Effect of cold treatment process on roundness of bearing ring

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Abstract

In the heat treatment of the bearing ring, due to the different degree of thermal expansion of the outer surface and inner metal of the bearing ring, and the large thermal stress and tissue stress generated in the ring, resulting in serious deformation of the ring in the diameter direction and increased roundness error. For these problems, the heat treatment test of the bearing ring was carried out, with the cold treatment process added to the heat treatment. The effect of cold treatment on the residual stress, retained austenite and roundness of the bearing ring was analyzed. The research results show that: because the degree of deformation of the bearing ring is affected by the residual stress, the cold treatment process can significantly improve the residual stress on the bearing ring surface and reduce the deformation. The cold treatment process can accelerate the transformation from retained austenite to martensite in the bearing ring, reduce the content of retained austenite, refine the martensite structure and promote the precipitation of network carbide. The cold treatment after quenching also can improve the roundness accuracy of the bear outer ring and the bearing ring raceway, and ensure the processing quality and dimensional stability, which will be a significant benefit in industrial applications.

1. Introduction

Rolling bearings are an important part of contemporary mechanical equipment [1–3], which are widely used in automobiles, home appliances, medical equipment and other fields [4, 5]. As one of the important components of the bearing, the roundness error of the bearing ring is a significant quality index for evaluating the quality of the bearing ring [6]. The roundness error of the rolling bearing ring has a great influence on the installation, vibration, noise and service life of the bearing [7]. With the rapid development of the bearing industry, the output and demand for precision bearings and low-noise bearings are increasing. At the same time, the bearing industry’s requirements for the dimensional stability of bearing rings continue to increase.

Heat treatment is one of the key working procedures to ensure the quality of bearing rings in the bearing production process. At present, the bearing industry mainly obtains qualified heat treatment organization by optimizing heat treatment parameters and selecting reasonable process flow, so as to reduce the internal stress of the bearing rings and the geometric and dimensional deformation of the bearing rings during heat treatment [8]. Su et al [9] reduced the furnace temperature of the rod rolling furnace, slowed down the heating speed of the bearing ring during quenching, stabilized the internal organization of the ring, achieved the purpose of artificial aging, better eliminated some vehicle stress and reduced the deformation of the ring due to the influence of vehicle stress. Also comparing the elliptical deformation and warpage deformation laws of Thin-walled bearing rings under different quenching methods. Feng et al [10] obtained the influence law of salt bath quenching and step quenching on the elliptical deformation and warpage deformation of Thin-walled bearing rings during quenching. Surn et al [11] Studied the influence of different heating parameters on bearing ring deformation and analyzed the influence of heating rate on ring roundness. Liu et al [12] discussed the generation mechanism of bearing ring deformation. it is concluded that the mesh belt furnace has the advantage of controlling ring
deformation. Xie [13] studied the influence of different heat treatment heating temperatures and residence times of the ring after rolling on the deformation of the bearing ring. Zhang et al [14] comprehensively summarized the change law of bearing ring size and the factors and mechanism affecting the heat treatment deformation of the bearing ring and put forward specific countermeasures to reduce the heat treatment deformation of the bearing ring according to the actual production situation. The above research reveals the mechanism and law of dimensional deformation of bearing rings by changing the heat treatment process parameters such as quenching and tempering. In addition, there are studies suggesting the use of cryogenic treatment for steel workpieces. Li et al [15, 16] studied the process methods that affect the stability of the internal structure of the bearing ring and the effect of different cryogenic treatment times on the performance of the bearing ring, proving that the cryogenic treatment can reduce the content of retained austenite in the bearing ring and can reduce defects in bearing steel.

Although there have been studies using cryogenic treatment to analyze the performance of bearing rings, the use of cryogenic treatment will cause excessive stress in the internal structure of the ring, which may cause cracks in the bearing ring and reduce the contact fatigue life and impact toughness of the bearing ring. Therefore, this article takes 6905 deep raceway ball bearing ring as the research object, adds a cold treatment process to the bearing ring heat treatment process, and compares the residual stress, retained austenite and roundness error of bearing ring with or without cold treatment. The effect of cold treatment process on the residual stress of the bearing ring, the content of retained austenite in the ring and the effect of raceway diameter deformation on ring roundness are explored.

