Microstructure and Properties of Two Cr8 Cold Working Die Steel

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Abstract. In this paper, we studied the effect on microstructure and properties during low tempering and high tempering temperature of HNC53 and KD11max Cr8 cold working die steel by means of hardness tester, universal tensile testing machine, pendulum impact tester, metallographic microscope, SEM and EDS. The results showed that the microstructure of the two materials were spheroidized pearlite and large eutectic carbide. After quenching then tempering at high temperature 520℃ and low temperature 200℃, the microstructure was martensite, eutectic carbide with large particles and small secondary precipitated carbide which was M7C3 type carbide. When KD11max was tempered at high temperature of 520℃, more nano-level secondary carbonization precipitated, and secondary hardening phenomenon was more obvious. The increase of Si and decrease of C could promote secondary hardening and improve the impact toughness of materials. KD11max impact toughness was better than HNC53.

1. Introduction
With the development of die manufacturing industry, the performance requirements of cold working die steel which should have both good wear resistance and good sufficient toughness are increasing[1-2]. D2 steel, the representative of Cr12 cold die steel, has high wear resistance, but due to its poor toughness, it is easy to fail in the early use, which has a bad impact on production and is difficult to meet the use requirements. Since the 1980s, the United States, Japan and other countries had been studying Cr8 cold working die steel due to its good wear resistance and toughness[3-4]. In recent years the research on microstructure and properties of Cr8 cold working die steel had been promoted due to more investment in this area. We can reduce the content of C and Cr of Cr8 die steel to reduce the content of M7C3 lekenite carbide thus greatly improve the impact toughness. At the same time, we can increase the content of Mo, V and other strong carbide forming elements to form secondary carbide and ensure the total amount of carbide thus improve the wear resistance. We can also add Ni, Si and other non-carbides forming elements to refine grain, strengthen matrix and enhance toughness[5]. Huang Dingjun and Yang Yitao from Shanghai University[6] studied the precipitation behavior of carbides of the spheroidization annealed 5Cr8Mo2SiV cold working die steel after quenching and tempering. The hardness, impact toughness and wear resistance of DC53 after low-temperature quenching and tempering were studied and compared with imported Cr12MoV by Shanghai University of Engineering Science. Hoyoung Kim and Jun-Yun Kang[7] studied the carbide evolution behavior of a Cr8 steel during the whole process of casting and heat treatment. The hardness, impact toughness, bending strength and wear resistance of SDC99, DC53, ASSAB88 and SLD-magic Cr8 cold working die steels were compared and studied by Li Chenhui and Xie Chen et al.[8] from Shanghai University. Carbide types and quantities of Cr8 and
Cr12 die steels were calculated respectively with JMatPro, and alloying principle of Cr8 die steels was analyzed.[9-10]

In this paper, HNC53 and KD11max Cr8 cold working die steel materials were heated to 1030 °C for quenching and then tempered at high temperature of 520 °C and low temperature of 200 °C respectively. The impact of chemical composition and tempering temperature on microstructure and properties of the materials were compared and analyzed, contribution of carbide precipitation to secondary hardening was discussed and to secondary hardening mechanism of steel was revealed.

2. Experiment
The test materials were HNC53 and KD11max Cr8 cold working die steel, and the chemical composition was shown in Table 1. It could be seen from the table that both materials are Cr8 cold working die steel materials. HNC53 material had 1.09% higher Mo content and 0.7% higher V content than KD11max while KD11max had higher Si, Mn and S content compared with HNC53, 0.55% higher Si, 0.26% higher Mn and 0.07% higher S.

| Table 1 | Chemical Composition of Test Steel |
|---------|-----------------------------------|
|         | C  | Si  | Mn  | Mo  | Cr  | V  | P  | S    |
| HNC53   | 1.07 | 0.84 | 0.40 | 2.32 | 8.49 | 0.35 | 0.038 | 0.029 |
| KD11max | 0.96 | 1.39 | 0.66 | 1.23 | 8.37 | 0.28 | 0.039 | 0.099 |

The two materials were heated to 1030 °C in a vacuum furnace, and quenched with nitrogen gas under pressure of 6bar and then tempered at two temperatures of 520 °C and 200°C respectively in box-type furnace and cooled down in the furnace.

