

## Influence of Quenching Temperature on Microstructure and Properties of Cr5 steel

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**Abstract.** The microstructure (before and after quenching), phase (before quenching), carbide content and hardness were studied by scanning electron microscopy, X-ray diffraction, optical software and Rockwell hardness tester. The results indicate that carbides of Cr5 steel have different morphology features and obvious aggregation phenomenon, most carbides dissolve in the matrix after quenching, the carbides of not dissolving with small particles distribute in the martensite. The style of carbides before quenching have  $M_7C_3$ 、 $M_{23}C_6$  and  $M_3C_2$ . volume fraction of carbides gradually reduce with quenching temperature increase, and the temperature of carbides dissolving in the matrix is 970C. Cr5 steel hardness increases and later decreases with the quenching temperature increases, the peak hardness (54HRC) is achieved in the 970C.

### 1 Introduction

Backup roll is an important consumable part in the modern mill, mainly used to support the middle roll or work roll to work, to prevent the work roll due to the large radial stress and deformation, which affects the quality of the products[1, 2]. Working nature and conditions of backup roll decide that they should have good wear resistance and fracture resistance, spalling resistance, and certain plastic toughness[4, 5]. At percent, the developing tendency of backup roll material present to reduce the carbon content, increase the chromium content, and add elements of molybdenum and vanadium, Cr5 steel is developed on the base Cr3, Cr4 steel in that principle. Compare with Cr3, Cr4 steel, the hardenability, hardness uniformity and comprehensive mechanical properties of Cr5 steel have greatly improved. Cr5 steel is primary materials to manufacture large backup roll of modern mill[6].

Due to adding more alloying elements which they are carbide forming element in the Cr5 steel, so there are a lot of carbides in Cr5 steel. Carbides can significantly increase Cr5 steel wear resistance when its diffusely distribute in the matrix. However, once carbides have unusually segregated in the local, microstructure of Cr5 steel will be worsen and form microstructure segregation. Cr5 style heavy backup roll, owing to its larger size, the process of steel ingot solidification will have a mass of carbides which segregated in local, for example, liquid chromatography carbide, Large network carbide and so on [7]. Heat treatment (heating, heat preservation) is one of the effective ways to eliminate or reduce carbide segregation. Carbides in the Cr5 steel are more sensitive to temperature, generally, they will dissolve into the matrix about 950 C[8]. During the follow-up soaking time, alloying elements will homogenize in the austenite to increase the stability of austenite and prepare for getting quenching martensite[9, 10]. In this paper, influence of quenching temperature on segregated carbides dissolution and properties of Cr5 steel was studied, lying a certain theoretical basis for later adjusting microstructure and resolving segregation.

### 2 test content

In this paper, the material used is Cr5 steel(heat treatment after being forged state), its chemical composition in table 1. The specific process of heat treatment after being forged is 900C normalizing

and 800C spheroidizing annealing and 650 C tempering (diffusion hydrogen processing). Test specimens were cut by molybdenum filament wire cutting machine, their size are 10 mm×10 mm×10 mm. Test specimens were heated in the SX-4-10 style chamber electric furnace, heating temperatures are 940 C, 955 C, 970 C, 985 C and 1 000 C respectively, soaking time is 60min, and then oil quenching. The samples before and after heat treatment were grinded, polished and corroded(corrodent is 4% nital) to prepare metallographic specimens. Finally, the microstructure (before and after quenching), phase (before and after quenching), carbide content and hardness were observed, analyzed, calculated and tested by means of scanning electron microscopy, X-ray diffraction, optical software and Rockwell hardness tester.

Table 1 Chemical composition of Cr5 style backup roll(wt,%)

C	Mn	Si	Mo	Cr	Ni	V
0.45-0.55	0.40-0.50	0.30-0.50	0.50-0.60	4.55-5.50	0.40-0.50	0.10-0.15

### 3 Interpretation of result

#### 3.1 Analysis on microstructure and XRD of before quenching

Fig1 and fig2 are microstructure(carbide segregation) and XRD of Cr5 steel after heat treatment after being forged. It can be seen from Figure 2 the matrix phase of Cr5 steel after heat treatment after being forged is  $\alpha$ -Fe, carbides style are  $M_7C_3$ ,  $M_{23}C_6$  and  $M_3C_2$  (M stand for Cr, Fe or Mo), and  $M_7C_3$  is mainly carbide phase. The carbide of Cr5 steel has a serious aggregation phenomenon, their morphology features have spherical, ellipsoidal, rod and irregularly distributing in the matrix, as figure 2 show. Carbide is the main reinforcing phase in steel, once carbides have unusually segregated in the local, which will cause the local stress concentration in steel substrate and its microstructure will be worsen. Finally, it will effect Cr5 steel spalling resistance, hardness uniformity and other special performance.

