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Effect of tempering conditions on wear resistance in various wear mechanisms of H13 steel

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ABSTRACT

In dry sliding wear of H13 steel, with increasing ambient temperature and load, the wear mechansim changed from adhesive wear to oxidative mild wear and finally to oxidative wear. In adhesive wear, the specimens tempered at 600, 200 and 440 °C presented higher wear resistance than the ones tempered at 500, 650 and 700 °C. In oxidative wear, the wear resistance increased in the following order: the specimens tempered at 700, 500, 200, 650, 440 and 600 °C. Wear resistance was suggested to depend on hardness and fracture resistance in adhesive wear and on the formers and thermal stability in oxidative wear.

1. Introduction

H13 steel as a hot-working die steel possesses high elevated-temperature strength and ductility, good tempering resistance and moderate cost, thus is widely utilized for plastic injection molding, die casting, forging and extrusion [1]. In hot-working processes, continuous mechanical and thermal loadings are applied to dies, finally leading to a heavy damage of the die surface. Thereinto, the wear has been proved to be an important limiting factor in the service life of dies. Therefore, the elevation of wear resistance of hot-work die steels has become one of the important concern to die researchers [2–4].

Generally, the wear resistance of a given material has close relation with its microstructure or heat-treatment process. So the researches on the effect of microstructure or heat-treatment process on the wear resistance are of important engineering value. Sawa et al. [5] found that the wear behavior of a dual phase steel depended strongly on the shape, size and distribution of martensite. Kim et al. [6] pointed out that the wear resistance of a carburized steel first decreased and then increased with increasing retained austenite content under a high normal load condition. Wang et al. [7] reported that despite their original high-hardness structure, 52100 and 1080 steels did not exhibit a better wear resistance; the wear resistances of various microstructures increased in the following order: martensite + carbide + retained austenite, spheroidized structure, martensite, bainite, lamellar pearlite. The favorable wear resistance of the pearlitic structure was reported to be attributed to its high work hardening in sliding contact [8]. However, the relationship between microstructure and wear resistance has been not clarified to date due to complicated sliding conditions that prevail different wear mechanisms.

Abouei et al. [9] pointed out that the friction and wear of the steels were related to the microstructure and the wear mechanism. In our previous work concerning the wear characteristics of H13 steel with various tempered states, it was found that the wear resistance strongly depended on the tempered conditions [10]. However, this primary work was merely performed under a load of 150 N at 25–400 °C. It is clear that this work lacks a systematical study and the relationships among the wear resistance, microstructure and wear mechanism need further exploration.

In the present study, wear test was carried out under a load ranging from 50–200 N at 25–400 °C. Friction, wear behaviors and mechanisms under various sliding conditions were systematically studied by examining morphology, composition and structure of the worn surface, subsurface and debris. On this basis, the effect of tempered conditions on the wear resistance of H13 steel under various sliding conditions was elucidated.

2. Experimental procedure

Dry sliding wear tests were carried out on a MG-200 type pin-on-disc high temperature wear tester. A commercial H13 steel

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containing Fe–0.38% C–5.15% Cr–1.45% Mo–0.90% V was selected as the pin with dimensions of 6 mm diameter and 12 mm length. A commercial D2 steel (Fe–1.51% C–11.52% C–0.45% Mo–0.21% V) was chosen as the discs with dimensions of 70 mm diameter and 8 mm thickness. The H13 steel was austenitized at 1040 °C for 20 min and oil quenched to attain a martensite plus a small amount of retained austenite (55 HRC), subsequently tempered at 200, 440, 500, 600, 650 and 700 °C for 2 h and cooled in air, respectively. The D2 steel was austenitized at 1150 °C, oil quenched and then tempered twice at 550 °C for 2 h to achieve a hardness of 60 HRC.

Wear tests were performed at the ambient temperatures of 25, 200 and 400 °C and the normal loads of 50, 100, 150 and 200 N. The sliding distance was 1.2×10^3 m and the sliding velocity was controlled at 1 m/s. Prior to each test, the contact surfaces of the pins and discs were prepared by grinding against a 400-grit silicon carbide paper to attain a R_a value of about 0.45 μm and then cleansed with alcohol.

Wear was determined by measuring the mass loss of the pin specimen using an electronic balance with an accuracy of ±0.01 mg. Each measurement was preceded by an ultrasonic washing in acetone and drying of the specimens. The mass loss was then converted into volume loss using a density of 7.76 g/cm^3, thus the wear rate was calculated from volume loss divided by sliding distance. Each data and deviation came from three or five wear tests. Friction coefficient was also recorded during the test.