10x10x10mm samples were cut from raw materials and heat-treated materials respectively and then pre-ground, polished and etched with 4% nitrates. Zeiss Axio Scope A1 optical microscope was used for microstructure observation. Rockwell hardness was tested following GB/T230.2-2002 "Metallic Rockwell Hardness" standard. Three 55×10×10mm samples were taken for U-port impact test respectively according to GB/T 229-2007 "Metallic Materials Charpy Pendulum Impact Test Method". Sample preparation, grinding and etching were first carried out. Then the microstructure was observed by Gemini SEM field emission scanning electron microscope. And also carbide was analyzed by energy spectrum according to standards of GB/T16594-94 "Measurement Method of Micron Length by SEM" and GB/T15616-95 "Quantitative Analysis Method of Metal and Alloy Electron Probe".

3. Results and Discussion

3.1. Metallographic Structure
The microstructure of raw materials was shown in Fig.1. It could be seen from the figure that both microstructure of Cr8 steel were spheroidized pearlite and large eutectic carbide. In HNC53, elongated eutectic carbides were distributed in bands, precipitated eutectic carbides were more abundant and the size was more uneven, large eutectic carbides ranged from 9 to 41 microns long and 2 to 11 microns wide. In KD11max large eutectic carbide ranged from 9 to 25 microns long and 2 to 15 microns wide, fine carbide particles in pearlite matrix ranged from 0.5 to 2 microns in size.
Two materials were tempered at 200°C and 520°C respectively after vacuum quenching. Fig. 2 and 3 showed the metallographic microstructure of the material at different tempering temperatures. It could be seen that after tempering at high and low temperatures, the carbides of the materials retained their original state and distributed along the segregation bands. The main structures were high-carbon acicular martensite, small amount of eutectic carbides and fine nanometer secondary carbonization precipitates. By comparison with large eutectic carbide of the original structure, it could be seen that after quenching the microstructure was austenitized, large amount of eutectic carbides were re-dissolved. Therefore, after quenching and tempering, the amount and size of eutectic carbides decreased, but the distribution along the original segregation position remained unchanged.

Figure 1 Microstructure of raw materials (a, c: HNC53; b, d: KD11max)

Figure 2 Microstructure after tempering at low temperature of 200°C(a: HNC53; b: KD11max)
3.2. Hardness and Impact work

According to the comparison of hardness in Fig. 4, hardness of both raw materials was about 20HRC. For both HNC53 and KD11max, secondary hardening phenomenon appeared when tempering at both high and low temperature, which led to the increase of material hardness. Among them, the phenomenon KD11max was more obvious.

In the tempering process of steel, carbide transformation is generally carried out in two ways.[11] First, the original carbides are gradually transformed into new carbides through the change of components and lattice recombination. Second, new carbides are formed independently in the process of nucleation and growth. In this process, old carbides gradually disappear and dissolve into supersaturated α-Fe, while new carbides precipitate thus the carbon content of supersaturated α-Fe decreases. Both kind of transformation are done by diffusion. Under low temperature, diffusion is slow, carbide precipitation is not obvious, with the increase of temperature, diffusion velocity gradually increase, the precipitation of carbide increase. Therefore, fewer carbide particles are precipitated and particles are smaller under low tempering temperature while the reverse is true at high tempering temperature. Secondary precipitated carbide has a great contribution to secondary hardening, so hardness is higher after tempering at 520℃.

The increase of Si content promotes secondary hardening of materials. This is because Si reduces the solid solubility of alloy, increases the amount of secondary hardening carbide, thus more nano-sized particles of secondary carbide precipitate. In addition, Si can increase the Ac1 and Ac3 temperature of material. When quenched at same temperature, high Si steel can dissolve less carbide, and there is less residual austenite which is retained to the tempering process after quenching. The higher the austenitizing temperature is, the more alloys dissolve into the austenite for secondary hardening, and the more austenitic transformation will occur in the tempering process, which is conducive to improving the hardness of the material. According to the chemical composition in Table 1, KD11max has higher Si content, so its hardness is higher.

According to the comparison in Fig. 4(a), the impact energy of both materials were about 6J, and the impact toughness of HNC53 and KD11max materials decreased after tempering at high and low temperature, and decreased slightly with the increase of tempering temperature. As could be seen from Fig. 4(b), the impact toughness of the two materials at 200℃ was better than that at 520℃. This is because the residual austenite helps to improve the impact toughness of the material. When the tempering temperature increases, the residual austenite will be transformed. At the same time, when the material is tempered at 520℃, the ε-carbide will turn into cementite, the coherent relationship will be destroyed, cementite grows, a large number of carbide M23C6 and M7C3 are precipitated in the grain boundary and easily coarsens, which are very bad for the toughness of material. Si can inhibit the increase of secondary carbide, refine the carbide precipitated during tempering, thus increase the impact toughness of the material. The decrease of C content can reduce the segregation degree of liquid carbide,
make the carbide as regular and round as possible, and improve the impact toughness of the material. Compared with HNC53, KD11max contains more Si and less C, so it has better toughness.

