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Influence of different cryotreatments on tribological behavior of 80CrMo12 5 cold work tool steel

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ABSTRACT

This experimental study investigated the effect of cryogenic treatments on the wear behavior of 80CrMo12 5 tool steel. For this purpose, two different cryogenic temperatures were used: −80 °C as the shallow cryogenic temperature and −196 °C as the deep cryogenic temperature. The results showed that the cryogenic treatments decrease retained austenite, which is more effective in the case of the deep cryogenic treatment (DCT). As a result, a remarkable improvement in the wear resistance of the cryogenically treated specimens was observed. In addition, DCT increases the percentage of carbides and their homogeneity in distribution. An optimum holding time was found in the deep cryogenic temperature, in which the hardness and wear resistance show maximum values. Moreover, the wear debris and worn surfaces showed that the dominant mechanism in the wear test is adhesive.

1. Introduction

Cryogenic treatment is a supplementary heat treatment that is performed on some tool steels before tempering as an effective method for decreasing residual stress, retained austenite and increasing wear life. Two types of cryogenic treatments are generally applied as follows: (1) the shallow cryogenic treatment which is performed between −60 °C and −90 °C; (2) the deep cryogenic treatment that is conducted at temperatures below −125 °C [1]. The cryogenic treatment consists of controlled cooling of conventionally hardened specimens to a selected temperature, holding for a certain period, followed by controlled heating back to the ambient temperature for subsequent tempering. The cryogenic treatment enhances the transformation of retained austenite (as a soft and unstable phase) to martensite (as a promising phase) and subsequently increases the hardness and wear resistance [2]. In the deep cryogenic temperatures, as well as retained austenite elimination, fine dispersed eta (η) carbides are precipitated. This higher proportion and more homogenized distribution of carbides are due to the crystal lattice contraction. In the deep cryogenic temperatures, the lattice contraction forces carbon atoms to diffuse out to neighbor dislocations and defects [3]. Moreover, some new dislocations are created in the deep cryogenic treatment as a result of a difference in the thermal expansion of austenite and martensite. This new dislocations provide suitable places for the segregation of carbon atoms and subsequently carbide nucleation in tempering. Thus, during tempering, these carbon atoms would produce new carbides, thereby leading to more homogenized carbide distribution [4–6]. Several investigators studied the cryogenic process and compared the effect of the cryogenic treatment on the wear behavior, hardness, tensile and other mechanical properties of different materials. The cryogenic treatment is conducted on different materials including tools steels [7–10], carburized steels [11,12], maraging steel [4,13], cast iron [14,15], tungsten carbide [16] and polymers [17].

Recent studies showed that the cryogenic treatment generally improves the wear resistance and hardness of tool steels. The wear resistance improvement varies from a few to a few hundred percentages in different kinds of steel [2–10]. In contrast, some researchers have been skeptical about the process and claimed that there is no noticeable difference in steels after and before the cryogenic treatment [18,19].

The present work compared the wear resistance of 80CrMo12 5 tool steel samples processed by conventional heat treatment (CHT), shallow cryogenic treatment (SCT) and deep cryogenic treatment (DCT) using a pin-on-disk wear tester. Moreover, these experiments tried to unfold the influence of the duration of the deep cryogenic treatment on the structure and wear behavior of the 80CrMo12 5 tool steel. To reveal the effect of cryogenic holding time and temperature on the wear behavior of the 80CrMo12 5 tool steel, the microstructure, hardness, morphology of wear surface and wear derbies were evaluated.

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Table 1
Chemical composition of the 80CrMo12 5 tool steel (wt.%).

Elements	Wt.%
%C	0.8
%Si	0.85
%Mn	0.25
%Mo	0.5
%Cr	3.06
%S	<0.005
%P	<0.009
%Fe	Remaining

Table 2
Heat treatment condition of the 80CrMo12 5 tool steel.

Sample no.	Heat treatment	Nomenclature
1	Conventional heat treatment	CHT
2	Shallow cryogenically treated at −80 °C for 24 h	SCT24
3	Deep cryogenically treated at −196 °C for 0 h (warm up the sample after reaching at −196 °C)	Instant DCT
4	Deep cryogenically treated at −196 °C for 6 h	DCT6
5	Deep cryogenically treated at −196 °C for 24 h	DCT24
6	Deep cryogenically treated at −196 °C for 48 h	DCT48
7	Deep cryogenically treated at −196 °C for 72 h	DCT72
8	Deep cryogenically treated at −196 °C for 168 h	DCT168

2. Experiments

The experimental testing was conducted on the 80CrMo12 5 commercial tool steel with a nominal composition reported in Table 1. The wear test samples were cut into disk shapes (dia 5 cm × 0.4 cm) using wire electron-discharge machining. To reach a uniform and smooth wear surface, the samples were machined and then ground up to 600 mesh papers, reaching a 0.4 μm surface roughness.

