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Effect of Austenitizing Temperature on Divorced Eutectoid Transformation of GCr15 Steel

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Abstract. The effects of holding temperature and holding time during the spheroidizing annealing on microstructure and mechanical properties of high-carbon chrome steel GCr15 were experimentally studied, especially the ripening process of carbides. The results showed that the spheroidization of carbides was accelerated by optimizing the spheroidizing annealing process. In the case of the same holding temperature, the amount of carbides increases first and then decrease with the increase of holding temperature. The best spheroidizing temperature was about 720°C. Under the conditions of various holding time, the size of carbides and the hardness decrease with the increase of holding time.

1. Introduction

In view of their good fatigue resistance, high wear resistance and good dimensional stability, GCr15 bearing steel have dominated the bearing market historically. As a kind of hypereutectoid steel, the microstructure of GCr15 after hot rolling was lamellar pearlite, which has a relative high hardness, and was unbeneficial for the following mechanical processing. As a consequence, a special soft annealing treatment, hereafter also referred to as spheroidization heat treatment, produces a mixed microstructure of relatively coarse spheroidized cementite particles embedded in ferrite, which facilitates machining, as well as warm and cold forming of the steel [1].

The traditional spheroidization heat treatment can be divided into two parts. (a) Continuous-cool spheroidal anneal: holding for a long time under the A_{c1} , and the spheroidizing process was achieved by the decrease of interfacial energy. (b) Isothermal spheroidal anneal: Austenitize for a minimum of 1 hour between A_{c1} and A_{cm} , then rapid cool to a temperature (lower than A_{c1}) and hold for a relative long time. Both of the two means need a long time to achieve spheroidization, which causes a relative high energy consumption. In order to reduce the holding time of spheroidizing annealing, considerable research efforts have been devoted to achieve the fast spheroidizing of bearing steels, such as thermos-mechanical controlled processing (TMCP) [2,3] and the application of Ultra-Fast cooling [4,5]. In recent years, the divorced eutectoid transformation reaction (DET) attracts more attention in the fields. If the austenite contains a distribution of fine cementite particles, the cementite new formed may precipitate by the means of DET instead of the traditional cooperative mechanism. Until now, a lot of experiments have been conducted to explain the transformation mechanism of DET [6-8], few works have been carried out to examine the effect of austenitizing temperature on DET, especially the influence on the type, size and morphology of carbides.

In the present experiment, a box type resistance furnace was used to examine the influence of austenitizing temperature. The purpose of this study was to find the best process parameters of heat treatment, and promote the efficiency of DET.



2. Methods and Materials

At the present work, the selected steel GCr15 was supplied by BX steel from China, and the chemical composition was given in the Table 1. The specimens(150mm×50mm×30mm) were all machined from the hot-rolled bar, and the initial microstructure was lamellar pearlite. The phase transition temperature of specimens was measured by dilatometry tests conducted on transformation measuring apparatus. To investigate the effect of austenitizing temperature, the experiments were classified as four groups. The experimental scheme is listed in Table 2. The text profile for DET is schematically illustrated in Figure1. After the holding of spheroidizing, the samples were cooled at a cooling rate of 25°C/h to 600°C in each experiment, and then air cool to room temperature.

The experimental bars were cut to metallographic specimens for metallographic examination. Then the grinded using successive sandpapers from grade #400 to #2000, followed by polishing with a 1μm diamond prior to hardness measurements and microstructure analysis, which was carried out on specimens etched in a 4% nital solution for about 5-10s. The specimens were investigated in a ZEISS ULTRA-55 field emission scanning electron microscope (FE-SEM) using an accelerating beam of 10eV. The software Image-Pro Plus was used to measure the quantity and size of carbides. Finally, the TCFE7 database of Thermo-calc software and MOBFE database of DICTRA dynamic software were used to calculate the growth behavior of carbides at various holding temperatures. The results of experiments can provide a reference for the optimization of DET.

Table 1. The composition of test steels (WT.%).

C	Cr	Mn	Si	Ni	S	P	Cu	Al	Ti	Mo
1	1.51	0.3	0.22	0.18	0.002	0.003	0.08	0.02	0.005	0.05

Table 2. Heat treatment process parameters.

