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Effects of cryogenic treatment on microstructure and abrasion resistance of CrMnB high-chromium cast iron subjected to sub-critical treatment

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Abstract

Effects of cryogenic treatment on the microstructure, and abrasion resistance of CrMnB high-chromium cast iron subjected to sub-critical treatment were investigated by optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD), and wear test. The results show that cryogenic treatment makes the alloy present a more refined and homogeneous matrix. In the course of sub-critical treatment followed by cryogenic treatment, the amount of precipitated secondary carbide was more than that in air cooling. Cryogenic treatment can further reduce the austenite content but cannot make retained austenite transform to martensite completely. After cryogenic treatment, the hardness and abrasion resistance of CrMnB high-chromium cast iron can be improved obviously due to the precipitation of carbides, the martensite transformation, and a refined microstructure resulting from cryogenics treatment.

Keywords: High-chromium cast iron; Cryogenic treatment; Sub-critical treatment; Martensite transformation; Abrasion resistance

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1. Introduction

High-chromium cast irons have long been considered candidate materials for wear resistance components in the mining and minerals industry [1–6]. In the as-cast condition, the microstructure consists essentially of dendrites of austenite in a matrix of a eutectic mixture of austenite and M_7C_3 carbides which is harder than silica embedded in a martensite matrix that contains retained austenite resulting from heat treatment [5].

For many applications the casting are heat treated prior to service. The destabilization heat treatment and sub-critical heat treatment are techniques in common use [1,5,6]. Compared with the destabilization heat treatment, adopting the sub-critical treatment can reduce cost and avoid distortion and fissuring of castings [7].

Over the past few decades, interest has been paid in the effect of low-temperature treatment on the performance of steels. Cryogenic treatment is an inexpensive one time permanent treatment affecting the entire section of the component unlike coatings [8]. Cryogenic treatment improves certain properties beyond the improvement obtained by normal cold treatment [9]. Most researchers believe that cryogenic treatment promotes the complete transformation of retained austenite into martensite at cryogenic temperatures, which is an attribute to improve wear resistance [10]. However, some researchers suggested there was always the retained austenite after cryogenics treatment in high-chromium cast iron [11,12].

We have investigated effect of cryogenic treatment with destabilization heat treatment on high-chromium cast iron [12]. This paper was aimed at the study of effect of cryogenic treatment with sub-critical treatment on the matrix structure and abrasion resistance of CrMnB high-chromium cast iron by the means of optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD), and wear test. The results of the study are presented and discussed here.

2. Experimental procedure

The high-chromium iron was cast from 1773 K as 80 mm diameter balls into a chilled mould. The chemical composition is given in Table 1. The ball was cut into sub-critical treatment samples, cryogenic treatment samples and X-ray diffraction samples. The test samples were subjected to sub-critical treat-

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Table 1
Chemical composition of the high-chromium cast iron (mass%)

Element	Mass (%)
C	2.92
Si	0.82
Mn	3.66
Cr	13.86
P	0.06
S	0.05
B	0.5

ment at serials of test temperatures. The holding time is 1 h for each temperature. After sub-critical treatment, the samples were either air-cooled to room temperature or put into liquid nitrogen directly and held for 3 h.

The bulk hardness (HRC) was measured using a Rockwell hardness tester with a load of 1.47 kN. The microstructure was characterized by optical microscope and scanning electron microscopy after etching. The contents of the retained austenite and martensite were measured using XRD, with X'Pert Philip X-ray diffraction instrument that used a Cu Kα X-ray source and a nickel filter. A continuously rotating/tilting sample holder was used to eliminate the effect of the texture. In the wear experiment, M-200 abrasion experimental tester with the 150-girt Al_2O_3 was used. The load was 50 N and the rotational speed of the sample was 200 rpm. The losing weight of the sample was measured by TG328A photoelectric balance and the abrasive resistance was evaluated using the mean value of the tests.

3. Results and discussion

3.1. Microstructure

The microstructure of the high-chromium cast iron in the as-cast condition is illustrated in Fig. 1. Typically, the high-chromium iron consists of boron-bearing hard eutectic carbides embedded in an austenitic matrix. X-ray diffraction of the specimen (Fig. 2) shows that the microstructural constituents of the high-chromium iron are austenite, $M_7(C,B)_3$ and martensite, the contents of austenite and martensite are 39.4% and 40.2%, respectively. Using quantitative metallographic analysis, the content of the boron-bearing eutectic carbide is 20.4%.

