Improving the Durability of the Wheel Hub Bearings by Utilizing the Sub-zero Treatment Technique

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ABSTRACT

A novel sub-zero treatment technique is introduced to improve the durability of the wheel-hub bearings. The X-ray diffraction method was introduced to assess the sub-zero treatment effects on the retained austenite transformation. The impacts of the treatment conditions on the mechanical properties, such as hardness and impact toughness, were also evaluated. Furthermore, the accelerated life test was carried out to reveal the relationship between the process parameters of the sub-zero treatment and the durability of 52100 wheel hub bearing. The results showed that the sub-zero treatments could improve the durability of 52100 hub bearings, and the amount of the retained austenite transformation is proportional to the sub-zero treatment temperature. But too much of the retained austenite transformation could reduce the fatigue life. It is also convinced that there is an optimized treatment temperature could improve the durability of 52100 wheel hub bearings.

INTRODUCTION

The Wheel-hub Bearing.

Wheel hub bearing is one of the most highly stressed parts in a passage vehicle. The pitting and wear of the bearings cause the early failure [1]. The failure of the wheel hub bearing usually occurs on the raceways of the outer ring and the inner ring depending on the working load. A wheel-hub bearing consists of four parts: inner ring, outer ring, balls and cage. Under the working service conditions, the inner raceways, the outer raceway and the balls take the working load, while the cage only separate the balls and keep them running stably.

Due to the inconsistent quality of the wheel hub bearings manufactured in China, it is difficult to meet the requirement of OEM. This paper presents the research result of using sub-zero treatment process to improve the wear resistance

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and fatigue behaviors of the inner track ring and outer track ring of SAE 52100 wheel hub bearing.

**Retained Austenite.**

The inner/outer raceways of wheel-hub bearings are made of SAE 52100 steel with a trace of alloys to achieve the desirable properties. The manufacturing processes of the inner/outer raceways involve heat treatment of quenching followed by tempering. One of the major problems with the conventional heat treatments is that the excessive amount of the retained austenite ($\gamma^R$) is soft and unstable at room temperature. The retained austenite could transfer into the martensite when in use. When this occurred, the volume could increase approximate 4%, and therefore introduced additional internal stress and caused the early failure of the component [2].

**The State-of-the-art of the Sub-zero Treatment.**

The sub-zero treatments can be classified as the cold treatment (0 ~ -80ºC), the shallow cryogenic treatment (-80 ~ -160ºC) and the deep cryogenic treatment (-160 ~ -196ºC). The sub-zero treatment is a novel process to improve the properties of the metal and its alloys developed in recent years. It puts the material in an environment under zero degree temperatures and leaves it for a defined period of time before bring the environmental temperature back to the room temperature. The objective of the sub-zero treatment is to make permanent changes to the microstructure of the material therefore to achieve the desired properties without major side effects.

In order to improve the fatigue life of SAE 52100 hub bearing, this research developed different processes to investigate the impacts of the treatment parameters on the mechanical properties of the material.

**SPECIMENS AND EXPERIMENTATIONS**

**Sample Preparation.**

The SAE 52100 steel was selected as the raw material for the inner ring and the outer ring of hub bearing, the chemical composition of the material is shown in Table 1. After machined in the lathe, the forging blanks were quenched (Q), processed under sub-zero temperature and tempered (T). Finally the raceways of the inner ring and outer ring were grinded, then assembled.

| Elements | C   | Si  | Mn  | Cr   | Mo  | P   | S   | Cu  | Ni  | Al  |
|----------|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|
| Wt%      | 0.93-1.05 | 0.15 | 0.25-0.45 | 1.35-1.60 | ≤0.10 | ≤0.025 | ≤0.015 | ≤0.30 | ≤0.25 | ≤0.050 |

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Heat Treatments.

In this study, the different specimens were processed differently. The conventional heat treatments, quenching (Q) and tempering (T) were conducted under the guidance of American Society of Testing Materials (ASTM). The cold treatment was applied between the hardening and tempering processes, as shown in Fig. 1.

With the conventional QT treatment, the specimens were heated to 840 °C in a tube furnace and held for 30 minutes for austenitizing. Then they were quenched in 20°C oil before tempered at 170 °C furnace for 2 hours.

