STUDY OF HIGH TEMPERATURE ABRASIVE WEAR BEHAVIOR OF VERMICULAR AND NODULAR CAST IRONS

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Abstract: This paper examines the influence of the graphite morphology on the high temperature abrasive wear behavior of vermicular and nodular cast irons, having same hardness. Wear tests were conducted on a 240-mesh Al$_2$O$_3$ abrasive paper at various temperatures in between 25 and 450 °C. The results showed that in all cases, the nodular cast iron exhibits a higher wear resistance than the vermicular cast iron. Generally the examined vermicular and nodular cast irons exhibit the highest resistance to abrasion at 150 °C.

Keywords: ABRASIVE, CAST IRON, HIGH TEMPERATURE, WEAR.

1. Introduction

Cast irons having desirable properties such as excellent castability, high wear resistance, ease of machining are relatively low cost when compared with alloy steels with similar mechanical properties [1-3]. Cast irons can be divided into gray cast iron, vermicular cast iron and nodular cast iron by their different graphite shapes. Vermicular cast iron (VCI) and nodular cast iron (NCI) are widely used in demanding applications (cylinder heads, exhaust manifolds and brake parts) for which the temperature and wear are usually localized at the surface of machine parts [4, 5].

It is well established that the properties and performance of any type of cast iron depend highly on the graphite type. The variations in graphite morphology cause the significant changes in total material loss through abrasion [6]. The understanding of the graphite’s role together with the matrix on the mechanical and physical properties of cast irons is still limited. There is no doubt that the mechanical behaviour of cast irons is a cooperative action between the matrix (ferritic, pearlitic or ferritic/pearlitic) and the graphite (flake, vermicular, mellable or nodular) under high temperature loading.

To address the need for operation in high temperature abrasive wear conditions, this study aims to determine the wear behaviour of two different classes of cast irons identified as VCI and NCI.

2. Methods and Procedures

The material used in the present study was VCI and NCI cast irons. The average hardness value of the VCI and NCI cast irons was 200 HB, which was measured five times by Brinell hardness tests using a load of 187.5 kg and 2.5 mm steel ball. The microstructural examinations were made on a Nikon model Optical Microscope (OM) after preparing the VCI and NCI cast irons in the standard manner and etching with 2 % Nital.

A schematic illustration of the high temperature abrasive wear testing machine used in this study is shown in Fig. 1. Wear tests were performed under a normal load of 10 N, by rubbing the samples machined into cylindrical shape of 6 mm in diameter and 20 mm in length, on an Al$_2$O$_3$ abrasive paper with a fineness of 240 mesh. Sliding speed of the belt was 0.5 m/s. During the wear tests, samples that were rubbing on the abrasive papers were moving perpendicular to the sliding direction so that they always passed over fresh abrasives. Total sliding distance of the samples on the abrasive papers was 8.4 m. Weight loss values were measured by means of a 0.1 mg precision scale. The abrasive wear test was carried out at various temperatures in between 25 and 450 °C. The effect of wear environment temperature on the abrasive wear behaviour of the VCI and NCI cast irons is analyzed on the basis of Relative Wear Resistance (RWR):

$$RWR=\frac{\text{total weight loss of VCI at room temperature}}{\text{total weight loss of other samples at other temperature}}$$

After the wear tests, worn surfaces of the samples were examined by a Scanning Electron Microscope (SEM) and a stylus profilometer. The roughness-measurement length was 2 mm for average-surface-roughness ($R_a$) and maximum-roughness-depth ($R_y$) determinations, in units of microns. The parameters $R_a$ and $R_y$ are the average absolute deviation of the roughness irregularities from the mean line and the largest value of the maximum peak to valley height parameters along the assessment length, respectively [7]. In order to understand the mechanism of material removal during wear testing, the subsurface hardness and cross-sectional micrograph of the worn surface were examined with microhardness under a load of 25 g and OM examination, respectively.

Fig. 1 Schematic view of the high temperature abrasive wear tester utilized in this investigation.