Sample number	Holding temperature/°C	Holding Time/h	Furnace-cooling temperature/°C
1#	780	2	600
2#	800	2	600
3#	820	2	600
4#	840	2	600
5#	820	1	600
6#	820	4	600

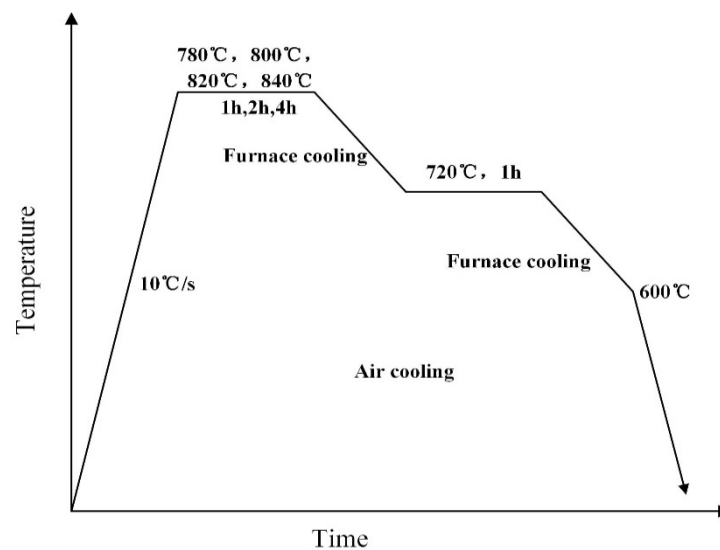


Figure 1. Schematic diagram of heat treatment profile of DET spheroidizing annealing

3. Results and Analysis

3.1. The Microstructure after Different Holding Temperatures

According to the result of dilatometry tests, the A_{c1} and A_{cm} of selected steel were 737.8°C and 853.2°C respectively. As a consequence, the austenitizing temperature selected was 780°C, 800°C, 820°C, 840°C. The initial microstructure of selected steel was lamellar pearlite with network carbides existed along the grain boundaries. And the microstructure after spheroidizing annealing consist of ferritic matrix and spheroidal carbides. According to the survey conducted by Li [9], the type of carbides after spheroidizing annealing was M_3C .

Figure 2 shows the microstructure of samples with different holding temperatures (sample 1 #,2 #,3 #,4 #). It can be seen that different spheroidizing effect occurred with the variation of temperature. When the holding temperature was 780°C and 800°C, the size of carbide particle was inhomogeneous. In addition to this, there was still a small amount of undissolved network carbides existed along the grain boundaries. More carbide particles with homogeneous size formed with the increase of holding temperature, as can be seen from the Figure 2(c). The amount of carbide particles has to peak when the holding temperature comes to 820°C. When the holding temperature further increase to 840°C, the size of particles was larger than the samples holding at 820°C, but the numbers of carbide particles decrease.