2. Methodology

2.1. Sample preparation

6065 bearing ring samples were manufactured as presented in figure 1. The raw material of the bearing ring used in the study is GCr15 bearing steel, and its chemical composition is shown in table 1. After the bearing ring is machined, the heat treatment process of the sample is selected. The samples of this heat treatment test are divided into two groups: the heat treatment process of Group I bearing ring includes quenching, cold treatment and high-temperature tempering. The heat treatment process of Group II bearing rings is only quenching and high-temperature tempering, and there is no cold treatment in the middle.

The specific heat treatment process of bearing ring is as follows: the quenching is carried out in a mesh belt heat treatment furnace, the quenching temperature is 830 °C, and the holding time is 40 min before oil quenching; the cold treatment is carried out in the DJIL-SLX11910 ultra-low temperature cryogenic box, and the cold treatment temperature is −80 °C. The holding time is 1.5 h; the high-temperature tempering temperature is 180 °C, and the holding time is 4 h.
The reason for fixing the cold treatment temperature and duration above is that the cold treatment temperature is determined by the martensite transformation termination temperature of GCr15 bearing steel. At the same time, it is also necessary to consider the effect of cold treatment on the mechanical properties of the bearing ring. After GCr15 bearing steel is quenched and cool, its martensite transformation termination temperature is about $-70 \, ^{\circ}C$. With the cold treatment temperature higher than $-70 \, ^{\circ}C$, although the hardness of the bearing ring can be increased, the bending strength and impact toughness will be reduced; on the contrary, a too low cold treatment temperature may cause cracks in the bearing ring, and its contact fatigue life will be reduced. For bearings with higher precision requirements, the cold treatment temperature should be close to but not higher than the martensite transformation termination temperature, so the cold treatment temperature in the test is selected as $-80 \, ^{\circ}C$. The duration should mainly consider factors such as the thermal conductivity, volume and the stability of the retained austenite transformation of the processed parts. The longer cold treatment time is better than the shorter ones because long-term cold treatment can fully transform the retained austenite in the steel and is more conducive to the formation of carbide particles. In order to ensure that the surface and the inside of the bearing ring can reach the same temperature for the uniform transformation of the structure during the cold treatment, it is generally held for 1 to 1.5 h at the specified temperature. In this test, the duration of bearing ring cold treatment is selected as 1.5 h.

2.2. Test method

Group I and Group II each selected 20 bearing rings as samples randomly. The outer ring diameter of samples was measured by using the bearing diameter measuring instrument. Subsequently, two bearing rings samples were taken from each of Group I and Group II.

The X-350A X-ray stress tester was used to measure the residual stress on the surface of the raceway and the retained austenite content of the bearing ring. The determination of residual stress was carried out according to GB-7704–2017 Non-destructive testing—Practice for residual stress measurement by X-ray standard, using the fixed inclination $\psi$ method, specific parameters: the tube voltage was 20 kV, the tube current was 5 mA, the tube target was made of Cr, K$\alpha$ radiation was used, the diffraction angle was 144.00$^\circ$ $\sim$ 168.00$^\circ$, the diffraction spot diameter $\Phi$ was 2 mm, the scanning step was 0.1$^\circ$, the count time per step was 0.5s, four fixed values of $\psi$ were adopted: 0$^\circ$, 25$^\circ$, 35.3$^\circ$ and 45$^\circ$. The determination of retained austenite content was carried out in accordance with YB/T5338–2006 Quantitative determination of retained austenite in steel X-ray diffractometer method standard, specific parameters: The tube voltage was 25 kV, the tube current was 5 mA, the tube target was made of Cr, K$\alpha$ radiation was used, the diffraction angle was 144.00$^\circ$ $\sim$ 168.00$^\circ$, the diffraction spot diameter $\Phi$ was 2 mm, the scanning step was 0.1$^\circ$. Choose austenite (220) and Fe (211) diffraction surfaces, and the scanning ranges were 123$^\circ$$\sim$132$^\circ$ and 144$^\circ$$\sim$168$^\circ$ respectively, the scanning step was 0.1$^\circ$ and 0.2$, and the count time per step 1s and 0.25s. The microstructure of the samples was observed by XJG-05 metallographic microscope to explore the effect of cold treatment on the residual stress before grinding on the surface of the raceway and the retained austenite content in the ring. The Y9025C roundness measuring instrument was used to measure the surface roundness of the outer ring and the raceway after the centerless grinding to explore the effect of raceway diameter deformation on the roundness.