3. Results and Discussions

The VCI cast iron presents ferrite in its microstructure, besides pearlite, vermicular (worm-shaped) graphite and traces of nodular graphite (Fig. 1 a). As shown in Fig. 1 b, the microstructure of the NCI cast iron consists of a pearlitic matrix with ferritic rings of varying thicknesses surrounding the graphite nodule size of 19.5 μm, which had a good nodularity. The Brinell hardness of the VCI and NCI cast iron was also similar, independently of the different graphite morphology.
The variation of the relative wear resistance experienced by the VCI and NCI cast irons is provided in Fig. 3 as a function of temperature. The NCI cast irons presented higher wear resistance than VCI cast irons when tested at 25, 150 and 300°C. However, the wear resistance of the VCI cast iron tested at elevated temperature (450°C) is slightly higher than that of the NCI cast iron. The highest relative wear resistance was obtained for the VCI and NCI cast irons at the temperature of 150°C. Microhardness measurements in the subsurface cross-section proved that this temperature corresponds to the beginning temperature of strain aging beneath the worn surface (Fig. 4). The improvement in the wear resistance of the VCI and NCI cast irons tested 150°C can be related to the strain aging phenomena of the subsurface layer during the wear test (Fig. 3). The trend displayed in the wear resistance has been observed in Celik’s results [8]. Above 150°C, the wear resistance diminished as a consequence of its low subsurface hardness at 300 and 450°C (Fig. 3). It can be concluded from Figs. 3 and 4 that when the temperature reaches up to 450°C, the abrasive particles penetrate and abrade the matrix.

VCI cast irons exhibit rougher worn surfaces and deeper abrasive groves accompanied by a high degree of plastic deformation than NCI cast irons (Figs. 5 and 6). It is supposed that when alumina abrasives reach the leading edge of the graphite flake, the width and depth of the scratch suddenly are increased due to the low hardness and low abrasion resistance of graphite flakes. Rₐ and Rᵤ values (Fig. 6) for the wear scars of the VCI and NCI cast irons exposed to wear increased when the testing temperature was increased to 300°C. Interestingly, the Rₐ and Rᵤ values decreased at temperature of 450°C as a result of penetration of abrasive particles.

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<thead>
<tr>
<th>Test Temperature (°C)</th>
<th>VCI</th>
<th>NCI</th>
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<tbody>
<tr>
<td>25</td>
<td></td>
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<td>150</td>
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<td>450</td>
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Fig. 5 High magnification SEM micrographs showing the morphology of the worn surfaces of the VCI and NCI cast irons abraded on a 240-mesh Al₂O₃ abrasive grains at room (25°C) and at elevated temperatures (up to 450°C).
Fig. 7 shows OM micrographs of cross-section of worn surfaces of the VCI and NCI cast irons after the wear test of 8.4 m travel distance. Fig. 7 illustrates that strong cracking had occurred under the worn surface of the VCI cast iron. The notch effect is higher for the VCI cast iron compared with that of the NCI cast iron with the same hardness, because thick flake graphite removal produces high stress concentration in the VCI cast iron \[9, 10\].

<table>
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<tr>
<th>Test Temperature (°C)</th>
<th>Materials</th>
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<tbody>
<tr>
<td>25</td>
<td>VCI</td>
</tr>
<tr>
<td>150</td>
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<td>300</td>
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Fig. 7 Cross-section observations of the damaged cast irons under the worn surface after chemical etching.

4. Conclusion

Effect of graphite morphology on high temperature abrasive wear properties of VCI and NCI cast irons has been investigated and the following conclusions may be drawn:

1. The results showed that the VCI cast iron presented greater wear losses than the NCI cast iron at any temperature applied.

2. The use of thick flake graphite cast iron for high temperature abrasive conditions increased a risk of damage. In abrasive working conditions, spheroidal graphite cast iron should be used, which is more crack resistant.

3. Formation of strain aging of the subsurface layer during wear process at 150 °C was contributed to increase in the wear resistance of the VCI and NCI cast irons. Above 150 °C, the wear resistance and subsurface microhardness of the VCI and NCI cast irons decreased with an increase of testing temperature.

Acknowledgements

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5. Literature


