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# Abrasive Wear Behavior and Mechanism of High Chromium Cast Iron

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**Abstract**: The abrasive wear behavior of high chromium cast iron (containing 12.9 mass% chromium) austenitized at 1 050 ℃ for 2 h and austempered in salt bath at 320 ℃ for 4 h was evaluated. Abrasive wear was performed using alumina abrasive under four different loads, namely 50, 100, 150, and 200 N, for 36 000 cycles. The worn surfaces and wear debris were analyzed by scanning electron microscopy, laser confocal microscopy and X-ray diffraction. Micro-hardness profiles were also obtained in order to analyze the strain-hardening effects beneath the contact surfaces. Results indicate that the retained austenite in high chromium cast iron has experienced induced martensitic transformation after tests, for small amounts of retained austenite could be detected by X-ray diffraction. In addition, there is a close relationship between wear mechanism and test load. Under the condition of lower test load, the wear mechanism is an uninterrupted and repeated process, during which matrix is cut at first and then fine carbides flake off. As to higher test load, scratching and spalling induced by cleavage fracture of blocky carbide are the wear mechanism.

**Key words**: high chromium cast iron; abrasive wear; wear mechanism; wear behavior; martensitic transformation

High chromium cast irons (HCCIs) are widely used in various industrial processes, such as mining, milling, earth-handling, and manufacturing, which require materials possessing high resistance to wear and corrosion[1]. For instance, HCCIs are extensively used as grinding balls[2]. That is due to the multiple advantages such as high levels of strength with good ductility and fracture toughness, higher fatigue strength and wear resistance[3-5]. The wear resistance of HCCIs is mainly attributed to its high volume fraction of chromium carbides[6-8]. Meanwhile, the toughness of the matrix also contributes to the wear resistance. Besides, the high concentration of chromium helps to prevent the formation of graphite and stabilize the carbides[9].

Abrasive wear is a problem which presents extensively in mining and mineral processing, metal working industries and other application fields. Nowadays, numerous studies have been performed on microstructures and mechanical properties of HCCIs[1,3,5]. Meanwhile, some studies have also been performed on abrasive wear behavior of HCCIs. Atabaki et al. [10] researched the wear properties of two different crushers used for grinding raw materials of cement industry by pin-on-disk wear test (alumina powders of 1 and 1/4 μm were used). The results showed that abrasive wear of high chromium cast iron is lower due to the presence of $M_7C_3$ carbides on the matrix. İzciler and Çelik[2] examined the abrasive wear performance of different heat-treated boron alloyed high chromium cast iron ore grinding balls. 80 grit $Al_2O_3$ and SiC abrasive papers, and 60 grit $Al_2O_3$ and SiC abrasive particles were used. The results showed that oil-cooled specimens had massive and much larger eutectic carbides. Fan-cooled and water-cooled specimens contained petal-like eutectic carbides. The oil-cooled specimens showed the best wear resistance. Pintaude et al. [11] assessed the influence of abrasive particle size on the wear behavior of martensitic high chromium white cast iron mill balls by granite grinding tests. Results showed that the relationship between grinding body size and ground material particle size is important to the wear of grinding body.

In this study, crude abrasive wear behavior of a kind of high chromium cast iron has been investigated (alumina abrasive of 5－8 mm was used). The strain-hardening effects beneath the contact surfaces were analyzed by micro-hardness profiles, and the worn surfaces were analyzed by scanning electron mi-

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croscopy (SEM), laser confocal microscopy (LSCM) and X-ray diffraction (XRD). The main goal was to provide a deep understanding on the wear behavior and wear mechanism of HCCI.

## 1 Experimental

### 1.1 Test material

The HCCIs with nominal chemical compositions of chromium (12.9 mass%), silicon (2.97 mass%), manganese (2.67 mass%), carbon (2.83 mass%), and iron, were cast into a metal mold. The ingots were heat treated at 1050 ℃ for 4 h and cooled down to 500 ℃ immediately in salt-mixture bath (with mass ratio of potassium nitrate to potassium chloride of 1 : 3), and then austempered in salt bath (with mass ratio of potassium nitrate to potassium chloride of 1 : 1) maintained at 320 ℃ for 4 h. Finally, they were cut into specimens with the same dimensions of $\phi$60 mm × 30 mm for abrasive wear tests.