3. Results and discussion

3.1. Effect of cold treatment on residual stress in bearing rings

Table 2 shows the maximum raceway diameter deformation and the minimum raceway diameter deformation of the bearing rings of Group I and Group II. It can be seen from the table that the average value of the largest raceway diameter deformation without cold treatment is 145.68 $\mu$m and the average value of the largest raceway diameter deformation after cold treatment is 98.37 $\mu$m. After the cold treatment, the average value of the largest raceway diameter deformation is 47.31 $\mu$m smaller than that of the untreated one; the average value of the smallest raceway diameter deformation without cold treatment is 93.42 $\mu$m, the average value of the smallest raceway diameter deformation after cold treatment is 54.16 $\mu$m, and the average value of the largest raceway diameter deformation after cold treatment is 39.26 $\mu$m smaller than that of the untreated one; the average deformation of the raceway diameter after cold treatment is 76.27 $\mu$m, which is 43.28 $\mu$m less than the average deformation of the raceway without cold treatment.

From the above comparison of the raceway diameter, it can be concluded that the average value of the maximum and minimum deformation of the outer ring raceway diameter after cold treatment is less than the average value of the outer ring raceway diameter deformation without cold treatment, which proves the cold treatment at $-80 \, ^{\circ}C$ for 1.5 h can effectively reduce the diameter deformation of the outer raceway and improve its forming accuracy.
The residual stresses at the maximum deformation and minimum deformation of the outer ring were measured by the x-ray diffraction method. The residual stresses at the maximum deformation and minimum deformation of four groups, as shown in table 3. As can be seen from the measurement results in table 3, the residual stresses at different test positions on the bearing rings surface of the two groups are negative. The negative values indicate that the residual stresses at the minimum deformation and maximum deformation point on the surface of the two groups are all compressive stresses.

In addition, the residual stress measured at the place where the raceway diameter deformation of the cold-treated bearing ring is the largest and the place where the raceway diameter deformation is the smallest is smaller than that of the non-cold-processed bearing rings sample. At the same time, comparing the residual stress values and raceway diameter deformation at the minimum and maximum deformation of each group, it can be found that the residual stress at the minimum deformation is less than that at the maximum deformation. The larger the raceway diameter deformation, the greater the residual stress.

Through the above analysis, it can be concluded that the residual stress on the raceway surface of the bearing ring is related to the amount of raceway diameter deformation. The cold treatment can improve the residual stress of the bearing rings raceway, and the smaller residual stress produces a smaller amount of raceway diameter deformation of the bearing rings raceway.

### 3.2. Effect of cold treatment on residual austenite content in bearing ring

The microstructure of the bearing ring after different treatments is shown in figure 2, where figure 2(a) is the metallographic structure of the bearing ring with cold treatment. Figure 2(b) shows the metallographic structure...
of the bearing ring without cold treatment. As can be seen from the figure, the black part is mainly martensite structure, and the off-white part is mainly austenite structure. The quenched and tempered martensite structure of the metallographic structure of the bearing rings samples is level 2, and the network carbide level is 1. There is no carbon-depleted decarburization phenomenon on the surface, which meets the technical standard of small bearing rings quenching and tempering martensite structure level 2 ∼ 4. Compared with the martensite structure of the bearing rings after the cold treatment is more refined, the content of retained austenite is less, and the content of network carbide is increased.

