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Tribology International 39 (2006) 641–648

TRIBOLOGY INTERNATIONAL

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Effects of vanadium and carbon on microstructures and abrasive wear resistance of high speed steel

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Received 26 August 2004; received in revised form 11 April 2005; accepted 18 April 2005
Available online 21 June 2005

Abstract

The effects of vanadium and carbon on microstructures and abrasive wear resistance of high speed steel were studied. The results show that the microstructures are characterized by VC, M_7C_3 and Mo_2C in the martensite and austenite matrix. Typical morphologies of vanadium carbides are found to be spherical, lumpy, strip, and short rod. On the other hand, the vanadium carbides have three kinds of distributions, i.e. grain boundary, chrysanthemum-like, and homogeneous distributions. The abrasive wear resistance of high speed steel depends on the hardness and microstructures. When the hardness is lower than HRC58, the abrasive wear resistance of the high speed steel mainly depends on its hardness. But when the hardness is higher than HRC58, it mainly depends on the amount, morphology and distribution of VC in the matrix. Many spherical or lumpy VC carbides are obtained when vanadium and carbon content is up to 8.15–10.20 and 2.70–3.15%. The excellent abrasive wear resistance would be obtained if such VC carbides disperse uniformly in the hardened matrix of high speed steel after quenched at 1050 °C and tempered at 550 °C.

Keywords: Vanadium; Carbon; High speed steel; Abrasive wear resistance; Hardness

1. Introduction

High speed steel with high vanadium content is a newly-developed wear-resistance material that has been studied and used as steel rollers in some countries. Previous research results showed that the service life of steel rollers made of high speed steel with high vanadium content is five times longer than that of high chromium cast iron [1–6]. Since 2002, through regulating chemical compositions, the high speed steel with high vanadium content is used as hammer, jaw and rotor in crushing industry. These service lives of abrasive wear resistant parts are three times longer than that of high chromium cast iron, and ten times longer than that of high manganese steel [7,8]. Therefore, this new wear-resistance steel can be used to replace high chromium cast iron in crushing industry. The carbon and vanadium in high speed steel are two crucial elements, which decide the properties of this steel and its service life. In order to get the proper chemical compositions for abrasive wear, optimize materials selection, and promote the application of high speed steel with high vanadium content in crush industry, the effects of carbon and vanadium contents on microstructures and abrasive wear resistance of high speed steel are studied systemically in the present paper.

2. Experiment procedure

2.1. Chemical compositions designing

Two group samples were used. The first group included five kinds of specimens and designed for V/C = 3, and the actual value of V/C ratio ranged from 2.94 to 3.11, as shown in Table 1. The second group was composed of six kinds of samples and designed for 10% V. The carbon content varied from 1.7 to 3.2%. Its actual chemical compositions are 9.80–10.20% V and 1.56–3.15% C, as shown in Table 2.

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doi:10.1016/j.triboint.2005.04.035

Table 1
Chemical compositions of the first group sample (wt%)

No.	V	C	V/C	Si	Mn	Cr	Mo	P	S
V-A	5.20	1.76	2.95	0.66	0.57	4.07	0.66	0.055	0.045
V-B	6.18	2.10	2.94	0.70	0.58	4.24	0.72	0.052	0.043
V-C	7.20	2.36	3.05	0.87	0.67	4.35	0.85	0.053	0.046
V-D	8.15	2.70	3.01	0.93	0.71	4.18	0.80	0.050	0.042
V-E	9.20	2.95	3.11	0.82	0.83	4.25	0.81	0.052	0.041

Table 2
Chemical compositions of the second group sample (wt%)

No.	V	C	V/C	Si	Mn	Cr	Mo	P	S
V-1	10.10	1.56	6.47	0.70	0.80	4.15	2.70	0.056	0.044
V-2	10.05	1.92	5.23	0.75	0.78	4.20	2.80	0.051	0.041
V-3	10.06	2.25	4.47	0.88	0.85	4.26	3.01	0.053	0.046
V-4	10.20	2.52	4.05	0.83	0.88	4.15	3.10	0.054	0.043
V-5	10.04	2.84	3.54	0.80	0.92	4.18	2.85	0.055	0.044
V-6	9.80	3.15	3.11	0.72	0.89	4.16	2.78	0.051	0.045

In order to enhance the hardness of this steel, 4% chromium was added into all the samples.

2.2. Samples preparation

The steel was melted in a 50 kg medium-frequency induction furnace. To increase the absorptivity of vanadium, the ferrovanadium was added in liquid steels after preliminarily deoxidized. The residence time of liquid steel at high temperature would be shortened to enable the 90% absorptivity of vanadium. And then the melted steel was deoxidized finally. The final deoxidation was conducted by adding 0.1% pure aluminum. The modifying agent used was 0.4% SIII (mainly containing rare earth) developed by researcher. The alloy melt was poured from the furnace at about 1500 °C, and cast samples at 1450 °C. The specimen size was 20 mm×20 mm×110 mm

2.3. Heat treatment technique

The samples after casting were quenched in air at 1050 °C and tempered at 550 °C for 2 h. The heat treatment technique adopted was based on the systematic research, which have been published in other essays [7,8]. The quenching furnace was SKZ-8-13 style silicon-kryptol resistance furnace controlled by a microcomputer, and possesses a relative accuracy of ±1 °C. The tempering furnace was SKZ-8-10 resistance furnace, and possesses a relative accuracy of ±5 °C.

2.4. Mechanical properties test

The hardness of specimens was tested in HR-150A Rockwell tester. Five points were measured for every sample, with the last value as the average of the five values. The toughness of materials was tested on a JB-300B pendulum-type impact-testing machine. The size of specimens was 20 mm×20 mm×110 mm without notch, and the span was 70 mm.

2.5. Abrasive wear performance test

The wear test was conducted on a pin-disk (type ML10) friction testing machine using 120-grit alumina waterproof-abrasive sand paper. This kind of machine was widely applied by many researchers in the past years, and the standard deviation of which is not more than 3% [9–11]. The photo and diagram of testing machine is shown in Fig. 1. The samples were at the foot of the pin, and the specimens' size was 4 mm×4 mm×4 mm. The disk of testing machine turns at the speed of 70 r/min when the pin moves at the speed of 5 mm/s from center of disk to brim for 70 mm with pressure at 15.6 MPa. So the moving pathways of samples are helical line. Each sample repeatedly moved for 20 times, and then the wear weight loss of which was measured. For every group, three samples were selected, and the wear loss is average result of the three repetitions.

(a)

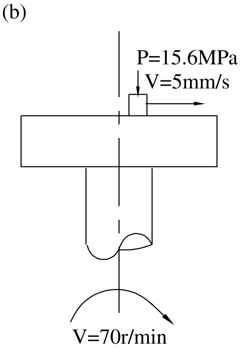
(b)


Fig. 1. The photo and diagram of testing machine. (a) Photo of testing machine. (b) Diagram of testing machine.