During the cold treatment (CT), two groups of CT specimens (CT40-1, and CT40-2) were heated to 840°C in a tube furnace and kept for 30 minutes for austenitizing. After fast quenched in 20 °C oil, the specimens were further cooled to -40 °C, and then kept in a well-insulated cryogenic treatment chamber for 1 hour, and 2 hours respectively. Finally, all specimens were tempered at 170 °C for 2 hours and cooled to room temperature as shown in Table 2.

| Codes | Description of the heat treatment cycles |
|-------|-----------------------------------------|
|       | Hardening | Sub-zero treatment | Tempering |
| QT    | --        | -40°C,1h           | 170°C,2h |
| CT40-1|           | -40°C,2h           |          |
| CT40-2|           | -80°C,1h           |          |
| SCT80-1|          | -80°C,2h           |          |
| SCT80-2|          | -120°C, 1h         |          |
| SCT120-1|         | -120°C, 2h         |          |
| SCT120-2|         | -160°C, 1h         |          |
| DCT160-1|         | -160°C, 2h         |          |
| DCT160-2|         | -196°C, 1h         |          |
| DCT196-1|         | -196°C, 2h         |          |
| DCT196-2|         |                    |          |
During the shallow cryogenic treatment (SCT), four groups of specimens (SCT80-1, SCT80-2, SCT120-1, SCT120-2) were heated to 840 °C in a tube furnace and kept for 30 minutes for austenitizing before fast quenched in 20 °C oil. Two groups of specimens were further cooled at -80°C and -120°C respectively, and held for 1 hour or 2 hours respectively in the well-insulated cryogenic treatment chambers. Finally, all specimens were tempered at the 170 °C for 2 hours and then cooled at room temperature.

During the deep cryogenic treatment (DCT), four groups of specimens (DCT160-1, DCT160-2, DCT196-1, DCT196-2) were initially heated to 840 °C in a tube furnace, then held for 30 minutes for austenitizing before fast quenched in the 20 °C oil. Specimens were further cooled to -160°C or emerged in the liquid nitrogen of approximately −196 °C. To hold respectively for 1 hour or 2 hours before further tempered in a tube furnace of 170°C for 2 hours. Then cool at room temperature.

**X-ray Diffraction Method.**

The amount of the retained austenite of the specimens were characterized by the diffractive amplitudes (austenite: \{200, 200\}; martensite: 200, 211\}) of the X-ray diffraction (XRD). Three test points with same intervals were selected for measurement on the external surface of every specimen. Using a Xstress 3000 diffractometer, scanning was conducted at 6° around each peak and 10 readings were collected each second according to the guidance of ASTM E975 standard.

**Hardness and Impact Test.**

In this study, the Rockwell hardness of the specimens was measured using a TH320 Rockwell hardness tester. The hardness of each sample was determined by averaging the measured hardness values at three locations on the circumferential face of the inner ring and outer ring of SAE 52100 steel wheel hub bearing, as shown in Fig. 2 (a).

The impact toughness test was performed on a ZBC1251-2 drop weight impact tester according to the ASTM A370 standard. The specimens (5 mm × 10 mm × 55 mm) were machined using Electric Discharge Machining (EDM) process as shown in Fig. 3 (b). A total of six groups of specimens with different heat treatment processes (QT, CT, SCT, and DCT) were tested. Each group has three samples. The average impact toughness of each specimen was calculated. All the tests were performed at the room temperature.
Accelerated Life Test.

The accelerated life tests of the samples were performed on ABLT-1A type bearing fatigue life test rig according to JB/T50013-2000 as shown in Fig. 3 [3,4]. Five groups of the samples with different heat treatment processes (QT, CT, SCT, and DCT) were tested, each group consisting of 10 hub-bearings. The samples with 17.31 kN axial load run at 2600 r/min during test till fatigue occurred as shown in Table 3. The average fatigue life of each group of samples was then calculated [5].

| Tester type | Rating life $L_{10}$ (hours) | Load (kN) | Test bearing speed (r/min) | Lubrication and cooling |
|-------------|------------------------------|-----------|---------------------------|------------------------|
| ABLT-1A     | 115                          | 0         | 17.31                     | Grease lubrication     |
RESULTS AND THE DISCUSSION

Retained Austenite Transformation.

The retained austenite contents in SAE 52100 steel specimens were measured using X-ray diffraction method. After conventional quench hardening and tempering, there was about 11.63% of the retained austenite observed in the sample. The lower temperature used in the sub-zero treatment, the more retained austenite transformed to martensite, as shown in Fig. 4. And it is obvious that the retained austenite measured is proportional to the treated temperature [6]. The retained austenite content can be calculated using the linear regression analysis

\[ f_A = 0.0003T + 0.0932 \]  

where, \( f_A \) is the retained austenite content in the specimen, \( T \) is the temperature.

