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Effect of Heat Treatment on Structure and Wear Resistance of High Chromium Cast Steel Containing Boron

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Abstract: The microstructure, mechanical properties and wear resistance of high chromium cast steel containing boron after different heat treatments were studied by means of the optical microscopy (OM), the scanning electron microscopy (SEM), X-ray diffraction (XRD), hardness, impact toughness, tensile and pin-on-disc abrasion tests. The results show that as-cast microstructures of boron-free high chromium steel consist of martensite and a few $(Cr, Fe)_7C_3$ carbide, and the macro-hardness of boron-free high chromium steel is 55−57 HRC. After 0.5 mass% B was added into high chromium cast steel, as-cast structure transforms into eutectic $(Fe,Cr)_2B$, $(Cr,Fe)_7(C,B)_3$ and martensite, and the macro-hardness reaches 58−60 HRC. High temperature quenching leads to the disconnection and isolated distribution of boride, and there are many $(Cr,Fe)_{23}(C,B)_6$ precipitated phases in the quenching structure. Quenching from 1050 ℃, high chromium steel obtained the highest hardness, and the hardness of high chromium cast steel containing boron is higher than that of boron-free high chromium steel. The change of quenching temperature has no obvious effect on impact toughness of high chromium steel, and the increase of quenching temperature leads to tensile strength having an increasing tendency. At the same quenching temperature, the wear resistance of high chromium cast steel containing boron is more excellent than that of boron-free high chromium steel. High chromium cast steel guide containing boron has good performance while using in steel bar mill.

Key words: high chromium cast steel; boron alloying; microstructure, mechanical property; wear resistance

White cast iron with high chromium content is widely used in wear applications. However, white cast iron has low toughness and is not safe in impact wear condition. Many attempts have been made to improve these types of materials regarding toughness and wear resistance by adding different alloying elements like vanadium, titanium, niobium, etc[1−4]. The main objective of adding additional alloying elements is to alter the carbide structure of the material. Size and composition of the carbide can also be altered using different solidification rates or heat treatments[5−7]. Many investigations have shown that the decrease of carbon content is an effective measure for improving the toughness of high chromium cast iron. On the basis of this, the materials scientists developed cast high chromium wear resistant steel[8−10]. Nevertheless, the volume fraction of carbide is the most important parameter to obtain wear resistance, although the composition of the surrounding matrix also contributes to the total material properties. So high chromium cast steel has lower wear resistance because of lower carbon content and smaller carbide volume fraction. Steels microalloyed with boron have high hardenability[11]. Usually boron is added into the low alloy cast steel in traces like 0.003−0.005 mass%. The micro-addition of boron can improve the hardenability and increase the wear resistance of low alloy cast steel[11,12]. When the boron content in low alloy cast steel exceeds 0.5%, high hardness boride appears in the as-cast structure, and the wear resistance can be obviously increased[13,14]. In the present study, a kind of high chromium cast steel containing boron was developed which has better wear resistance than cast high

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chromium steel and higher strength and toughness than high chromium white cast iron. The aim of present study is to investigate the effect of quenching treatment on microstructure, mechanical properties and wear resistance of high chromium cast steel containing boron. High chromium cast steel containing boron has been successfully used in the rolling mill guide.

1 Experimental Procedure

1.1 Preparation of sample

The steels were melted in a middle-frequency induction furnace with a maximum melting capacity of 150 kg. After being deoxidized with aluminium at 1 600—1 620 ℃, the molten steel was transferred into a pre-heated ladle. After the removal of dross and slag, the molten steel was poured at 1480 ℃ into the metal molds to produce Y-block ingot according to Refs. [15,16]. The metal molds were preheated before casting, and the preheating temperature was 240 ℃, and the preheating time was 3 h. Moreover, high chromium cast steel guides containing boron were cast by the lost wax casting method. Final chemical composition of samples is shown in Table 1. The samples were heat-treated at 900, 950, 1000, 1050, and 1100 ℃ for 2 h, respectively, followed by oil cooling to the room temperature. Then, the samples were tempered at 200 ℃ for 6 h, followed by cooling to the room temperature in still air. Metallurgical samples were cut directly from 10 mm above the bottom of the Y-block ingot. The shape and dimension of Y-block ingot are shown in Fig. 1.

Table 1 Chemical composition of specimens mass%

Element	C	B	Cr	Si	Mn	Al	Fe
Boron-free high Cr steel	0.35	—	10.06	0.41	0.32	—	Balance
High Cr steel containing boron	0.34	0.46	10.03	0.40	0.35	0.37	Balance

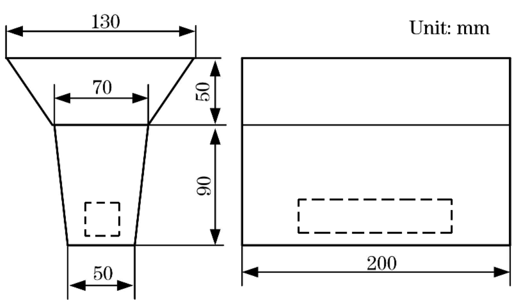

Fig. 1 Shape and dimension of Y-block ingot

1.2 Microstructure examination

The investigation techniques used for the microstructure characterization of cast high chromium steel included X-ray diffraction (XRD), optical microscopy (OM), and scanning electron microscopy (SEM). The samples were etched with 5% nital for optical microscopy examination, while a mixture of 5 mL HCl, 45 mL 4% picral and 50 mL 5% nital was used as an etchant for SEM analysis. XRD was carried on an MXP21VAHF diffractometer with copper Kα radiation at 40 kV and 200 mA. The sample was scanned in the 2θ range of 20°—80° in a step-scan mode (0.02° per step). The measurement of volume fraction of boride and borocarbides used a Leica digital images analyzer on the deeply etched specimens.

1.3 Mechanical performance tests

The tensile tests were performed on a universal material testing machine. The dimensions of specimens were ϕ 10 mm×130 mm. Three identical specimens were tested, and the ultimate tensile strength was determined from the load-displacement diagrams. The average values from three test specimens were reported here. Charpy unnotched impact tests were performed at room temperature using a 300 J capacity machine for the specimens with dimensions of 20 mm×20 mm×110 mm. Impact toughness values were also the average of three specimens. The macro-hardness testing was done using an MW32-HR-150 type hardness tester. The micro-hardness was measured by using a Vickers micro-hardness tester at a load of 0.5 N. At least seven indentations were made on each sample under each experimental condition to check reproducibility of the hardness data.

1.4 Sliding wear tests

Wear tests were conducted in an ML-10 type pin abrasion testing machine shown in Fig. 2[17]. Test load was 4.9 N, the maximum sliding distance was 16.4 m and the sliding speed was 0.1 $m \cdot s^{-1}$ for all the tests. The disk dimension was 220 mm in diameter and 5 mm in thickness. The samples were abraded on a 280 grit SiC water sandpaper. The size of the specimens was ϕ6 mm × 25 mm. The mass losses were measured by using a scale with 0.1 mg resolution. The relative wear resistance (β) is the ratio of the wear mass loss of contrast material (Cr12MoV steel) to that of boron-free high Cr steel and high Cr steel containing B respectively.