ISSN 1027-5495. Functional Materials, 30, No.2 (2023), p. 212-216.
doi:https://doi.org/10.15407/fm30.02.212

Effect of heating temperature and holding time on microstructure and mechanical properties of quenched GCr15 bearing steel

Guiyan Ye, Yujun Li

School of Materials Science and Engineering, Jiujiang University, 332005 Jiujiang, China

Received November 20, 2022

The effects of heating temperature and holding time on the quenching microstructure and hardness of bearing steel GCr15 were studied by means of optical microscopy (OM), scanning electron microscopy (SEM) and hardness testing. The results show that when GCr15 steel is quenched between A_{c1} + (30–50°C), the microstructure obtained by the metallographic method consists of acicular martensite + undissolved carbides + residual austenite. The longer the holding time, the thicker the martensite sheet, the less undissolved carbide and the more residual austenite. The hardness decreases with increasing holding time. When the heating temperature is lower than Accm, the microstructure of GCr15 steel after quenching consists of acicular martensite + undissolved carbide + residual austenite; the acicular martensite becomes coarser and the hardness increases with increasing temperature of heating. When the heating temperature is higher than Accm, the microstructure of GCr15 steel after quenching is acicular martensite + residual austenite, and the amount of residual austenite increases with increasing temperature, while the hardness decreases.

Keywords: GCr15 steel, quenching, acicular martensite, hardness, residual austenite, undissolved carbides.

Вплив температури нагрівання та часу витримки на мікроструктуру та механічні властивості загартованої підшипникової сталі GCr15. *Guiyan Ye, Yujun Li*

Вплив температури нагрівання та часу витримки на мікроструктуру гарту та твердість підшипникової сталі GCr15 вивчали за допомогою оптичної мікроскопії, скануючої електронної мікроскопії та вимірювання твердості. Результати показують, що коли сталь GCr15 гартується між A_{c1}+(30–50°C), отримана металографічна мікроструктура є голчастим мартенситом + нерозчинені карбіди + залишковий аустеніт. Чим довший час витримки, тим товщі мартенситний лист, тим менше нерозчинених карбідів і тим більше залишкового аустеніту. Зі збільшенням часу витримки твердість зменшується. Коли температура нагрівання нижча, ніж Accm, мікроструктура сталі GCr15 після загартування — це голчастий мартенсит + нерозчинений карбід + залишковий аустеніт; голчастий мартенсит стає більш грубим, а твердість збільшується із підвищенням температури. Коли температура нагрівання вища за Accm, мікроструктура сталі GCr15 після загартування являє собою голчастий мартенсит + залишковий аустеніт, кількість залишкового аустеніту збільшується, а твердість загартування зменшується зі збільшенням температури нагрівання.

1. Introduction

GCr15 bearing steel is a common high carbon chromium rolling bearing steel, mostly used for manufacturing rollers, shaft sleeves, and steel balls on transmission shafts. The biggest characteristic of bearing steel during service is that it bears great friction and pressure, so it needs to have high wear resistance and hardness [1–

