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Effects of carbides on abrasive wear properties and failure behaviours of high speed steels with different alloy element content

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ABSTRACT

High speed steels (HSSs) are effective materials applied in aggressive environments where abrasion resistances are required because they have hard carbides and relatively ductile matrix to bind carbides. But there are many kinds of carbides in HSSs, which lead to different effect on wear properties of HSSs. In this paper, three kinds of casting HSSs with VC, M_6C or M_2C type carbide were prepared respectively through the reasonable design of alloy elements, and then the effects of carbide type on wear behaviours were researched under different abrasive particle size and load using abrasive wear testing machine. The microstructures and failure behaviours of HSSs were analyzed by electron microscopy. The results showed the abrasive particle size and load had obvious effect on wear weight loss of high speed steel (HSS), but the carbide type decided the relative wear resistance of HSS. As the abrasive particle size or load increased, the wear weight loss of any HSS increased obviously. For the fine abrasive wear, the HSS with M_6C had higher relative wear resistance than HSS with M_2C. But the contrary was the case for the coarse abrasive wear. For any abrasive particle size and load, the HSS with VC had more excellent wear resistance than HSS with M_6C or M_2C type carbide. The relative wear resistance of HSS with VC was three times higher than that of HSS with M_6C or M_2C. The excellent wear resistance of HSS with VC was mainly attributed to VC characteristics, such as high hardness and good morphology, which can resist micro-cutting of abrasive particles efficiently.

1. Introduction

High speed steels are characterized by many high hardness carbides such as M_6C, M_2C and MC distributed in matrix composed of martensite and austenite with high strength and toughness, so they have excellent wear resistance under extreme wear conditions [1–4]. In recent years, HSSs have been applied for rolls. The previous research results showed that HSSs, compared with high chromium cast iron, have more excellent wear resistance because they have stiffer carbides and more excellent red hardness [1,2,5–7].

Recently, the pulverization industry develops rapidly. Large amounts of wear-resistant parts such as hammerhead, jaw plate and lining board were consumed in pulverization industry. The high chromium cast iron or high manganese steel is often used to manufacture the wear-resistance parts [8,9]. However, the serving life is not satisfactory because it is difficult for the two kinds of materials to resist severe abrasive wear in the process of service. In the previous research, it was proved that HSSs with high hardness carbides can resist rolling/sliding wear effectively when they are used for rolls [2–5,10,11]. To improve the serving life of wear-resistant parts in pulverization industry, we developed HSSs enhanced by VC carbides based on the above research results, and researched on the abrasive wear property [12–14]. The results show the HSSs with VC carbides have more excellent wear resistance than high chromium cast irons and high manganese steel [15,16]. Nevertheless, there are many kinds of carbides in HSSs, such as VC, M_6C and M_2C. The different carbide type may have different effects on the wear properties of HSSs. In the paper, three kinds of casting high-speed steels with VC, M_6C or M_2C type carbide respectively were prepared through the reasonable design of alloy elements, and then the effects of carbide type on abrasive wear behaviours were researched under different abrasive particle size and load.

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2. Experimental methods

2.1. Chemical compositions

The chemical compositions of HSSs were fabricated according to conventional HSSs. In order to obtain VC, M_6C and M_2C carbides respectively, about 10 wt% vanadium, 10 wt% tungsten or 10 wt% molybdenum was added into three kinds of HSSs, respectively. Accordingly, the three kinds of HSSs were also named V10, W10 and Mo10, respectively.

In addition, approximate 4 wt% chromium was mixed in the tested alloy to ensure the realization of a high-hardness HSS. Based on the method of definite proportion of carbon, the effect of secondary hardening is optimal when alloy elements and carbon contents meet the constant proportion of molecular formula of carbide, so the carbon contents in HSSs were designed according to the method of definite proportion of carbon [17]. The actual chemical compositions of the three kinds of materials are listed in Table 1.

Table 1
Chemical compositions of HSSs (wt%).

Materials	C	V	W	Mo	Cr	Mn	Si	S、P	RE
V10	2.95	9.96	—	2.31	4.13	0.76	0.62	≤ 0.03	0.4
W10	1.30	—	10.02	2.20	4.20	0.82	0.60	≤ 0.03	0.4
Mo10	1.43	—	—	10.01	4.20	0.78	0.59	≤ 0.03	0.4

2.2. Preparation of samples

The alloy ingots were produced by melting the raw materials in a 50 kg intermediate frequency induction melting furnace. The deoxidation was conducted by adding 0.1% pure aluminum. The melting alloys were tapped from the furnace at approximate 1500 – 1550 °C and casted at 1450–1480 °C.