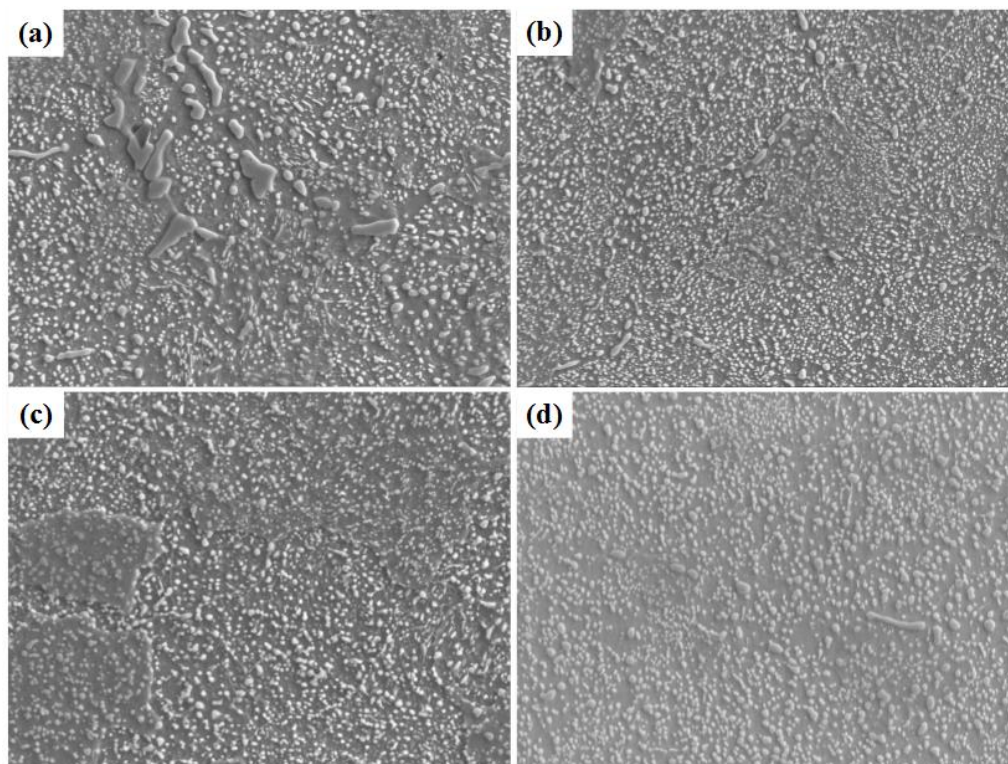


Figure 2. SEM micrograph of samples with different holding temperatures
(a) 780°C (b) 800°C (c) 820°C (d) 840°C

Figure 3 is observed with SEM to observe the microstructure of samples with different holding time (sample 5#,6#,7#,8#). It can be seen from the Figure 3 that the least time cost to realize spheroidization was 2h (holding temperature 820°C). According to the Figure 3(a), the holding time was too short to eliminate the network carbides exist along the grain boundaries. With the increase of holding time (Figure 4(b)-(c)), the size of particles grew up gradually, which has an unbeneficial influence to the homogenization of carbon element during the followed quenching treatment. Consequently, the best holding time to achieve spheroidization at 820°C is 2h.

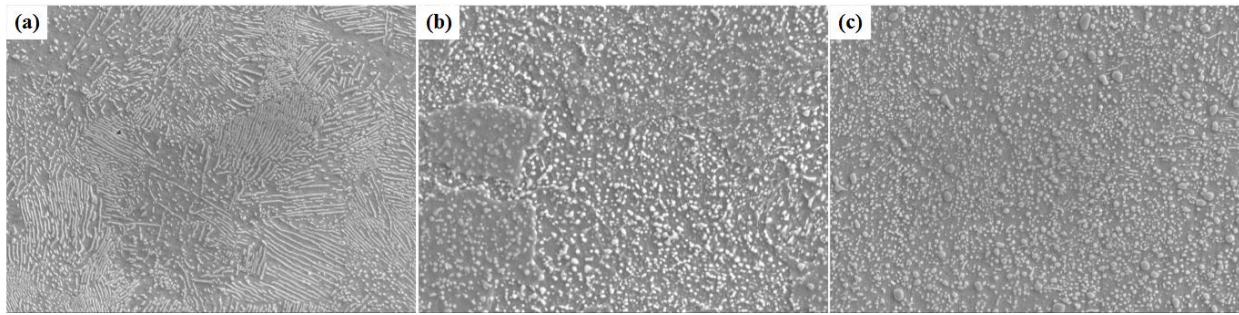


Figure 3. SEM micrograph of samples with different holding time with the same holding temperature
(a) 820°C 1h (b) 820°C 2h (c) 820°C 4h

3.2. The Result of Microhardness

The result of microhardness is corresponded with the result of microstructure. In order to reduce the error, five or more points were measured to measure the microhardness of samples. The result of microhardness is shown Figure 5. Figure 5(a) shows the microhardness of samples with different with different holding temperatures, corresponding to the Figure 4(a). It can be indicated from the Figure 4(a) that the microhardness of samples with undissolved network carbides was about 220 HV, which is higher than the standard of hardness required after spheroidization. With the increase of holding temperature, the microhardness of samples decreases first and then increase, and when the holding temperature was 820°C, the microhardness comes to the minimum, about 190 HV. Figure 4(b) shows the microhardness of samples with different with different holding time. With the same holding temperature, increasing the holding time, decreasing the microhardness of samples after spheroidization. In conclusion, the microhardness of samples decreases with the increase of carbide particles size.