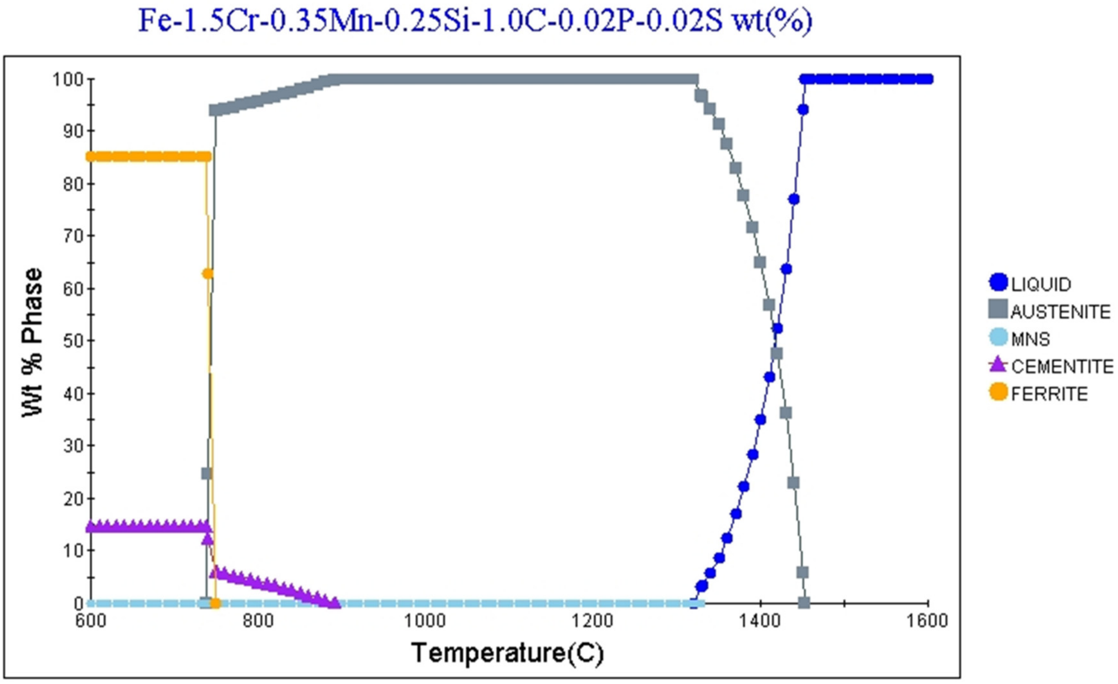

Fig. 1. Temperature chart of A_1 and A_3 calculated by Jmatpro software.

3]. The heat treatment of GCr15 steel mainly includes spheroidization annealing, quenching, and low-temperature tempering. Spheroidization annealing, as a preparatory heat treatment, is chiefly aimed at reducing hardness and facilitating cutting processing. The principal purpose of quenching and low temperature tempering is to obtain a tempered martensite matrix, granular carbide and a small amount of residual austenite to meet the requirements of the working environment. The heating temperature and holding time of quenching have an extremely important impact on the final structure of GCr15 steel [4–5]. Unreasonable heating temperature and holding time may lead to coarse martensite, too large carbide particle sizes, uneven distribution of particles, and too much residual austenite, which will ultimately affect the hardness, wear resistance and toughness of bearing steel [6].

In this work, the quenching heat treatment of GCr15 steel after spheroidization annealing was conducted. The impact of quenching heating temperature and holding time on the microstructure and hardness properties of GCr15 steel was analyzed.

Table 1. Chemical composition of GCr15 steel (wt%)

C	Si	Mn	Cr	P	S
1.00	0.25	0.35	1.50	0.020	0.020

2. Experimental materials and methods

The experimental specimens used in this work was GCr15 bearing steel after spheroidization annealing, with a particle size of 16×17 mm. The main components are shown in Table 1. Based on the chemical composition of the steel grade, the values of phase transition critical point temperatures A_1 and A_{cm} were calculated by Jmatpro 6.0 software, as shown in Fig. 1. According to Fig. 1, the equilibrium A_1 and A_{cm} temperatures of GCr15 bearing steel are 748 and 890°C, respectively. According to the principle of heat treatment, the suitable heating temperature for quenching GCr15 bearing steel should be A_{c1} + (30–50°C).