![Figure 4. Effects of temperature on retained austenite transformation.](image-url)

Variation of the Hardness.

The Rockwell hardness of the specimens treated at different conditions is showed in Fig. 5. The hardness of the samples taken shallow cryogenic treatment increased sharply because of the transition of the retained soft Austenite to the hard Martensite. The group of the SCT 80-2 sample, which had kept at -80°C for 2 hours during shallow cryogenic treatment, had the maximum hardness of HRC61.9. For the deep cryogenic treatment, the hardness of the samples declined gently with the decrease of the temperature. That is because that the secondary finer carbides precipitated around the grain boundaries of the Martensite (\( \alpha \)) and caused reduction of the carbide content in the Martensitic grains.
Impact Toughness.

The results of the toughness impact tests for the specimens with different heat treatment conditions are shown in Fig. 6. The impact toughness of the sub-zero treated specimen decreases with the treatment temperature. The minimum impact toughness was measured with the samples kept at -80°C for 2 hours during shallow cryogenic treatment. Oppositely the impact toughness of the DCT specimen increases when the temperature decreases in the deep cryogenic process. This is due to the fact that the lower cryogenic temperature, the more precipitation of uniformly-distributed secondary finer carbides. And those secondary finer carbides have more defaults in crystal structure, may effectively block the crack propagation and increase the energy dissipation during the crack propagation process.
TABLE 4. THE RESULTS OF THE ACCELERATED FATIGUE LIFE TEST OF THE WHEEL HUB BEARINGS.

| Codes  | Retained austenite (%) | Average life (hours) | Average life (million revolutions) | Reliability (%) |
|--------|------------------------|----------------------|------------------------------------|-----------------|
| QT     | 11.63                  | 139.7                | 21.79                              | 96.70%          |
| CT40-2 | 7.98                   | 174.9                | 27.28                              | 99.49%          |
| SCT80-2| 6.80                   | 188.1                | 29.35                              | 99.22%          |
| SCT120-2| 5.62                  | 146.5                | 22.85                              | 99.62%          |
| DCT160-2| 3.30                   | 90.3                 | 14.09                              | 99.20%          |

Accelerated Life Test of the Hub Bearing.

The accelerated life test results for SAE 52100 steel wheel hub bearing samples with different heat treatments are shown in Table 4. The average life of the group of QT hub bearing samples (with 11.63% retained austenite) is 139.7 hours (21.79 million revolutions) [7]. The average life of the CT40-2 and SCT80-2 samples are longer than the QT hub bearing sample. This may be caused by the transformation of the retained austenite into the martensite, and the formation of very fine η-carbides during the cold treatment or shallow cryogenic treatment. The test results also indicated that the maximum average life (188.1hous, 29.35 million revolutions) was obtained with the SCT80-2 wheel-hub bearing samples (6.8% retained austenite), which were kept at -80℃ cryogenic treatment chamber for 2 hours. However, the average life of SCT120-2 samples was lower than the SCT80-2 hub bearing samples. And the average life of the SCT160-2 samples (3.3% retained austenite) decreased sharply and was obviously lower than the QT hub bearing samples. This result shows that the reduced amount of retained austenite may not improve the fatigue life of the SAE 52100 hub bearings. Therefore, only the optimized content range of the retained austenite will improve the fatigue behavior of SAE 52100 steel wheel hub bearings.

CONCLUSIONS

The sub-zero treatments can effectively reduce the retained austenite content in the steel SAE 52100. The amount of retained austenite transformation is proportional to the temperature used in sub-zero treatment.

The hardness of the sub-zero treated specimen is higher than that that of the QT specimen. The maximum (HRC61.9) was found with the SCT80-2 specimen. But impact toughness of the sub-zero specimen is lower than the QT specimen. The minimum impact toughness was obtained with the SCT 80-2 specimens.

Based on the accelerated life test, the fatigue life of CT40-2 and SCT80-2 sample is obviously longer than the QT samples. It is concluded that the sub-zero treatments can improve the fatigue life of SAE 52100 steel hub bearings, but too much retained austenite transformation may reduce the fatigue life. Therefore, only optimized treatment temperature could improve the fatigue life of SAE 52100 steel wheel hub bearing.
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