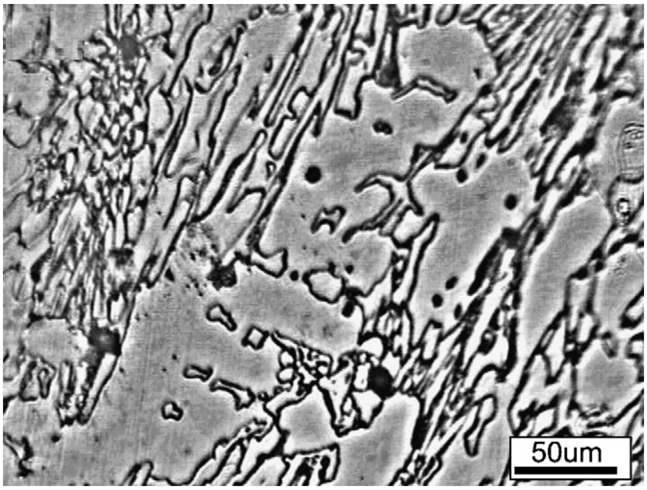

Fig. 1. The microstructure of the as-cast high-chromium cast iron.

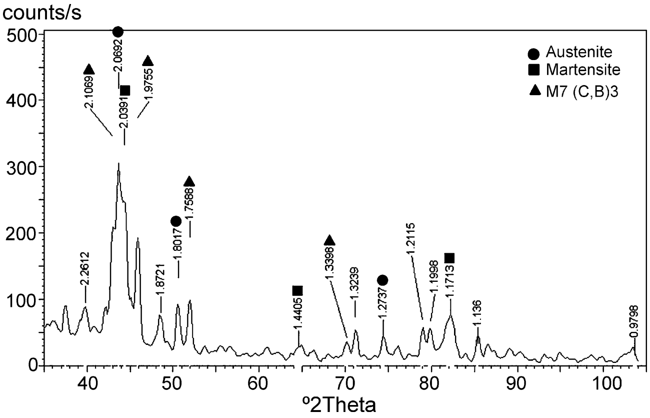

Fig. 2. The XRD pattern of the as-cast high-chromium cast iron.

Fig. 3 shows the micrographs of cryogenically treated and non-cryogenically treated samples after sub-critical treatment at 550 °C for 1 h. As shown in them, some boron-bearing secondary carbides $M_{23}(C,B)_6$ precipitated during the sub-critical heat treatment, the etched secondary carbides appear dark in the microstructure. They are distributed more homogeneously in the cryogenically treated sample than in the non-cryogenically treated one. After the cryogenic treatment, the diffraction intensities of martensite in the matrix increases. By calculation from

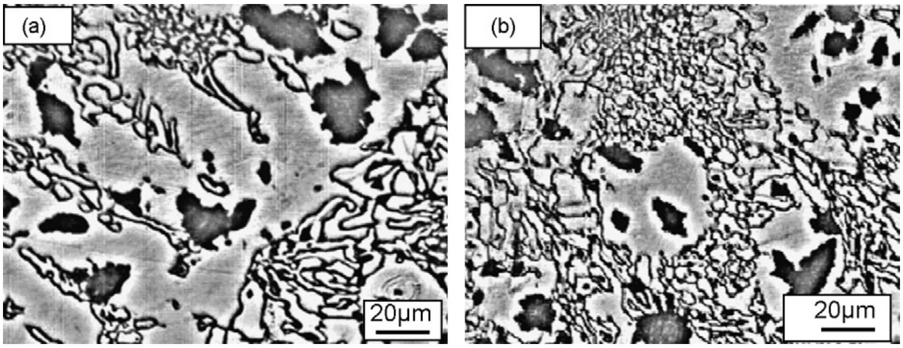

Fig. 3. The microstructure of the high-chromium cast iron: (a) air cooling after sub-critical treatment at 550 °C and (b) cryogenic treatment after sub-critical treatment at 550 °C.