The heating equipment is a KSL-1000X box type resistance furnace. In order to study the effect of heating temperature on the microstructure and properties of GCr15 steel, some specimens were heated in the furnace with a rate of 10°C/min to the temperatures of 840°C, 920°C and 1000°C, re-

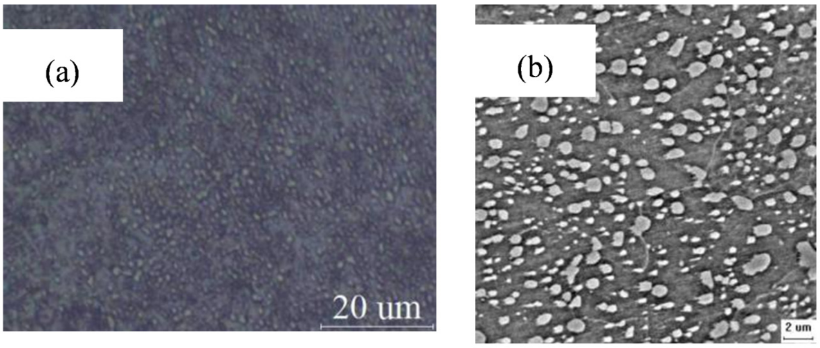

Fig. 2. OM (a) and SEM (b) image showing microstructure of the test steel.

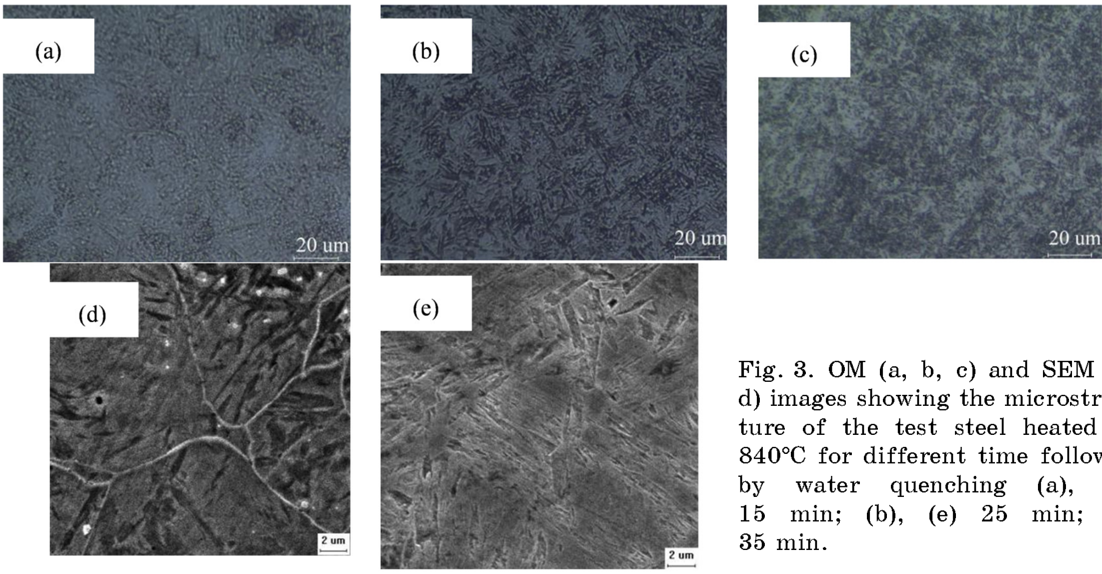

Fig. 3. OM (a, b, c) and SEM (c, d) images showing the microstructure of the test steel heated at 840°C for different time followed by water quenching (a), (d) 15 min; (b), (e) 25 min; (c) 35 min.

spectively, for austenitization. After holding for 15 minutes, they were directly quenched to room temperature by water. To study the effect of heating temperature on the microstructure and properties of GCr15 steel, some specimens were heated at the same rate to the temperature of 840°C for austenitization. After holding for 15, 25, and 30 minutes, respectively, they were also directly quenched to room temperature by water.

After the heat treatment, all the specimens were subjected to grinding and polishing, and then etched with 4 % nitric acid alcohol solution. Microstructure was observed by a Zeiss Axio Scope A1 optical microscope (OM) and a TESCAN VEGA II LSU scanning electron microscope (SEM). Hardness was tested by a HRSS-150 Rockwell hardness tester.