The samples were austenized at 1050 °C for 40 minutes, air quenched, and then three times tempered at 560 °C. A silicon-kryptol resistance furnace (SKZ-8–13) was the quenching furnace used in this study and it was controlled with a microcomputer. A resistance furnace (SKZ-8–10) was the tempering furnace used in this study.

2.3. Mechanical properties test

The macro-hardness of the specimens was measured using an HR-150A Rockwell tester. The Vickers hardness was tested using a micro-hardness tester (HVS-1000A) with a load of 200 g and a dwell time of 20 s. Five points were measured for each sample, and the last value was the average of the five values. The toughness of a 20 mm × 20 mm × 110 mm smooth specimen was tested on a JB-300B pendulum-type impact testing machine, and the gauge length was 70 mm.

2.4. Wear performances test

The wear test was conducted on a pin-on-disk (type ML-100) wear testing machine using grit alumina water proof abrasive sand paper, and the abrasive particle sizes of sand papers were 4.5 μm, 8.5 μm, 28 μm and 58 μm, respectively. 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% [14,18]. The diagram of testing machine is shown in Fig. 1. The samples were pins, and the specimens' size was φ5 mm × 30 mm. The disk of testing machine turned at the speed of 70 r/min when the pin moved at the speed of 5 mm/s from center of disk to brim for 70 mm with pressure at 0.50 Mpa, 0.76 Mpa, 1.27 Mpa and 2.55 Mpa, respectively. So the moving pathways of samples are helical line. Each sample repeatedly moved for 10 times, and then the wear weight loss of which was measured. For every group, three samples were selected, and the weight loss is the average result of the three repetitions. The wear resistance was specified by β with $\beta = W^{-1}$. The weight loss of sample was measured using a TG328B analytical balance, which ranges from 0 to 200 g and possesses a relative accuracy of 0.1 mg. The relative wear resistance was specified by ε ($\varepsilon = \beta/\beta 0 = W0/W$).

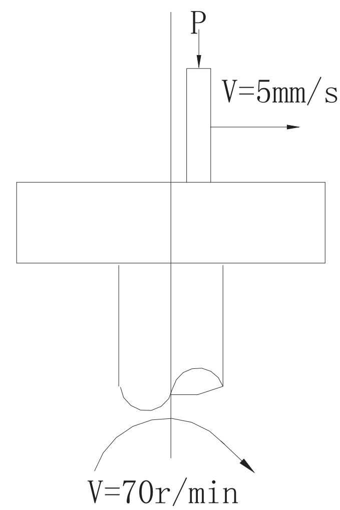

Fig. 1. The diagram of testing machine.

2.5. Microstructures analysis and worn surface observation

The microstructure and worn surface of the HSSs were observed using JSM-5160LV type scanning electron microscope (SEM). The phase structures of carbides and matrix in HSSs were analyzed using X-ray diffraction (XRD).

3. Results

3.1. Microstructure of HSSs

Fig. 2 shows the microstructures of HSSs. The HSS with high vanadium content was characterized by primary lump VC carbides evenly distributed in matrix composed of martensite and austenite [Fig. 2(a) and (b)]. However, the carbide of HSS with high tungsten content was primary fishbone-like M_6C carbides, which were distributed in matrix composed of martensite and austenite [Fig. 2 (c) and (d)]. In the process of heat treatment, some fine secondary carbides precipitated from matrix. The molybdenum element in HSS with high molybdenum content mainly formed M_2C-type carbide with lamellar structure [Fig. 2(e) and (f)]. The M_2C-type carbides were mainly distributed at the grain boundaries of matrix composed of martensite and austenite.

3.2. Mechanical properties of HSSs

Table 2 shows the hardness and impact toughness of the experimental HSSs. After heat treatment, the hardness of all the tested three HSSs was higher than 60HRC. Besides, the Mo10 has slight higher hardness than V10 and W10. The V10 had higher impact toughness than the other two kind of HSSs. Fig. 3 shows the fracture morphologies of HSSs. It can be seen from Fig. 3 that all the three kinds of HSSs were mainly brittle fracture type. The V10 had much finer grains on the fracture surface than W10 and