After testing, the retained austenite content of the cold-treated bearing ring is 3.4%, and the retained austenite content of the un-cold-treated bearing ring is 6.9%. After the cold treatment, the retained austenite content in the bearing ring has decreased significantly, but the retained austenite structure has not been eliminated completely, and there is still a small amount of residual austenite. The reason is that during cold treatment, a large amount of residual austenite structure of the bearing ring changes to martensite structure, but due to the different densities of the two structures, a reverse pressure is formed, which prevents the retained austenite structure from completely transforming into the martensite structure.

It can be concluded from the above analysis that after cold treatment, the transformation speed of retained austenite in the bearing ring to martensite can be accelerated, and the retained austenite content in the bearing ring can be effectively reduced.

### 3.3. Effect of cold treatment on the roundness of the bearing outer ring

Generally, the roundness error of bearing rings can be divided into the roundness error of the bearing outer ring and the roundness error of the bearing ring raceway. The bearing ring needs to be stored for 15 days after centerless grinding of outer ring and before the raceway grinding process. Conventionally, during storage, the release of residual stress will cause the ring to deform and cause roundness errors.

The effect of cold treatment on the roundness of the bearing outer ring is analyzed firstly. The roundness of 20 outer ring samples of Group I and Group II before grinding is measured by the roundness measuring instrument. The roundness of 20 outer rings is shown in table 4. It can be seen from table 4 that the minimum roundness of the bearing outer ring after the cold treatment is 0.37 \( \mu \text{m} \), the maximum roundness is 0.88 \( \mu \text{m} \), and the average value is 0.59 \( \mu \text{m} \). The maximum roundness of the bearing outer ring without cold treatment is 0.94 \( \mu \text{m} \), the roundness minimum is 0.45 \( \mu \text{m} \), and the average value is 0.62 \( \mu \text{m} \). The average roundness of the two groups is lower than 0.7 \( \mu \text{m} \) required for the roundness of outer rings of 6905 bearing rings, and the roundness of bearing outer ring after cold treatment is generally smaller than that of group II by comparison.

It can be obtained that whether the bearing ring is cold-treated or not, the roundness of outer rings can reach the standard. Obviously, the cold treatment after quenching can effectively reduce the roundness error of the outer ring and prevent the bearing ring from deformation during storage.

### 3.4. Effect of cold treatment on the roundness of the bearing ring raceway

Afterward, the two groups of bearing rings raceway are grinding, and the roundness of bearing rings raceway of the two groups is shown in table 5. It can be seen from table 5 that the average roundness of the bearing rings raceway after the cold treatment is 0.67 \( \mu \text{m} \), which is greater than the roundness of the bearing outer ring. Because of the roundness of the bearing rings raceway of most samples exceeding 1.0 \( \mu \text{m} \), the average raceway roundness of the untreated bearing rings is 1.52 \( \mu \text{m} \). Among them, the raceway roundness of No. 7 and No. 15 samples even exceeds 2.0 \( \mu \text{m} \), exceeding the roundness technical requirement standard of bearing ring raceway. Therefore, comparing the dimensional accuracy with and without cold treatment, it can be clearly pointed out that the cold treatment can promote the reduction of the roundness after raceway grinding.
Figure 3 shows the effect of the raceway diameter deformation of the two groups on the roundness of the bear ring raceway. With the increase of the diameter deformation of the bearing rings raceway, as shown in figure 3, the roundness error of the raceway after grinding of Group I and Group II shows an upward trend. The greater the raceway diameter deformation before grinding, the greater the raceway roundness error after grinding.

