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Surface failure behavior of 70Mn martensite steel under abrasive impact wear

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ABSTRACT

The aims of this paper are to reveal the surface failure behavior of 70Mn martensite steel under abrasive impact wear by impart wear tests. The wear tests were performed with the MLD-10 abrasive wear testing machine, using SiO_2 abrasive with three different impact loads for 30000 cycles. Worn surfaces and white-etching layers (WEL) were analyzed by scanning electron microscopy, x-ray diffraction and transmission electron microscopy, and the abrasive impact wear mechanism was analyzed. Strain-hardening effects beneath the contact surfaces were researched by Micro-hardness profiles. Results indicated that the main formation mechanism of white-etching layers (WEL) in test steel were the formation of twin martensite and accumulation of dislocations attributing to plastic deformation during impact wear tests. The thickness and hardness of WEL were both increased with test load, which led to an increased brittleness of WEL. Under the effects of impact load, the micro-cracks initiated at subsurface and extended to surface, eventually led to delamination and fracture. Therefore, the delamination and fracture resulting from plastic deformation fatigue were the primary surface failure mechanism of the steel at abrasive impact wear.

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1. Introduction

Martensite steel with high wear resistance has been widely used in several structural applications, such as mining, milling, automotive, railroad, construction, defense, etc., which is attributed to the multiple advantages of martensite steel such as high levels of strength and wear resistance. As one of common martensite steels, 70Mn martensite steel is extensively used in grinding balls. The good wear resistance of 70Mn martensite steel is mainly attributed to the high volume fraction of martensite, and a small number of retained austenite is good for toughness [1].

Abrasive wear is a problem presenting extensively in mining and mineral processing, metal working industries among other applications. Nowadays, many studies have been focused on the wear behavior of wear-resistant materials, especially the abrasive wear and impact wear behavior. Shao et al. [2] researched the impact assessment of 2Cr13 martensite stainless steel on a specifically developed ball-on-flat impact tester. Results showed that the main form of wear under repetitively impact was fatigue spalling. Gündüz et al. [3] studied the sliding wear behavior of carbon micro-alloyed steels on a 320 mesh SiC paper, and found that the higher hardness and wear resistance were due to martensite phase in water cooled sample which contained higher amount of carbon in solid solution. Lin et al. [4] researched the wear behavior of hardened medium carbon steel. Xu et al. [5] studied the wear behavior of high-vanadium high-speed steel under high-stress rolling–sliding contact.

White etching layer (WEL) is an important characteristic of the friction surface, usually very hard to etch and no obvious characteristics of the hardening layer under optical microscope, which has important influence on friction and wear properties of materials. WEL thickness is approximately 0.1–100 μm, most commonly a thickness of 10–50 μm, which, depending on the forming condition and the original organization. The main feature is that its hardness is up to 1300 HV, but commonly is in the range 700–1200 HV [6]. In addition, different angles of micro-cracks are widespread in the white layer, which has very important influence on wear behavior of further [7,8]. Yang et al. [8] proposed that when the microcracks inside the WEL propagate along the path parallel to the worn surface (WS), the delamination occurs along the boarder of the WEL and WS, and microcracks propagate along the direction which is parallel to flow lines in the deformation zone, the spalling occurred. Although numerous studies [9–11] have been performed on WEL, the explanation of the formation mechanism is not identical. There are mainly two views: one is supposed that dynamic recrystallization occurs in the band of WEL

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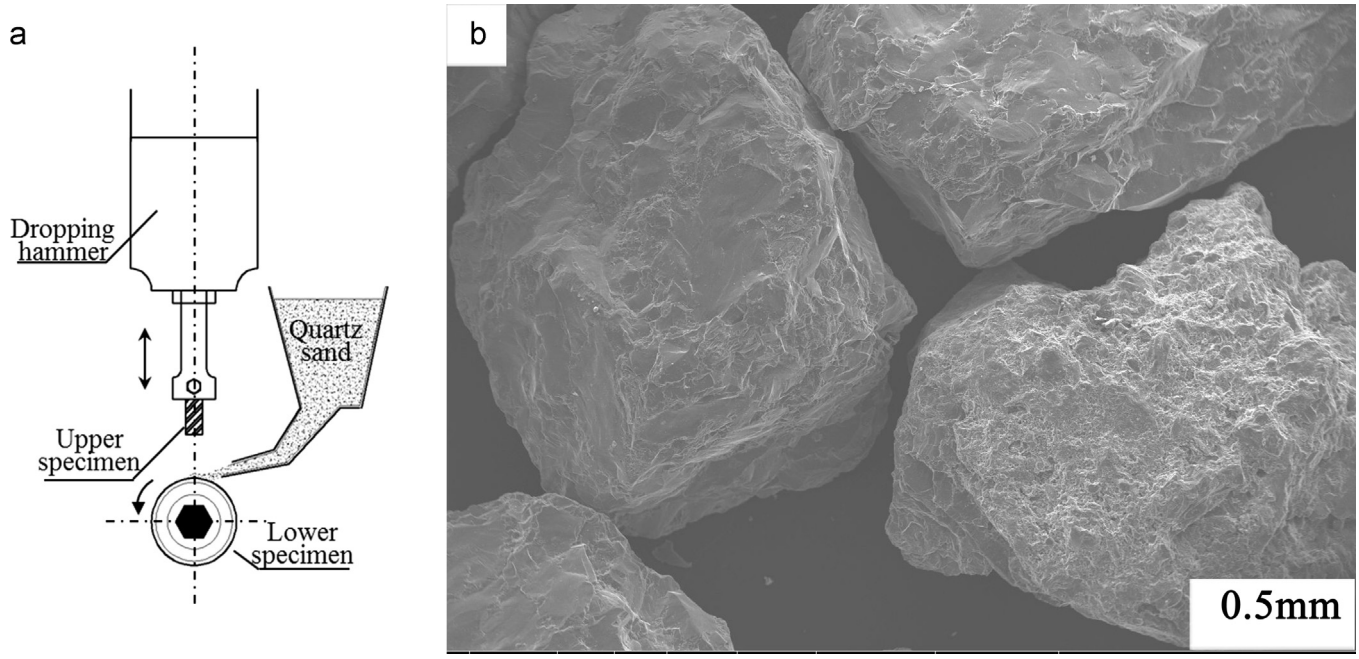