![Graph: Hardness and Impact Energy Comparison]

**Figure 4** Comparison of materials (a) Hardness (b) Impact energy

### 3.3. SEM and EDS analysis

Fig. 5 and 6 were SEM microstructure of materials at two different tempering temperatures. After quenching, the material formed high-carbon acicular martensite. The black part in Figure 6 and 7 was large eutectic carbide, tempering microstructure still retained high carbon acicular martensite shape after quenching. When tempering at 520°C, a large number of small nano-sized particles precipitated on the martensite and dispersed on the matrix, as shown in small white speckled particles. When tempering at 200°C, less nanometer secondary carbide particles precipitated.

![SEM Image](image)

**Figure 5** SEM image after tempering at a low temperature of 200°C (a: HNC53; b: KD11max)
Figure 6 SEM image after tempering at a high temperature of 520°C (a: HNC53; b: KD11max)

Fig. 7, 8 and Table 2, 3 were the energy spectrum location map and EDS components of materials tempered at 200°C. Figure 9, 10 and Table 4, 5 were the location map of energy spectrum and EDS components of materials tempered at 520°C.

EDS analysis of the carbide showed that it was M7C3 type carbide with Cr as main alloying element and a small amount of Mo and V. Most M7C3 type carbides were the carbide from raw materials. The Si content of HNC53 carbide was significantly lower than that of KD11max.

Figure 7 Energy spectrum location map and energy spectrum of HNC53 tempering at low temperature

| Table 2 | EDS composition analysis table of HNC53 low-temperature tempering at different positions |
|---------|----------------------------------------------------------------------------------------|
| C  | Si  | P  | S  | V  | Cr  | Mn  | Fe  | Mo  |
|------|-----|----|----|----|-----|-----|-----|-----|
| 1   | 13.25 | 0.01 | 0.05 | 0.28 | 3.86 | 39.25 | 0.51 | 35.37 | 7.42 |
| 2   | 5.42 | 0.94 | 0.02 | 0.05 | 0.14 | 6.28 | 0.36 | 84.74 | 2.04 |
Figure 8  Energy spectrum location map and energy spectrum of KD11max tempering at low temperature

Table 3  EDS composition analysis table of KD11max low-temperature tempering at different positions

|   | C   | Si  | P   | S   | V   | Cr  | Mn   | Fe  | Mo  |
|---|-----|-----|-----|-----|-----|-----|------|-----|-----|
| 7 | 7   | 5.73| 1.39| 0.09| 0.02| 0.11| 6.13 | 0.57| 84.86| 1.10 |
| 8 | 8   | 12.41| 0.36| 0.00| 0.03| 2.20| 33.45| 0.60| 47.67| 3.25 |

Figure 9  Energy spectrum location map and energy spectrum of HNC53 tempering at high temperature

Table 4  EDS composition analysis table of HNC53 high-temperature tempering at different positions

|   | C   | Si  | P   | S   | V   | Cr  | Mn   | Fe  | Mo  |
|---|-----|-----|-----|-----|-----|-----|------|-----|-----|
| 45| 45  | 13.12| 0.04| /   | 0.14| 3.54| 42.82| 0.36| 34.10| 5.88 |
| 46| 46  | 5.92 | 0.78| 0.02| 0.03| 0.20| 6.09 | 0.50| 84.72| 1.72 |
4. Conclusions
1) The microstructure of both Cr8 steel raw materials are pearlite and large block eutectic carbide. After quenching at 1030 ℃ then tempering at 520 ℃ or tempering at 200 ℃ the microstructure become high carbon acicular martensite and eutectic carbide and secondary precipitation carbide. The carbide is M7C3 type carbide. The carbide content of HNC53 is lower than that of KD11max.
2) When the two materials are tempered at high temperature 520℃ or low temperature 200℃, fine nano-sized secondary carbide precipitates and dispersed on the matrix. When tempering at 520℃, the secondary hardening of KD11max is relatively obvious. The increase of Si content can also promote the secondary hardening of materials.
3) The residual austenite will be transformed when the two materials are tempered after quenching. The increase of Si content and the decrease of C content can improve the impact toughness of the materials, and KD11max has the best impact toughness.

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