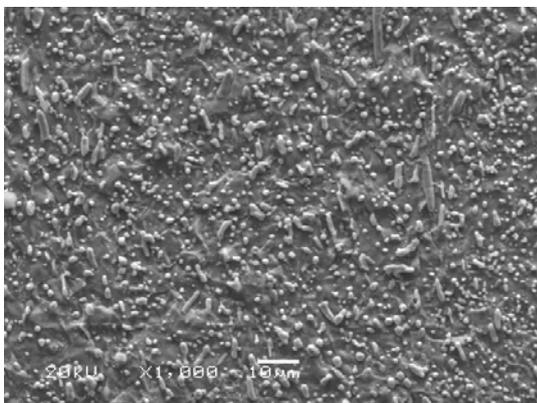


Fig. 1 Microstructure(carbide segregation) of Cr5 steel before quenching

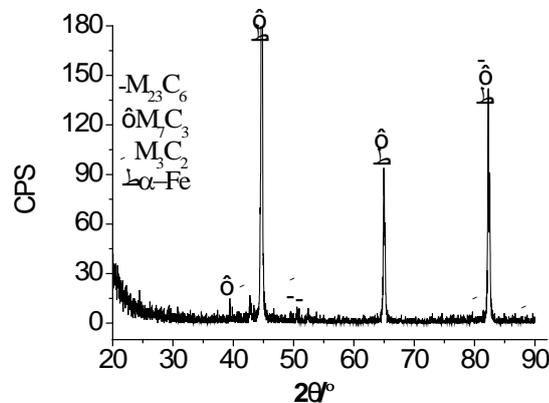


Fig. 2 XRD Cr5 steel before quenching

#### 3.2 Analysis of Cr5 steel microstructure after quenching

Figure 3 is a set of microstructure pictures under different temperature and the same soaking time quenching, among them a, b, c, d and e corresponding heating temperature are 940 C, 955 C, 970 C, 985 C and 1 000 C respectively, and soaking time are 60 min. Cr5 steel is medium carbon steel, both its mainly alloying element Cr and matrix element Fe belong to the transitional elements, Cr atoms are easy to replace Fe atoms form substitution solid solution or react with carbon generated carbides[11]. The carbides include  $Cr_3C$ ,  $Cr_7C_3$ ,  $Cr_{23}C_6$  and  $Cr_3C_2$ , and they will change under certain conditions. The temperature of  $Cr_3C$  style carbides dissolving into matrix is above  $A_{c1}$  or  $A_{cm}$ , but  $Cr_7C_3$  and  $Cr_{23}C_6$  are over 950 C[8].

It can be seen from Figure 3 the microstructure of test samples after quenching is martensite, residual austenite and not dissolving carbides, the massive spherical, ellipsoidal and rod carbides have disappeared. There are still a lot of granular carbides distributing in martensite in steel when

quenching temperature(940 C and 955 C) is lower. The volume fraction of carbides will reduce with the heating temperature continues to rise, it will close to zero when the temperature rise to 1000C.rising temperature not only means to promote the dissolution of carbide, accompanied by the growth of austenite grain. Acicular martensite after quenching is smaller when quenching temperature(940 C and 955 C) is lower. austenite grain and acicular martensite began to grow up when quenching temperature rise to the 970 C. The austenitic grain size and acicular martensite have fully grown at 1 000 C.

