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Effect of Cryogenic Treatment on Properties of Cr8-Type Cold Work Die Steel

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Abstract: The effect of cryogenic treatment on the properties of Cr8-type cold work die steel was investigated. The results show that cryogenic treatment increases hardness by decreasing retained austenite, but the degree depends on the austenitizing temperature. When quenching at lower austenitizing temperature, the steel can obtain higher toughness by cryogenic treatment substituting conventional treatment process. Cryogenic time has little effect on cryogenic treatment. Conversely, cryogenic temperature has a great effect on cryogenic treatment and the effect of cryogenic treatment is more obvious with decreasing cryogenic temperature. In addition, deep cryogenic treatment improves the wear resistance by precipitating more homogeneous specific carbides.

Key words: cryogenic treatment; tool steel; cold work die steel; property; wear resistance

With rapid development of modern manufacturing technology, the requirements to precision and service life of cold work die steel become higher and higher. Moreover, the most important factor to service life is the wear resistance of the die materials[1]. Cryogenic treatment, as an effective way to improve the properties of tool steels, is widely used for high precision parts and components. Several papers have been published that cryogenic treatment can improve wear resistance of tool steels[2-4]. The common practice identifies −60 ℃ to −80 ℃ as treatment temperature called shallow cryogenic treatment (SCT). Deep cryogenic treatment (DCT) ranging from −125 ℃ to −196 ℃ improves certain properties beyond the improvement obtained by normal cryogenic treatment. And the greatest improvement in properties is obtained by carrying out the deep cryogenic treatment between quenching and tempering[5]. In recent years, a new kind of Cr8-type cold work die steel has been widely used due to its high-strength and high-toughness. The steel have obvious secondary hardening effect after two times tempering at 520 ℃[6]. However, the effect of cryogenic treatment on this type steel has not been studied extensively. In this work, SCT and DCT were applied to the Cr8-type cold work die steel named Cr8WMo2V2Si for investigating their effect on the properties. In addition, the effects of cryogenic time and austenitizing temperature on cryogenic treatment were also investigated.

1 Experimental Material and Procedure

The nominal composition of the test steel is shown in Table 1. In order to investigate the effect of cryogenic temperature and cryogenic time on cryogenic treatment, four treatment cycles were carried out as shown in Table 2. In this table, Q is quenching, T is tempering at 520 ℃ for 1 h, S is shallow cryogenic treatment at −80 ℃, and DCT is deep cryogenic treatment at −196 ℃. The cryogenic treatment was carried out after quenching. In this case, the samples were direct immerged in liquid nitrogen after oil-quenching from austenitizing temperature in B, C and D treatment cycle. In cycle D, the

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Table 1　Nominal composition of the test steel (mass percent, %)

C	Si	Mn	Cr	Mo	W	V
1.00	0.90	0.35	8.10	2.10	1.00	2.10

Table 2　Treatment cycle of experiment

Code	Treatment cycle
A	Q+T+T
B	Q+DCT_1+T
C	Q+DCT_2+T
D	Q+S+T

Note: DCT_1—Direct immersion in liquid nitrogen for 1 h; DCT_2——Direct immersion in liquid nitrogen for 4 h.

liquid nitrogen had already been mixed to −80 ℃ by alcohol. In addition, in order to investigate the effect of austenitizing temperature on cryogenic treatment, two austenitizing temperatures were used which signed as No. 1 (1 100 ℃) and No. 2 (1 140 ℃) respectively before the letter.

The size of the samples which were used in Charpy U-notch impact toughness test were 10 mm×10 mm×55 mm. Wear test were carried out by dry sliding test on M-200 wear tester. The contents of the retained austenite and phase analyses were measured using XRD with the X-ray diffraction instrument having a CuKα X-ray source. The microstructure observation was carried out by transmission electron microscope (TEM).

2　Results and Discussion

Table 3 shows the hardness and impact energy of the test steel after treated by different treatment cycles. The results show that cryogenic treatment, when carried out after quenching at 1 100 ℃, does not increase hardness in cycle 1C and even decreases hardness in cycle 1D. But it increases impact toughness in cycle 1B and 1C. When cryogenic treatment is carried out after quenching at 1 140 ℃, it increases hardness and decreases impact toughness. These results can exposit the effect of austenitizing temperature on cryogenic treatment that austenitizing temperature has an important effect on the properties of the steel in cryogenic treatment. It is more obvious that cryogenic treatment causes the increase of hardness at higher austenitizing temperature. This is useful for obtaining differently desired properties by using of different treatments. A lower austenitizing temperature can be selected to obtain higher impact toughness without losing hardness or a higher austenitizing temperature can be selected to obtain higher hardness in cryogenic treatment. Actually, all the phenomena are due to the different content of retained austenite. Table 4 shows the content of retained austenite of different treatment cycles and the corresponding XRD patterns are given in Fig. 1. Higher austenitizing temperature lower the M_s by dissolving more of the excess carbides in the austenite prior to the quench[7]; the lower the M_s is, the higher the content of retained austenite. So the content of retained austenite is higher when quenching at 1 140 ℃. After two times tempering, the content of retained austenite when quenching at 1 140 ℃ is still higher than that of quenching at 1 100 ℃. But after deep cryogenic treatment, the content of retained austenite when quenching at 1 140 ℃ is lower than that of quenching at 1 100 ℃. It is proved that deep cryogenic treatment is an effective way to decrease retained austenite. However, the effect depends on the austenitizing temperature and the higher the austenitizing temperature is, the more obvious the effect. In the case of quenching at 1 100 ℃, the degree of decreasing retained austenite by deep cryogenic treatment is lower than that by two times tempering. This is the reason why the cryogenic treatment increases the impact toughness. In addition, longer cryogenic time and shallow temperature are not good for both hardness and impact toughness as shown in Table 3.

Table 3　Test results of different treatment cycles

Code	1A	1B	1C	1D	2A	2B	2C	2D
Hardness (HRC)	63.7	63.7	63.4	63.4	62.8	63.9	63.5	63.4
Impact energy/J	9.0	10.7	9.3	8.3	7.7	7.0	6.7	5.0

Table 4　The content of retained austenite after different treatment cycles

Quenching temperature	1 100 ℃	1 140 ℃
Q	8.14%	11.47%
Q+T+T	0.99%	2.57%
Q+DCT_1+T	1.53%	1.42%

In order to investigate the effect of deep cryogenic