Aiming at the problems of large deformation of bearing rings raceway diameter and large raceway roundness error in Group II without cold treatment, the grinding cycle of this batch of bearing rings raceway is adjusted. The process parameters of bearing ring raceway grinding are shown in table 6. For the grinding cycle of original raceway grinding, the average processing time of each bearing ring is 10 s, and the rough grinding time and fine grinding time are both 2 s. For the adjusted raceway grinding cycle, the average processing time of each bearing ring is shown in table 6.

| Table 4. Roundness of bearing outer ring. |
|----------------------------------------|
| Sampling number | Group I (/μm) | Group II (/μm) |
|-----------------|---------------|----------------|
| 1               | 0.37          | 0.64           |
| 2               | 0.50          | 0.94           |
| 3               | 0.77          | 0.88           |
| 4               | 0.68          | 0.66           |
| 5               | 0.67          | 0.62           |
| 6               | 0.63          | 0.60           |
| 7               | 0.56          | 0.56           |
| 8               | 0.63          | 0.45           |
| 9               | 0.50          | 0.56           |
| 10              | 0.78          | 0.68           |
| 11              | 0.42          | 0.51           |
| 12              | 0.72          | 0.53           |
| 13              | 0.88          | 0.59           |
| 14              | 0.68          | 0.76           |
| 15              | 0.59          | 0.49           |
| 16              | 0.41          | 0.69           |
| 17              | 0.44          | 0.48           |
| 18              | 0.78          | 0.35           |
| 19              | 0.33          | 0.52           |
| 20              | 0.49          | 0.76           |
| Average         | 0.59          | 0.62           |

| Table 5. Roundness of bearing ring raceway. |
|--------------------------------------------|
| Sampling number | Group I (/μm) | Group II (/μm) |
|-----------------|---------------|----------------|
| 1               | 0.53          | 1.23           |
| 2               | 0.69          | 1.44           |
| 3               | 0.72          | 0.88           |
| 4               | 0.88          | 1.56           |
| 5               | 0.66          | 0.98           |
| 6               | 0.70          | 1.03           |
| 7               | 0.69          | 2.42           |
| 8               | 0.82          | 1.55           |
| 9               | 0.69          | 0.72           |
| 10              | 0.83          | 0.85           |
| 11              | 0.56          | 1.32           |
| 12              | 0.74          | 1.14           |
| 13              | 0.88          | 1.75           |
| 14              | 0.58          | 0.76           |
| 15              | 0.56          | 2.03           |
| 16              | 0.49          | 1.43           |
| 17              | 0.55          | 0.95           |
| 18              | 0.76          | 1.07           |
| 19              | 0.51          | 1.55           |
| 20              | 0.62          | 1.24           |
| Average         | 0.67          | 1.52           |
rings is 16 s, the rough grinding time is extended to 7 s, and the fine grinding time is extended to 3 s. Use the adjusted grinding cycle parameters to perform raceway grinding on the bearing rings.

The adjusted grinding cycle parameters are used for raceway grinding of bearing rings, and 20 bearing rings samples were taken for raceway roundness measurement. The raceway roundness error is 0.82 μm. Although properly prolonging the grinding cycle and extending the rough grinding and fine grinding time of the raceway can effectively control the roundness error of the raceway and it is smaller than the roundness of the bearing rings raceway machined in the original grinding cycle, it still cannot reach the raceway roundness of the cold treated bearing rings in Group I. In order to meet the technical standard, the 6905 bearing ring needs to be cold treated.

4. Conclusions

(1) It is verified that the cold treatment can significantly reduce the residual stress on the surface of the bearing ring raceway. Small residual stress makes the bearing raceway less deformed and high forming accuracy.
(2) With the cold treatment condition of 1.5 h and — 80 °C, the transformation rate of residual austenite to martensite in the bearing ring can be accelerated and the content of residual austenite in the bearing ring can be effectively reduced.

(3) Cold treatment after quenching can effectively reduce the roundness error of the outer ring and prevent the bearing ring from deformation during storage or use.

(4) Under the condition that the 6905 bearing ring is subjected to raceway centerless grinding without cold treatment, the raceway roundness is out of tolerance. Although changing the grinding process can effectively reduce the raceway roundness error, the control effect is worse than that of cold treatment. Therefore, applying cold treatment to the bearing production process can improve product quality and production efficiency.

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Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

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