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Research on wear resistance of high speed steel with high vanadium content

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Abstract

Different microstructures and mechanical behaviors were obtained after vanadium and carbon contents of high speed steel were changed, and the abrasive wear property of which were studied. Results show that the wear resistance of high speed steel generally depends on the hardness and microstructures. At hardness of lower than HRC58, the wear resistance of the alloys mainly depends on its hardness. At hardness of higher than HRC58, the wear resistance of the alloys mainly depends on the amount, morphology and distribution of VC in the matrix. When vanadium and carbon content is up to 8.15–10.20% and 2.70–3.15%, respectively, the large amount of and uniformly distributed spherical or lumpy VC carbides can be obtained, which can resist the micro-cutting of Al_2O_3 abrasive, and minimizes width and depth of the furrow. This leads to the excellent wear resistance of high speed steel with high vanadium content.

Keywords: Vanadium; Carbon; High speed steel; Hardness; Wear resistance

1. Introduction

High speed steel with high vanadium content is a newly-developed wear-resistance material that has been studied and used in some countries for making steel rolls. Preliminary research results have shown that the service life of steel rollers made of high speed steel with high vanadium content is five times longer than that of cast iron with high chromium content [1–6]. Since 2002, we have applied high speed steel with high vanadium content to crush industry such as hammer, jaw, rotor, etc., for abrasive wear after regulating chemical composition. The service life of which were three times longer compared to cast iron with high chromium content and ten times longer compared to steel with high manganese content [7,8]. Therefore, with its excellent performance, this new wear-resistance material is expected to replace cast iron with high chromium content. Carbon and vanadium are two crucial elements in high speed steel, whose content decides the performance of the material and the service life of products. Aimed at abrasive-wear items for crush industry, this study determine effect of carbon and vanadium contents on microstructure and abrasive wear property of high speed steel, get the proper chemical composition for abrasive wear, optimize materials selection, and promote the application of high speed steel with high vanadium content in crush industry.

2. Experiment procedure

Two group samples were used. Consisting of five samples as listed in Table 1, the first group was designed for V/C = 3 and the actual value of V/C ranged from 2.94 to 3.11. On the other hand, the second group was composed of six samples and designed for V (wt.%) = 10%. Carbon content varied from 1.7 to 3.2%. Its actual chemical compositions are V (wt.%) = 9.80–10.20% and C (wt.%) = 1.56–3.15% (Table 2).

The alloy ingot was produced by melting the raw materials in a 50 kg intermediate frequency induction melting furnace. The final deoxidation was conducted by adding 0.1% pure aluminum. The modifying agent used was 0.4% SIII (mainly

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

No.	V	C	V/C	Cr	Mo
V-A	5.20	1.76	2.95	4.07	0.66
V-B	6.18	2.10	2.94	4.24	0.72
V-C	7.20	2.36	3.05	4.35	0.85
V-D	8.15	2.70	3.01	4.18	0.80
V-E	9.20	2.95	3.11	4.25	0.81

containing rare earth) which was developed by researcher. The melting alloys were tapped from the furnace at about 1500 °C, and cast at 1450 °C.

The specimens with the size of 20 mm × 20 mm × 110 mm were air quenched at 1050 °C for 2 h and tempered at 550 °C for 2 h. The quenching furnace used was SKZ-8-13 silicon-kryptol resistance furnace controlled by a microcomputer, with the difference in temperature at ±1 °C. On the other hand, the tempering furnace used was SKZ-8-10 resistance furnace, with the difference in temperature at ±5 °C.

The hardness of specimens was measured using an 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 20 mm × 20 mm × 110 mm smooth specimens was tested on a JB-300B pendulum-type impact testing machine without notch. The gauge length was 70 mm.

The wear test was conducted on an ML-10 friction testing machine using alumina waterproof-abrasive sand paper NO 120. The test distance was 70 mm × 20 mm, with pressure at 250 N. For every group, three samples were selected. The relative wearability was specified by ε. $\varepsilon = M_0/M$, where M_0 expresses the maximum wear loss in all the specimens, and M expresses the wear lost of each tested specimen. The amounts of wear of samples were measured using TG328B analytical balance, whose range of measurement was 0–200 mg and precision was 0.1 mg. Microstructure was observed and abrasive surface was analyzed by means of a SEM (JSM-5160LV) device and image analysis apparatus (OLYMPUS PMG3), respectively, in the experiment.

Cross-section surfaces were made by the following procedure. After an abrasive surface was protected by plastic, the specimen was cut into two parts along the direction vertical to the wear track by a line-cutting instrument. The cutting surface is made metallography surface, and the morphology of the abrasive surface and the sub- surface are observed and taken photos by SEM along the direction vertical to the wear surfaces.

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

No.	V	C	V/C	Cr	Mo
V-1	10.10	1.56	6.47	4.15	2.70
V-2	10.05	1.92	5.23	4.20	2.80
V-3	10.06	2.25	4.47	4.26	3.01
V-4	10.20	2.52	4.05	4.15	3.10
V-5	10.04	2.84	3.54	4.18	2.85
V-6	9.80	3.15	3.11	4.16	2.78

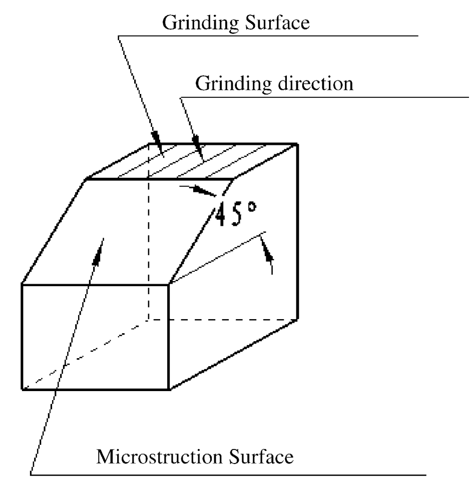

Fig. 1. Grinding Incline.

Fig. 1 is the diagram that sloping -section surfaces are made. After an abrasive surface was protected by plastic, A specimen' angle was cut out along the direction vertical to the wear track by an electric spark cutting instrument. Then the cut surface was made metallographic surface. Sequentially, the plastic protecting wear surface was dissolved in acetone solvent. The intersectant area between the wear and metallographic surface was observed and taken photos by SEM, which presented microstructure (not eroded) one side, the morphology of grinding surface the other side.

3. Results

3.1. Microstructure

The morphology and distribution of VC were observed using an OLYMPUS PMG3 image analysis system and JSM-5160LV SEM. OLYMPUS PMGS was also used to measure the vanadium carbide content according to the different color of VC from other phases. Area percent of VC was calculated by measuring the pixels of VC and total pixels of micrograph.

3.1.1. Typical microstructure

At the contents of V = 8–10%, C = 2.7–3.2%, Cr = 4%, and Mo = 3%, the typical microstructure of high speed steel with high vanadium content are composed of VC, M_7C_3, Mo_2C, M, A_{Res} (Fig. 2), with M and A_{Res} representing the martensite and retained austenite. On the other hand, Mo_2C was not found in the microstructure of the first group samples because of low Mo content (Mo = 0.8%).

3.1.2. Effect of carbon and vanadium contents on the morphology and distribution of VC

Fig. 2(a and b) shows the micrographs of the specimens at content V/C 3, which only strikingly display vanadium carbides. At V and C contents of 5.20–6.18% and 1.76–2.10%,