For conventional heat treatment (CHT), the samples were preheated at 620 °C for 20 min and then austenitized at 920 °C for 20 min. Then, the samples were quenched in oil to room temperature and tempered at 150 °C for 3 h.

To compare the effect of the cryogenic treatment on the mechanical properties of the 80CrMo12 5 tool steel, the samples were cryogenically treated in two different temperatures. For the shallow cryogenic treatment, after quenching, the samples were cooled to −80 °C with the cooling rate of 1 °C/min. The samples were held at the same temperature for 24 h and then heated up to room temperature. Tempering was conducted at 150 °C for 3 h (SCT24). For the deep cryogenic treatment, the samples were uniformly cooled to −196 °C with the cooling rate of 1 °C/min, held for 24 h and heated up to room temperature with the heating rate of 1 °C/min. Afterward, the samples were tempered at 150 °C for 3 h (DCT24). The details of DCT24 are illustrated in Fig. 1.

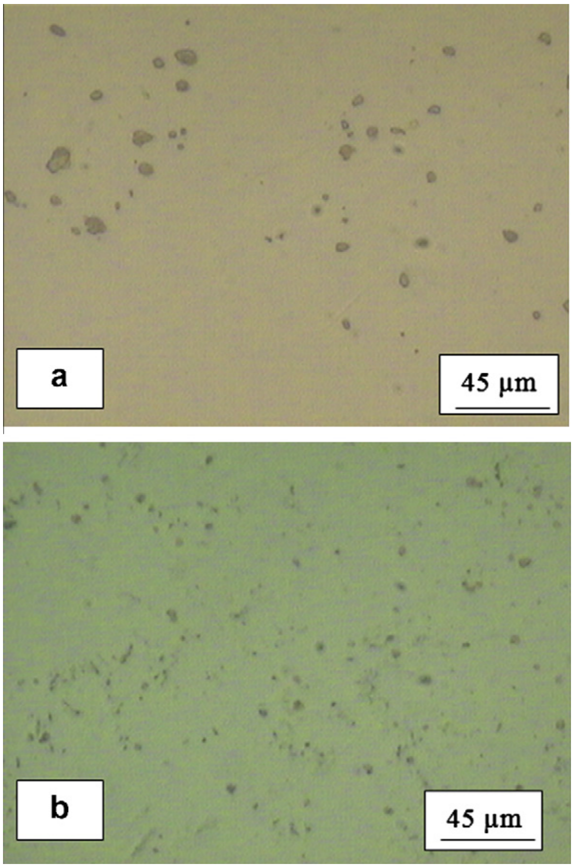

Fig. 2. Optical microscope images of the carbide particles: (a) CHT and (b) DCT24 samples.

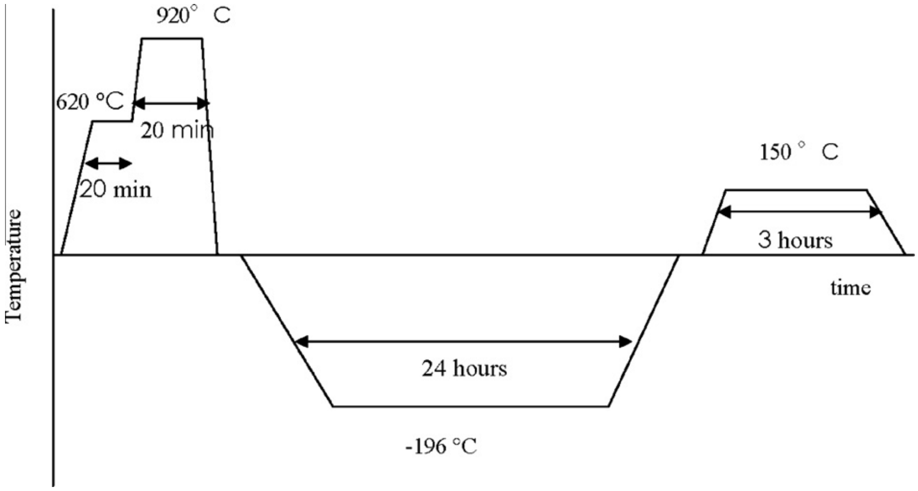

Fig. 1. Schematic presentation of deep cryogenic processing cycle for DCT24 sample.