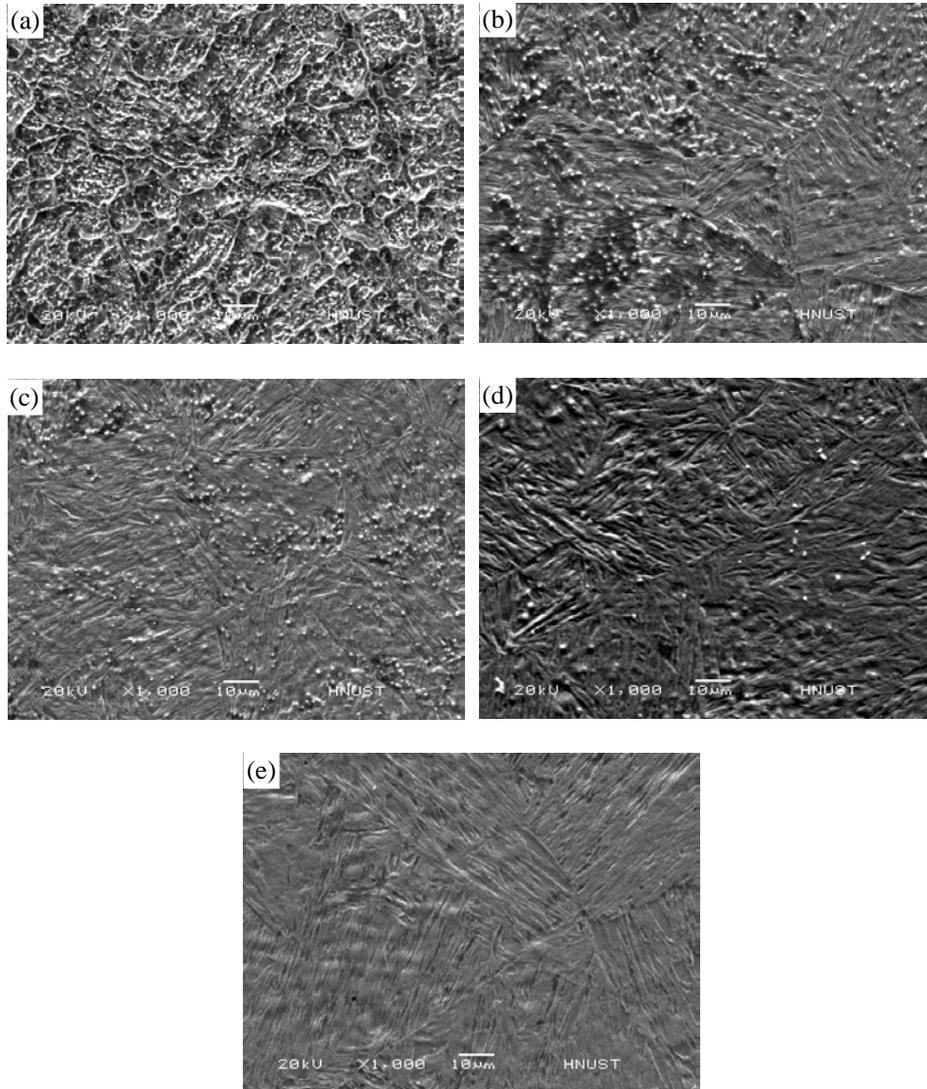


Fig. 3 Microstructure of Cr5 steel under different temperature quenching  
 (a)940 C, (b) 955 C, (c) 970 C, (d) 985 C, (e) 1 000 C

### 3.3 Hardness and volume fraction of Cr5 steel after quenching

Figure 4 is a variation diagram of hardness and carbide volume fraction of Cr5 steel under different temperature quenching. It can be seen from the curve of carbide volume fraction in the figure 4 that the temperature of carbide large dissolving into matrix is about 970 C, this moment the carbide volume fraction is 7%, the carbide volume fraction continue to reduce with temperature rising, when the temperature reached 1 000 C, the carbide volume fraction to 1%. Cr5 steel hardness increases and later decreases with the quenching temperature increases, the peak hardness (54 HRC) is achieved in the 970 C, as the curve of hardness in the figure 4 show. The hardness of martensite increase rapidly with carbon content aggrandizing when the carbon content of martensite is less than 0.4%, but when carbon content of martensite is more than 0.4%, The hardness of martensite increase slowly with carbon content aggrandizing. Ms point (temperature of martensite transformation) will decrease with carbon content of austenite rising, the hardness of martensite after quenching was increased, but the content of residual austenite also will increase, this cause effect steel hardness decreasing. It can be

seen from Figure 3 that austenitic grain increase rapidly and microstructure of martensite become bulky when the temperature is more than 970 C. The cause of steel hardness decrease rapidly is residual austenite and austenitic grain increasing. When the temperature reached 1 000 C, the steel hardness to 49 HRC.

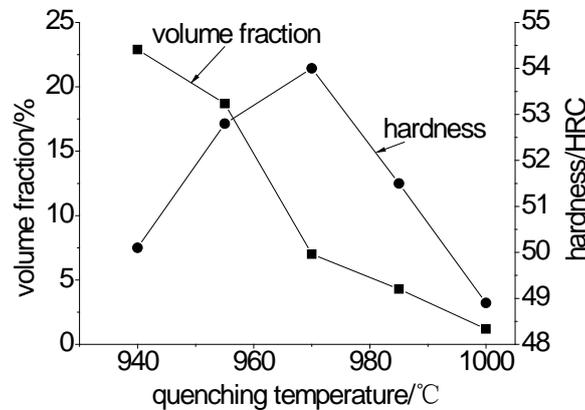


Fig. 4 hardness and carbide volume fraction of Cr5 steel under different temperature quenching

#### 4 Summary

1. Carbide style of Cr5 steel after heat treatment after being forged are  $M_7C_3$ ,  $M_{23}C_6$  and  $M_3C_2$ , their morphology features have spherical, ellipsoidal, rod and irregularly distributing in the matrix.

2. Carbides in the Cr5 steel are more sensitive to temperature, most carbides will dissolve into matrix and not dissolving into matrix diffusely distribute in the martensite with small granular when the temperature is about 970 C. Microstructure of Cr5 steel after quenching will become worse, austenitic grain increase rapidly and martensite become bulky when the temperature is more than 970 C.

3. Cr5 steel hardness increases and later decreases with the quenching temperature increases, the peak hardness (54 HRC) is achieved when the heating temperature is 970 C.

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