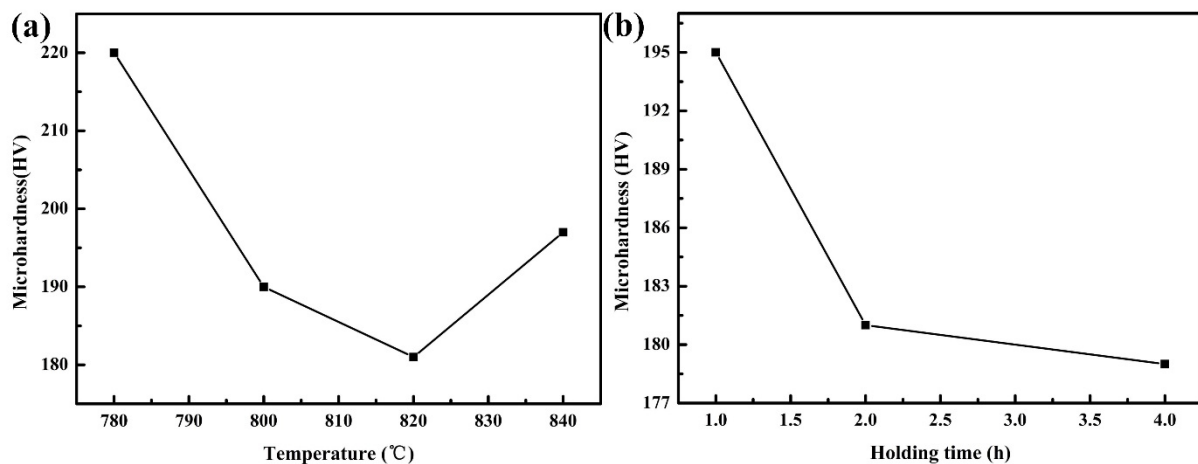


Figure 4. Microhardness of samples with different kinds of heat treatments
(a) Samples with different holding temperature (b) Samples with different holding time

3.3. The Growth Behavior of Carbides

In order to deeply investigate the growth behavior of carbides, Thermo-calc software and MOBFE database of DICTRA dynamic software was used to observe the growth of interface during the DET, especially the behavior of globular carbide. Particles model is established to simulate the growth behavior of carbides at different holding temperature with the same holding time. The initial compositions of cementite and austenite inherit from the spheroidized cementite and ferrite, which is shown as the Table 3. The growth behavior of carbides should follow the rules of Oswald Ripening, which means that small particles dissolve and the resultant material deposits on larger particles causing them to grow. The result of simulation is conducted on the basis of the result obtained by

experiments above.

First of all, the dissolution behavior of austenite with various temperature is simulated. The result of simulation is shown in the Figure 5. According to the Figure 5, when the holding temperature is higher than 850°C, the influence of holding temperature on the cementite dissolution is negligible, whereas to the holding temperature region of our experiment, the decrease of holding temperature increase the content of cementite. If the holding temperature is too low to dissolve the network carbides, the nucleation site for the carbides newly formed decreased, which hinder the spheroidization.

The growth behavior of carbides with the same size at different holding temperature is shown in Figure 6. The phase content of selected steel at different temperatures is shown in the Figure 6. It can be seen that the content of cementite decreases with the increase of holding temperature at 760°C to 840°C, proving that the amount of residual carbides can be influenced by the holding temperature. In addition to this, the coarsening rate coefficient of residual carbides with various holding temperatures is calculated by DICTRA dynamic software. The result of simulation is shown in Figure8, which indicated that the coarsening rate coefficient increase with the holding temperature. Larger coarsening rate coefficient demonstrate that less time is needed to complete the spheroidization. In conclusion, the influence of holding temperature on DET is twofold. On the one hand, increase the holding temperature decrease the amount the amount of residual carbides, on the other hand, the increase of holding temperature increase the coarsening rate coefficient. According to the result obtained by the experiment above, the best holding temperature of DET is about 820°C.

Table 3. the initial compositions of spheroidized cementite and ferrite.

Element	Spheroidized cementite (wt.%)	Ferrite (wt.%)
C	6.749	0.187
Cr	11.874	0.517

