Elimination of Cracks in GCr15 Bearing Rings After Heat Treatment

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Abstract: The main chemical components of GCr15 bearing steel are Fe, Cr, C, Mn, etc., which are mainly used to produce bearing rings, rolling elements and other rolling bearing manufacturing industries. After more than one hundred years of development, GCr15 material is used for manufacturing bearing components, and it is called "heart of industry" because GCr15 material is one of the best quality steels [1]. After heat treatment, GCr15 material steel has the "most extensive" practicality for various working conditions of the bearing, such as high load capacity, good fatigue resistance, strong wear resistance, and high hardness, better temperature adaptability and so on [2]. This paper first discusses the heat treatment process of GCr15 material, and then analyzes and studies the cracking phenomenon of a certain batch of 1m diameter GCr15 material bearing ring blanks after heat treatment, and focuses on the fracture morphology, chemical composition, microstructure and other phenomena. The analysis found the cause of the crack and improved the original heat treatment process, that is, before quenching, isothermal spheroidizing annealing is used and the spheroidizing annealing temperature is strictly controlled, bainite austempering is used to replace martensite quench tempering after quenching, and finally, the problem is solved through experimental verification.

Keywords: GCr15; bearing ring; heat treatment; crack

1. The performance and chemical composition of GCr15 material
GCr15 material has been invented for 119 years. Although there is almost no change in its chemical composition, there have been several major improvements in the heat treatment method, resulting in a major breakthrough in its performance, which also improved its comprehensive performance greatly and become one of ultra-pure and extremely representative high-quality steel. The C element content in GCr15 material is between 0.95% and 1.02%, which is a hypereutectoid steel. The higher C content makes GCr15 material have higher hardness and wear resistance. The Cr content in it is between 1.30% and 1.65% that can make the austenite more stable and improve the hardenability of GCr15 material. In addition, Cr element is also a carbide forming element. The alloy cementite formed by Cr and C element greatly reduces the accumulating tendency of GCr15 material during annealing. At the same time, Cr element can also make the cementite structure more refined. In low-temperature tempering, the fine-grained alloy cementite structure will increase the tempering stability, thereby
satisfying that the bearing rings and rolling elements have high hardness, high wear resistance and strength. However, the content of Cr should not be too high. If the content of Cr is too high, the amount of retained austenite will be greatly increased after quenching and heat treatment of the GCr15 material, which will lead to instability of the structure and affect the hardness and wear resistance of this kind of steel [3].

GCr15 material has a very good comprehensive performance. After quenching and low-temperature tempering heat treatment, a relatively uniform metalliclographic structure can be obtained, as well as high hardness, high wear resistance and very good corrosion resistance and contact fatigue strength, etc. Therefore, GCr15 material is mainly used under the working conditions of large load, high wear resistance and greater contact fatigue strength. GCr15 material steel is one of the representative high-quality steels in high chromium and high carbon bearing steels. See Table 1 for its chemical composition. The service performance and service life of GCr15 material are greatly affected by the heat treatment process. Among them, spheroidizing annealing is one of the most important heat treatment processes. The spheroidizing annealing can greatly reduce the hardness of the material, which is conducive to subsequent machining and will greatly reduce it. The cracking of the GCr15 material after quenching will affect the ultimate performance of the bearing [4].

Table 1. The chemical composition of GCr15

| Steel grade | Chemical composition (mass fraction,%) |
|-------------|----------------------------------------|
|             | C    | Si    | Mn   | Cr   | Mo   | P     | S     | Ni   | Cu   | Ni + Cu |
| GCr15       | 0.95-1.05 | 0.15-0.35 | 0.25-0.45 | 1.40-1.65 | ≤0.1 | ≤0.025 | ≤0.025 | ≤0.3 | ≤0.25 | ≤0.5    |

2. Common heat treatment process of GCr15

Heat treatment plays an important role for GCr15 steel to meet various bearing performance and high service performance requirements. Commonly used GCr15 material bearing steel heat treatment processes is as follows.

(1) Spheroidizing annealing

Spheroidizing annealing is mainly to reduce the hardness of GCr15 material steel, so as to complete the subsequent metal cutting process, and to form fine, small, uniform, round and uniformly distributed carbide particles on the steel matrix. This microstructure is mainly to prepare for the final heat treatment process of martensite quenching and tempering [5]. The size, number and shape of the fine, small, uniform, round and uniformly distributed carbide particles have a great impact on the performance of GCr15 steel. Since most of the carbide particles cannot be dissolved during quenching and tempering, their shape is determined by the spheroidizing annealing process, so the spheroidizing annealing heat treatment process should be strictly controlled.