### 1.2 Abrasive wear test

The wear resistance at abrasive wear was determined by using a self-designed experimental tester (Fig. 1) against the $Al_2O_3$ particles with the Moh's hardness of 9 H for 36000 cycles. The specimens were fixed on fixture, driven by a DC motor with a normal rotation speed of 300 r/min. Four different loads of 50, 100, 150, and 200 N were applied on the test specimens against the abrasive. The required load was provided by means of adding and subtracting weight. The value of pressure was measured by pressure sensor, and displayed by matching display screen. Mass loss was determined as a function of load to a precision of 0.01 g, and then converted into the wear rate.

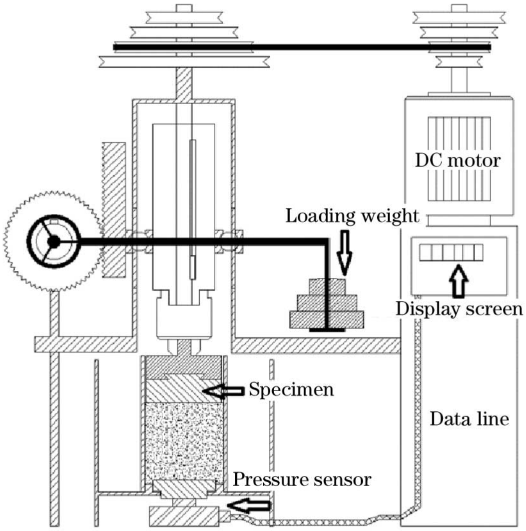

**Fig. 1 Design drawing of abrasive wear tester**

### 1.3 Characterization of specimens

The specimen without wear, worn surfaces and any change in the subsurface region were studied by using a ZEISS DV4 optical microscope, an LEXT OLS4100 laser confocal microscope and a ZEISS EVO18 scanning electron microscope. The worn surfaces were observed immediately after the test without any cleaning, and cut into longitudinal section in order to study the characteristics of the subsurface region.

The X-ray diffraction analysis was performed using an X-ray detector with monochromatic CuKα radiation, in order to study the characteristics of worn surfaces and the composition of wear debris.

The Vickers hardness values of cast, heat treated and wear test specimens were obtained from the mean of at least five suitably spaced hardness indentations using a load of 50 g. The subsurface microhardness tests were performed on all the test specimens up to a depth of 80 μm to study the extent of white-etching layer (WEL) and transition region.

## 2 Results and Discussion

### 2.1 Microstructure

#### *2.1.1 Heat treatment microstructure*

Fig. 2 shows the microstructure of high chromium cast iron after heat treatment. Martensite, retained austenite, $M_7C_3$ carbide and a small amount of secondary carbides are distributed in the matrix. The microstructure is relatively uniform except blocky $M_7C_3$ carbide.

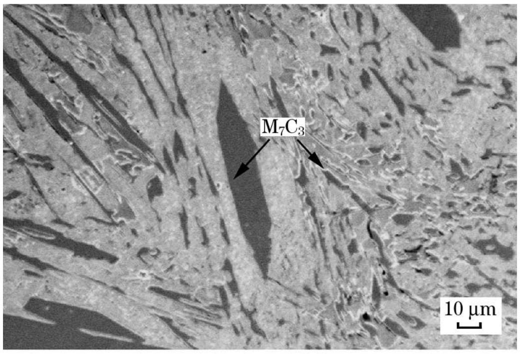

**Fig. 2 SEM image of high chromium cast iron**

#### *2.1.2 Microstructure of test specimens*

Fig. 3 presents the cross section SEM image of high chromium cast iron after wear test. It is obvious that the degree of fluctuation appearing at worn