite. Normalized specimen Fig. 2 (b) had the same ferritic/pearlitic matrix consisting of more amount of pearlite. It was observed that pearlite nucleates around the graphite nodules. On the other hand austempered specimen Fig. 2 (c) showed upper bainitic matrix since austempered at 500°C [14], with graphite nodules embedded within the matrix.



Fig. 2: (a) As-cast

Fig. 2: (b) Normalized

Fig. 2: (c) Austempered

Fig. 2: Microstructure of respective specimens

#### 3.2: Hardness and Wear System Response



Fig. 3 Vickers Hardness of respective specimens

The Vickers hardness plot was presented in Fig. 3. It was found that normalized specimen having pearlitic/ferritic matrix had highest and austempered specimen with upper bainitic matrix had the lowest hardness value among all the three specimens. Although the as-cast specimen is having pearlitic/ferritic matrix like normalized specimen, higher pearlite content increased the hardness of the later [15]. On the other hand the lowest hardness value of austempered specimen was due to the coarse upper bainitic matrix [13]. Fig. 4 depicts the variation of weight loss/gain with variation of applied load for respective specimens. Continuous weight loss was observed for as-cast specimen when load was increased from 10N to 20N. But when load was increased to 30N a weight gain was observed. However in case of austempered specimens weight gain was observed for 20N and 30N, and there was no weight loss or gain was observed for normalized specimen at 20N. When compared with respect to hardness of respective specimens the weight loss at 10N is lowest for the hardest specimen due to higher amount of pearlite in the matrix. On the other hand the as-cast ferritic/pearlitic matrix with moderate hardness value showed significantly high loss in weight as compared to the austempered which weight loss is slightly higher than normalized. At 20N load upper bainitic matrix with lowest hardness value showed a marginal gain in weight whereas normalized specimen had neither lose nor gained any weight but as-cast specimen had significantly lose some weight. Further at 30N again weight gain was observed for both austempered and as-cast specimen whereas normalized specimen showed weight loss. However the gain in weight for austempered specimen was very less.



Fig. 4: Load vs. Weight loss for different hardness level

## 3.3: Wear morphology

The worn surface of as-cast and heat treated specimens taken under optical microscope at 200X were shown in Fig. 5. The wear direction was indicated by black arrow in every respective case. In each of the as-cast and heat treated specimen the principal mechanism was observed to adhesive wear for 10N and 20N loading condition Fig. 5(a) - (f). Shallow pits formed due to delamination [9, 12] were observed in each specimen and get deposited over the graphite nodules Fig. 5(a). Correlation between hardness and wear properties was clearly evident from the micrographs i.e., higher hardness can yield better wear resistance as can be seen in Fig. 5(a)-(c) for 10N, Fig. 5(d)-(f) for 20N and Fig. 5(g)-(i) for 30N. On further analysis of worn surfaces under NOVA NANOSEM 450, field emission scanning electron microscope, the EDAX analysis showed that austempered specimen when subjected to wear under 20N and 30N load (Fig. 6 (a) and Fig. 6(b)), oxides were observed at different areas which caused the gain in weight after the wear test. Also the as-cast specimen operated under 30N (Fig. 6(c)) load was observed to have oxides at the wear debris leading to gain in weight after the test. The red rectangles in the respective figures show the area where presence of oxide was detected.



(a) As-cast 10N



(b) Normalized 10N



(c) Austempered 10N



(e) Normalized 20N



(d) As-cast 20N



(f) Austempered 20N

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(g) As-cast 30N



(b)



(i) Austempered 30N Fig. 5: Worn surface of respective specimen at varying load condition





(c)

Fig. 6: FESEM and EDAX analysis of specimen observed to have oxides. (a) Austempered at 20N load, (b) Austempered at 30N load, (c) As-cast at 30N load

Also with increase in applied load the width and depth of wear track was increased. Micro cracks were also observed along the wear direction in each specimen and crack length was observed to be decreasing with increase in applied load. The features of worn surface in case of 30N load was very distinct than those for 10N and 20N. In as-cast condition Fig. 5(g), the wear surface observed to have ploughing marks at some area and nodules were started to disrupt from their original shape, suggesting adhesive wear [16]. However in case of normalized specimen Fig. 5(h) graphite shape disruption was observed along with delaminated layer over nodules. On the other hand austempered specimen Fig. 5(i) showed particle pull out from the worn surface along with breaking of wear surface.

### **IV. Conclusion**

The wear behavior of as-cast pearlitic/ferritic ductile iron was compared with upper bainitic austempered and pearlitic /ferritic normalized specimens. From investigation the following conclusions can be drawn:

- 1. Austempering at higher temperature leads to transformation of pearlitic/ferritic matrix into coarse upper bainitic matrix and decreases the hardness.
- 2. Specimen with higher amount of pearlite was harder and appeared to be more resistant to wear.
- 3. A considerable gain in weight was observed for austempered specimen at 20N load whereas the normalized specimen does not show any weight loss or weight gain.
- 4. Wear surface morphology of as-cast and heat treated specimens for 10N and 20N does not show any significant difference. Whereas for 30N loading condition ploughing marks was observed for as-cast specimen and austempered specimen showed particle pull phenomena along with breaking of wear continuity.

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