Fig. 1. MLD-10 impact tester (a) and SEM micrograph of abrasive particles (b).

whereas dynamic recovery takes place [10], another formation mechanism is ascribed to the strong plastic deformation [11].

In this study, the surface failure behavior of 70Mn martensite steel was investigated by impact wear test. The strain-hardening effects beneath the contact surfaces were analyzed by micro-hardness profiles. The worn surfaces were analyzed by scanning electron microscopy (SEM), and the formation mechanism of WEL was discussed according to transmission electron microscopy (TEM). The main goal was to provide an increased understanding of the wear performance of 70Mn martensite steel and formation mechanism of WEL.

2. Experiment

2.1. Experimental material

The experimental material was prepared by forging and heat treatment, and the chemical composition is presented in Table 1. The initial forging temperature and final forging temperature were 1100°C and 950°C respectively. After the forging, the experimental material was air-cooled to 840 °C and water-quenched, then tempered at 200 °C for 2 h. The Vickers hardness of samples were also measured using calibrated standard hardness-testing machine.

2.2. Impact wear test

The wear resistance at abrasive impact wear (AIW) was determined with an experimental impact tester MLD-10 (Fig. 1(a)) against the friction wheel for 30000 cycles. The linear speed of rotating friction wheel was 0.2 m s^{-1}. The lower specimen was a quenched carbon steel (carbon content of 0.44 wt%, hardness of 55 HRC) with the size of 15 mm (thickness) × Φ30 mm (inner diameter) × Φ50 mm (external diameter), Ra = 1.6 μm. The upper specimen was the tested materials with the size of 10 mm × 10 mm × 30 mm. Prior to wear testing, specimens were mechanically ground upto Ra = 0.2 μm,▿ = 9, cleaned ultrasonically, dried and eventually weighed by an electronic weighing scale (with 0.1 mg accuracy). The impact frequency was 150 times/min and impact energy of 1.5 J, 2.5 J and 3.5 J were applied (corresponding to impact hammer falling body height of 15 mm, 25 mm and 35 mm, respectively). Impact energy is defined as:

Table 1
Chemical composition of 70Mn martensite steel and hardness in normalized condition.

Element	C	Si	Mn	P	S	Fe	Hardness (HV)
Weight%	0.75	0.3	1.1	< 0.1%	< 0.04%	Bal	625

$$A_k = P \times H \quad (1)$$

where P is impact hammer free-fall height (mm), H is impact hammer weight 10 kg.

All samples were ground with SiO_2 particle (with particle size 0.5–1.5 mm was used; particle flow rate of 1 cm^3 s^{-1} and feeding angle of 80°), the density of particle was 2.6 g/cm^3, the SEM micrograph of abrasive particles as shown in Fig. 1(b). The hardness of SiO_2 was measured by a Nano Indenter XP with 11.27 GPa. Weight loss was determined as a function of load cycles to a precision of 0.01 g and then converted into the wear rate (the formula is shown in Section 3.3). The weight loss was measured every 3000 cycles, each test at a given impact load and test time was repeated three times with identical new samples, and the data for average mass loss after each interval of time were used for the analysis of wear rate.

2.3. Micro-hardness test

The Vickers hardness values of cast and heat treated samples were measured by means of at least three suitably spaced hardness indentations using a load of 100 g by a LEICA-VMHT 30 M. The surface and subsurface hardness measurements were also made with a 100 g load. The subsurface micro-hardness tests were performed on all the test samples up to a depth of 1 mm to study the extent of deformed zone.

In the process of impact wear samples subjected to impact deformation is serious leading to the abrasion surface for the deformation of the largest part of the specimen the bulge in the

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