Phase on the worn surface was identified by a D/Max-2500/pc type X-ray diffractometer (XRD) with Cu Kα radiation. Morphology and composition of the worn surface, subsurface and wear debris were examined by a JSM-7001 F type scanning electron microscope (SEM) and an Inca Energy 350 type energy dispersion spectrometer (EDS). Microhardness distribution from the worn surface to the substrate was measured using a HVS-1000 type digital microhardness tester. Hardness and impact toughness of the steel were determined using a HR-150 A type Rockwell apparatus and a JBGD 300 type high and low temperature impact test machine, respectively.

3. Results and analysis

3.1. Microstructure and mechanical property

The H13 steel was austenitized at 1040 °C for 20 min and oil quenched to attain a martensite plus a small amount of retained austenite, subsequently tempered at 200, 440, 500, 600, 650 and 700 °C for 2 h and cooled in air, respectively. SEM micrographs of quenched martensite and the typical tempered microstructures of the steel are shown in Fig. 1.

The variations of the hardness and impact toughness of H13 steel with tempering temperature are shown in Fig. 2. The hardness first slightly decreased with increasing tempering temperature. When tempering temperature reached 440 °C, alloy carbides started to precipitate. A secondary hardening with

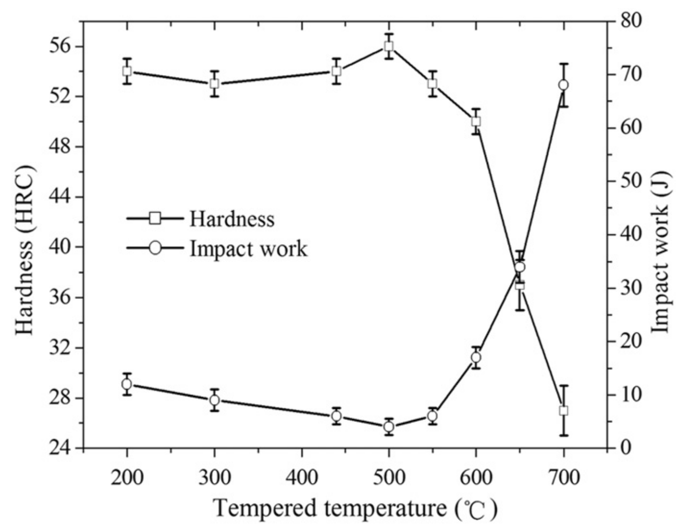

Fig. 2. Variations of hardness and impact work with tempering temperature in H13 steel.

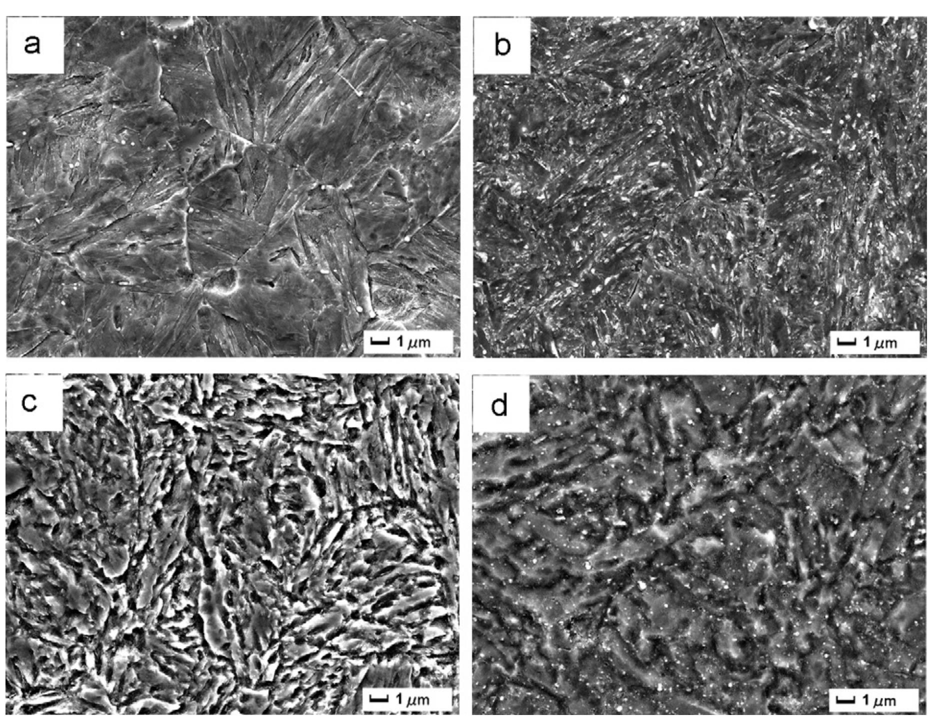

Fig. 1. SEM micrographs of quenched martensite (a) and the typical tempered microstructures of the specimens tempered at 200 (b), 650 (c) and 700 °C (d).