3. Results and discussion

3.1 Initial microstructure and hardness of GCr15 steel

The GCr15 steel used in this work was spheroidized and annealed, with the aim of reducing hardness and facilitating processing. Its microstructure is spherical or granular pearlite (with spherical or granular carbides distributed on the ferrite matrix). No lamellar carbides were observed in the microstructure [8], as shown in Fig. 2. It can be seen from the figure that the size of the spheroidized carbides varies, and the carbides are dispersed on the ferrite matrix [7]. The hardness tested using a HRSS-150 Rockwell hardness tester is 54HRA (approximately 176HBS), which is very suitable for cutting processing.

3.2 Effect of holding time on the microstructure and hardness of GCr15 steel

Figure 3 shows the microstructure morphology of quenched GCr15 steel with different holding times. It can be seen from

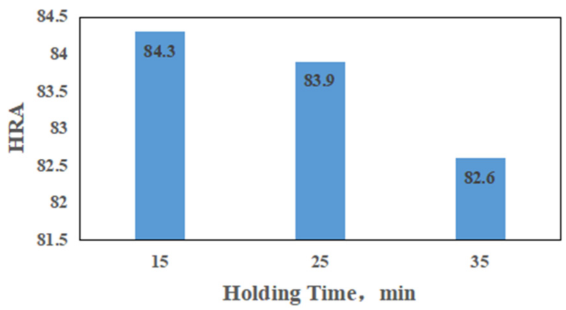

Fig. 4. Hardness of GCr15 steel specimens quenched at different holding time.

the figure that the microstructure of quenched GCr15 under different holding times are mainly composed of acicular martensite matrix, undissolved carbide, and residual austenite. From Fig. 3(d), it can be seen that when the holding time is 15 minutes, the network of undissolved carbides still exists at the original austenite grain boundaries. As the holding time increases, the undissolved carbides at the grain boundaries gradually dissolve. When the holding time is 25 minutes, there are no undissolved carbides at the austenite grain boundaries, so no obvious grain boundaries can be seen after quenching, as shown in Fig. 3(e). It can be seen from Fig. 4 that the hardness decreases with increasing holding time. This is because the longer the holding time, the thicker the martensite sheet, the less undissolved carbide and the more residual austenite.

3.3 Effect of heating temperature on the microstructure and hardness of GCr15 steel

Figure 5 shows the microstructure morphology of GCr15 steel quenched from different heating temperatures. The heating temperature has a significant impact on the quenching microstructure of GCr15 steel. When the heating temperature is 840°C, the quenching microstructure of GCr15 steel are mainly composed of acicular martensite, undissolved carbide, and residual austenite. The thickness of the acicular martensite is relatively small, and the amount of undissolved carbide is larger, as shown in Fig. 5(a) and (d). When the heating temperature rises to 920°C, the acicular martensite in the quenching microstructure becomes coarse and the amount of undissolved carbide becomes less, as shown in Fig. 5(b) and (e). When the heating temperature continues to rise to 1000°C, no undissolved carbides can be observed in the quenched microstructure, only coarser martensite sheets and residual austenite. This is due to the fact that under this temperature, GCr15 steel has been completely austenitized, and all carbides are dissolved in austenite.

Fig. 6 shows the hardness changes of GCr15 steel after quenching from different heating temperatures. As shown in the figure, with an increase in the heating temperature, the hardness of GCr15 steel first increases and then decreases. This may be due to austenite grain growth when the temperature rises to 920°C, and the quenched martensite sheet also becomes coarse, so the hardness increases. When the temperature continues to rise to 1000°C, exceeding the Accm temperature, the carbides