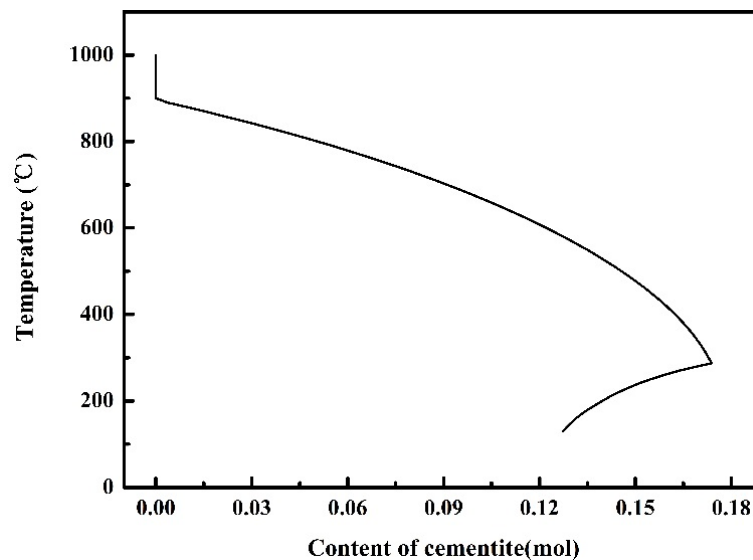


Figure 5. Content of cementite of samples with different holding temperatures

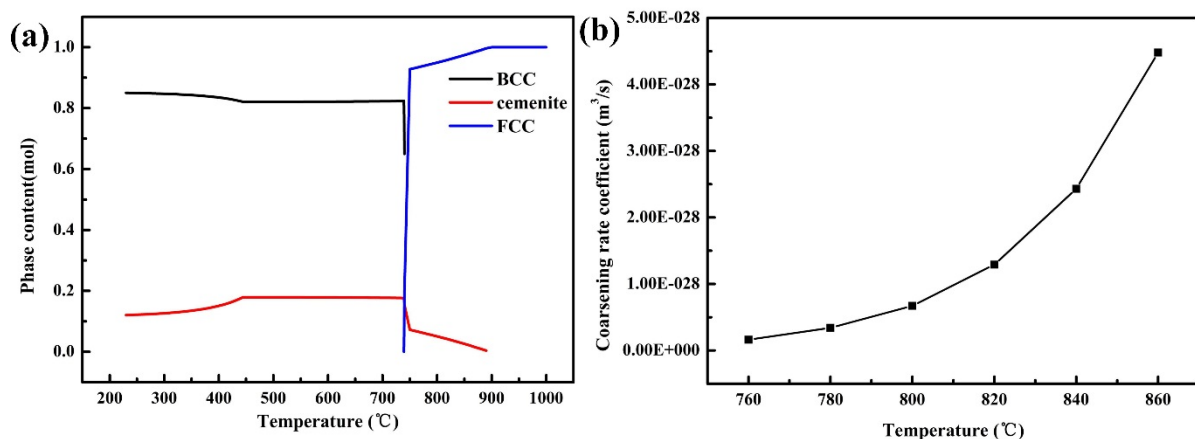


Figure 6. Result of simulation calculated by DICTRA dynamic software

(a) Phase content of selected steel with different temperatures

(b) Coarsening rate coefficient of carbides with different holding temperatures

3.4 Discussion

The DET occurs at the region of $\gamma + M_3C$, which was shown in the Figure 6(a). And the transformation process of DET was shown in the Figure 7. The carbides undissolved can supply the nucleation sites of carbide particles newly formed. If the holding temperature was too low, not only cannot dissolve the network carbides, but also slow down the diffusion rate of C and Cr. As a result, lower holding temperature leads to a relative longer holding time to achieve spheroidization. With the increase of holding temperature, the quantities of undissolved carbides turn less, even the diffusion rate of C and Cr was higher, the amount of carbides decrease instead. According to the result of experiments, the best holding temperature to achieve spheroidization is 820°C, and the least time was about 2 h.

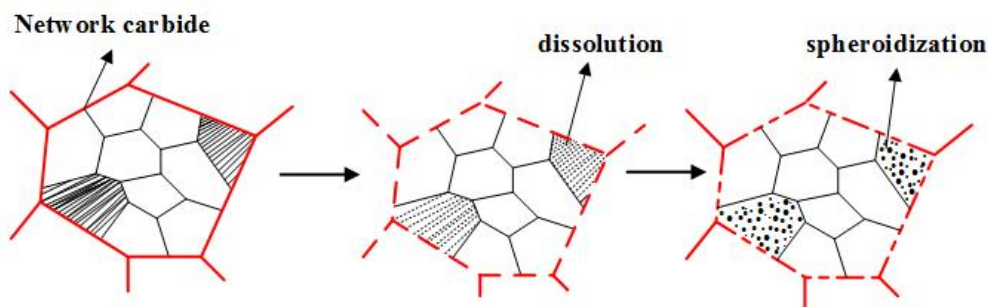


Figure 7. Spheroidizing process of GCr15 during the DET

4. Conclusion

(1) The holding temperature varies from 780°C to 840°C, the amount of carbides increases first and then decreases with the increase of holding temperature.

(2) With the increase of holding time, the size of carbide particles increases, which leads to a decrease of microhardness.

(3) The microhardness of samples after DET at 820°C for about 1 h was about 193 HV, which is in accord with the hardness requirements after spheroidization.

(4) The best process of GCr15 steel to achieve spheroidization is holding temperature 820°C, holding time 2 h.

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