The traditional spheroidizing annealing heat treatment is at a temperature slightly higher than Ac1. For example, the GCr15 material is heated to a temperature of 780-810 °C and kept warm, and then slowly cooled with the furnace temperature. The cooling rate is generally 25 °C/h. After the temperature dropped below 650 °C, the material was taken out and cooled in the air, as shown in Figure 1. If the cooling rate is too fast, the carbide particles are too fine and dispersed, and the hardness of the material is relatively high. If the cooling rate is too slow, the carbides will be coarse and the hardness of the material will be relatively low.
Figure 1. Traditional spheroidizing annealing process

The isothermal spheroidizing annealing heat treatment process is to heat the GCr15 steel to 780-800 °C at a heating rate of 30 °C/h, and quickly cool it to a temperature below Ar1, such as about 680-720 °C, and perform isothermal treatment. During the isothermal process, the austenite state slowly transforms to ferrite and carbide. After the transformation is completed, it is taken out from the furnace and is air-cooled, as shown in Figure 2. Compared with the traditional spheroidizing annealing process, this process has its advantages, that is, it saves the entire heat treatment time, and makes the residual carbide after heat treatment fine and uniform, and greatly improves the hardness of the material.

Figure 2. Isothermal spheroidizing annealing process

In addition to the traditional spheroidizing annealing and isothermal spheroidizing annealing heat treatment process, there is also a repeated spheroidizing annealing process, that is, the first heating to 810 °C and then cooling to 710 °C, then heating to 780 °C and then cooling to 710 °C. The process can be repeated several times according to the needs of the different situation, and it is cooled in the air after being moved out of the furnace, as shown in Figure 3. However, the heat treatment process is relatively cumbersome in operation.
Martensitic quenching and tempering

Martensitic quenching and tempering refer to the combined heat treatment process of quenching and low temperature tempering of GCr15 material steel. It is generally used as the final heat treatment of bearing steel. The heating temperature is between Ac1-Acm, that is, the temperature is between 830-850 °C. When the austenitizing temperature is higher, the original structure is more unstable. The amount of retained austenite in the structure after quenching is also greater, and the larger the martensite structure in the form of flakes, the greater the proportion of twins in the substructure, which is extremely easy to form microfissure after quenching and heat treatment. At the same time, with the increase of the austenitizing temperature of GCr15 material steel, the hardness will be greatly improved after quenching and heat treatment, but the toughness will also be slightly reduced. However, if the austenitization temperature is too high, the amount of retained austenite after quenching and heat treatment will be too much, but the hardness of the material steel will be greatly reduced, and the impact toughness and fatigue resistance will also be greatly reduced. Under general circumstances, the quenching temperature of the steel needs to be strictly controlled. Under normal circumstances, the metallographic structure of the GCr15 material steel after martensite quenching is martensite, retained austenite, and undissolved carbides. Under general circumstances, tempering heat treatment is required immediately after quenching. Low-temperature tempering treatment can achieve the effect of eliminating the internal stress of the material, improving the toughness of the material, and stabilizing its structure and size. The tempering temperature of GCr15 material steel is generally controlled at 150-160 °C. The structure after tempering is tempered martensite, with uniform fine carbides and a small amount of retained austenite [6].

Bainite austempering

Bainite austempering is to heat the GCr15 material steel from the quenching temperature, that is, the temperature to 830-850 °C, and cool it to a certain temperature above the Ms point at a cooling rate greater than the critical quenching cooling rate, that is, 200-350°C for heat preservation. Then it was taken out from the quenching heat treatment process in which the material is cooled to room temperature in the air. The remarkable feature of this process is that the austempering is generally performed in a nitrate bath furnace. During the quenching process, the material is forced to transform from the supercooled austenite state to the lower bainite [7].

After GCr15 material steel is subjected to bainite austempering heat treatment, its structure consists of the lower bainite with martensite residual carbides. Compared with the martensite quenched and tempered structure, the lower bainite structure obtained by the bainite austempering has higher toughness at the same tensile strength. Due to the uniform distribution of carbides in the lower bainite, it does not precipitate along the original austenite grain boundaries, but precipitates at an angle of
55-65° with the long axis of the ferrite sheet, and does not form twin crystal. Its substructure shows a high-density dislocation, and the quenched and tempered structure is lamellar martensite. The greater the proportion of twin crystal in the substructure, the larger the number of microcracks in the lamellar martensite. Because of the high carbon content in GCr15, this high-carbon martensite has a high solid-solution carbon content and a high solid-solution strengthening effect that seriously damages the toughness of the steel. The lower bainite obtained by austempering of bainite does not have the above-mentioned defects, so it has higher toughness, while the lower bainite does not have the above-mentioned defects, which is in line with its high-density dislocation substructure. After austempering, the structural stress and thermal stress are both small. If the lower bainite structure is tempered again, the toughness can be more improved. In addition, the impact toughness of bainite austempering is higher than that of carburizing, and the surface stress is surface compressive stress. Its heat treatment effect can be compared with carburized bearings. For small and medium-sized carburized bearings, this process should be used instead.