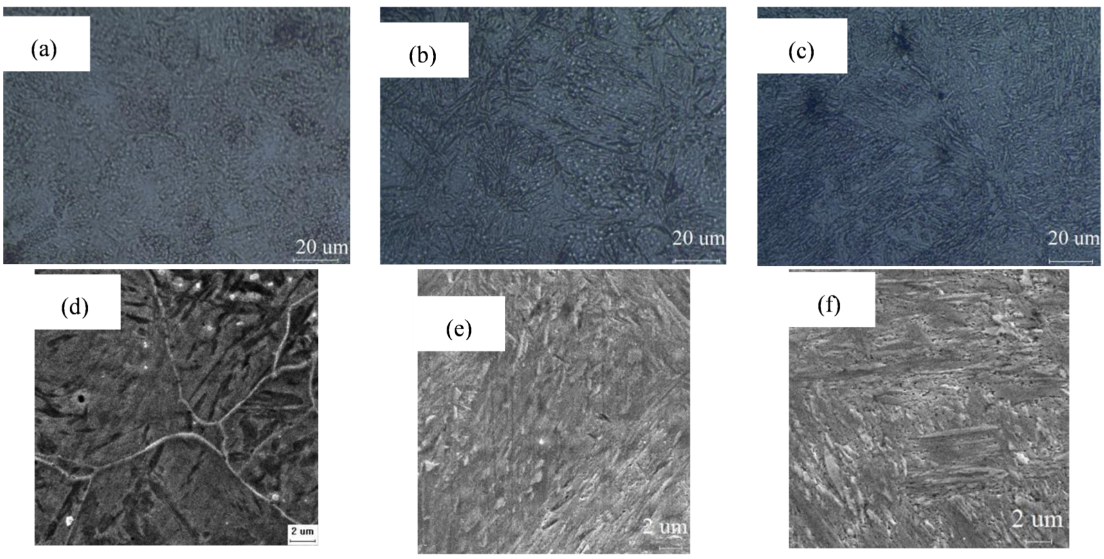

Fig.3. OM (a, b, c) and SEM (c, d) images showing the microstructure of the test steel heated at 840°C for different time followed by water quenching (a), (d) 15min; (b), (e) 25min; (c) 35min.

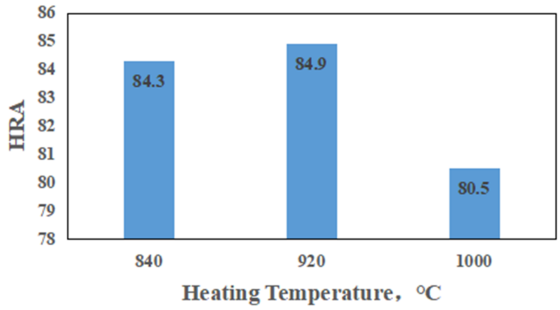

Fig. 6. Hardness of GCr15 steel specimens quenched from different heating temperatures.

completely dissolve in the austenite, resulting in the carbon content of the austenite being too high. Although the austenite and martensite sheets continue to coarsen, the amount of residual austenite becomes more after quenching, which reduces the hardness of GCr15 steel. Therefore, when the heating temperature is lower than Accm, the microstructure of GCr15 steel after quenching consists mainly of acicular martensite, undissolved carbide, and residual austenite; with increasing temperature, the acicular martensite becomes coarse, and the hardness increases. When the heating temperature is higher than Accm, the microstructure of GCr15 steel after quenching is mainly composed of acicular martensite and residual austenite, and the amount of residual austenite increases with an increase in heating temperature, thus, the quenching hardness decreases.

4. Conclusions

1) When GCr15 steel is quenched at a reasonable heating temperature, the metallographic microstructure obtained is mainly composed of acicular martensite, undissolved carbides, and residual austenite.

2) The longer the holding time, the thicker the martensite sheet, the less undissolved carbide, and the more retained austenite. The hardness decreases with an increase in the holding time.

3) When the heating temperature is lower than Accm, the microstructure of GCr15 steel after quenching is mainly composed of acicular martensite, undissolved carbide, and residual austenite, and the acicular martensite becomes coarser with an increase in the temperature, and the hardness increases as well. When the heating temperature is higher than Accm, the microstructure of GCr15 steel after quenching consists mainly of acicular martensite and residual austenite, and the amount of residual austenite increases with increasing temperature, and the quenching hardness decreases too.

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