3. Phenomenon and analysis of cracks in GCr15 bearing ring after heat treatment

A certain batch of material is GCr15, bearing ring blanks with a diameter of 1m is used, as shown in Figure 4. The heat treatment furnace used is shown in Figure 5. After the bearing blank was quenched and tempered by martensite, it was found that there were obvious cracks on its surface. Due to the large volume of the bearing blank and the relatively high casting cost, crack analysis is required. Now the large-size bearing ring blanks are intercepted by a wire cutting machine and sent to the inspection department for appearance and fracture examination. It is found that the cracks are distributed along the circumference with partial bifurcations. The distribution along the radial direction is shown in Figure 6. The surface fractures distributed along the circumference have relatively thick surface morphology. Where the fractures originate from the surface of the section, the fractures distributed along the radial direction are relatively fine. Therefore, the fracture is originating from the circumferential crack, as shown in Figure 7. Observed under the electron microscope at 100 times magnification, the matrix structure is martensite with retained austenite, as shown in Figure 8. At 500 times magnification, there is an oxidative decarburization structure at the cracks, and the surface with a thicker fracture is severely oxidized and decarburized. As shown in Figure 9, Figure 10.
Figure 6. Cracks in the bearing ring

Figure 7. Fractures distributed along the circumference and radially distributed

Figure 8. Matrix structure (magnification 100 times)

Figure 9. Oxidative decarburization structure at the cracks (magnification 500 times)
In view of the surface crack phenomenon and test results of the bearing ring blank after martensitic quenching and tempering heat treatment, the organization experts consulted, and the analysis opinions are as follows:

(1) According to the analysis of the examination results, the sample fracture originates from the surface of the part. There are two types of fractures. One is the thicker fracture, which belongs to the fracture before heat treatment and quenching, and the other is the thinner fracture, which belongs to the quenching crack.

(2) The bearing ring blank has cracks before quenching in martensite quenching and tempering treatment. Before quenching, the crack fracture is relatively thick, and the crack breaks along the circumferential direction. During quenching, the crack expands and breaks in the radial direction, and the crack fracture is fine.

4. The strategy analysis and conclusions of cracks in GCr15 bearing rings after heat treatment

Comprehensive use of the theory of the influence of the pre-heat treatment process on the performance of GCr15, the experts decided to consider the use of a combined heat treatment process to solve the problem, analyze the cracks before and after quenching separately and find solutions. For cracks before quenching, isothermal spheroidizing annealing and strictly controlling the spheroidizing annealing temperature are used to solve the cracks. The cracks generated after quenching are solved by bainite austempering instead of martensite quenching and tempering. The details are as follows:

First of all, for the cracks with relatively thick fractures and cracks in the circumferential direction before quenching, consider the use of GCr15 steel isothermal spheroidizing annealing process to solve the problem, that is, after heating to 790 °C, rapid cooling it to 690 °C for isothermal, and during the isothermal treatment, GCr15 steel will transform from austenite to ferrite. After the transformation is completed, the GCr15 steel is taken out of the furnace and cooled in air. The theoretical basis is that the isothermal spheroidizing annealing heat treatment process that will make the carbides in the structure fine and uniform, which will greatly reduce the probability of cracks.

Secondly, for the cracks generated after cracking in the circumferential direction and quenching with relatively fine fracture and expansion, consider using bainite austempering instead of martensite quenching and tempering heat treatment to solve the problem. The theoretical basis is that the lower bainite structure obtained by austempering of bainite has much better plasticity than martensite, which can effectively alleviate the stress concentration at the crack tip and release part of the internal strain energy of the matrix.

According to the what have been mentioned above, the original heat treatment process is improved, that is, the heat treatment combination plan of isothermal spheroidizing annealing bainite and austempering is used to replace the traditional combination heat treatment plan of spheroidizing annealing martensite quenching and tempering, and the heat treatment temperature is strictly controlled. The test verified that no such crack was found anymore, and the problem was solved.
Acknowledgments

2017 General Project of Scientific Research in Liaoning Province (QL201723); Fund Project of Liaoning Science and Technology in 2019 (BS-201933); Dalian Ocean University Second "Zhan Lan Scholar Project" funded project(191022007); Scientific Research Funding Project of Liaoning Provincial Department of Education in 2019.

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