Influence of repeated quenching-tempering on spheroidized carbide area in JIS SUJ2 bearing steel

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Abstract. High-carbon high-strength JIS-SUJ2 bearing steel is mainly used for rolling contact applications which require high fatigue strength. We had applied repeated quenching which refine the prior austenite grains to this steel. In this work, we prepared JIS SUJ2 bearing steel bar specimens which were quenched three times (Q3T1) and quenched-tempered three times (QTQTQT) in order to investigate the influence of tempering before quenching on the microstructure. The specimens were etched by picral to observe the microstructure. We found that the spheroidized carbide area was important for the prior austenite grain formation.

1. Introduction

High-carbon high-strength JIS-SUJ2 bearing steel is mainly used for rolling contact applications which require high fatigue strength and wear resistance. Quenching is one of the methods which improve the fatigue strength and wear durability.

Repeated quenching is used as one of the microstructure refinement methods [1-3]. In particular, repeated quenching refines the prior austenite grains. Because the prior austenite grain refinement improves the fatigue strength, repeated quenching has been investigated as the method that improves the fatigue strength [4, 5]. Ohki et al. reported that additional quenching after nitridizing (FA-treatment) refined the prior austenite grains and which indicated the refinement of martensitic structure. The FA-treatment also increased the retained austenite [6]. Santos et al. reported that the repeated quenching increased the retained austenite and a large amount of retained austenite improved the wear resistance of samples [7]. Mizobe et al. investigated the relation between the repeated quenching and the fatigue strength. They prepared the repeated quenched JIS SUJ2 bearing steel and performed the rotating bending fatigue tests. They reported that the fatigue strength depended on the variation of non-metallic inclusions in the refined the prior austenite grains [4, 8, 9].

In this work, we prepared JIS SUJ2 bearing steel which were quenched three times (Q3T1) and quenched-tempered three times (QTQTQT). We measured Vickers hardness and the value of the retained austenite, and focused on the microstructure transformation in order to investigate the influence of tempering before quenching.
2. Test method

2.1. Specimen (JIS SUJ2 steel) and heat treatment

We prepared JIS SUJ2 steel bars whose diameter was 10 mm. Table 1 shows the chemical composition of the specimens. Before the heat treatment, the material was spheroidized annealed.

Figure 1 shows the heat treatment process. Specimens were quenched at 850°C for 40 minutes and tempered at 180°C for 60 minutes. We prepared two type of specimens: specimens which were quenched three times and tempered once (Figure 1(a)), and the specimens which were quenched-tempered three times (Figure 1(b)). The former and later are referred to as Q3T1 and QTQTQT, respectively.

Table 1 Chemical composition of the JIS SUJ2 steel bar (weight %)

|     | C    | Si   | Mn  | P   | S   | Ni  | Cr  | Mo  | Cu  | Ti  |
|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|
|     | 0.99 | 0.26 | 0.4 | 0.019 | 0.007 | 0.08 | 1.38 | 0.02 | 0.11 | 0.002 |

(a) Q3T1

(b) QTQTQT

Figure 1 Heat treatment process.
2.2. X-Ray measurement and microstructure
We used Bulker D8 DISCOVER with GADDS (2D detector) in order to measure the amount of retained austenite. Table 2 shows the test conditions of the retained austenite measurement. Figure 2 shows the observation points of the retained austenite and the measurement increments were 0.5 mm. Before the measurement, specimens were cut and polished by 1µm diamond paste.

Vickers hardness distributions of Q3T1 and QT samples were measured by a MATSUZAWA VMT-X7s. The test conditions were a load of 10 kgf and a time of 15 seconds. Furthermore, in order to observe the microstructure, the specimens were etched by picral for 360 seconds and observed by laser confocal microscope (LCM).

Table 2 Observation conditions for retained austenite measurement.

| X-ray source | Cr Kα |
|--------------|-------|
| Power        | 35 kV 40 mA |
| Diameter of collimator | 0.5 mm |
| Detector distance | 150 mm |
| Measurement angle | 60 to 90 (2θ) |
| Scan time   | 1200 sec / point |

![Figure 2 Observation points of the retained austenite.](image)

2.3. Observation of electron probe micro analyser (EPMA)
EPMA(JXA-8230) was used in order to determine the kinds of element. Table 3 shows the test conditions of EPMA observation, and the detection elements were Carbon, Chromium, Sulphur, Phosphorus and Iron. Before the observation, we prepared etched samples in order to emphasize the edge of microstructure.

Table 3 Observation condition of EPMA analysis.

| Cathode | W filament |
|---------|------------|
| Power   | 30kV and 500mA |
| Scan type | Beam scan |
| Resolution | 384x288 pixel |
| Magnification | 10000 |
| Probe   | Electron probe |
3. Results and discussion

3.1. Vickers hardness distribution and retained austenite

Figure 3 shows Vickers hardness distribution of Q3T1 and QTQTQT samples. The average of Vickers hardness was 819HV in Q3T1 sample and 840 HV in QTQTQT sample. The average of Vickers hardness of QTQTQT sample was slightly higher than that of Q3T1 sample.

Figure 4 shows the retained austenite distributions of Q3T1 and QTQTQT samples. The average of retained austenite was 24.2% in Q3T1 samples and 22.1% in QTQTQT samples. The average of retained austenite of QTQTQT sample was lower than that of Q3T1 sample. This indicates that tempering before quenching decreased the retained austenite.

3.2. Microstructure

Figure 5 shows the microstructure of the sample etched by picral. In previous work, we applied mathematical method to analyse the patterns of prior austenite grains[10]. In the present work, we observed spheroidized carbides to fur the investigate the effect of quenching times on microstructure. Figure 5(a) shows the microstructure of the Q3T1 sample (×1000). Figure 5(b) shows the microstructure of the QTQTQT sample (×1000). In both pictures, the spheroidized carbide clusters can be seen. We define this area as “spheroidized carbide area”. The spheroidized carbide area of QTQTQT sample was larger than that of Q3T1 sample. Figure 5(c) shows the microstructure of the spheroidized carbide area of the Q3T1 sample (×3000). Figure 5(d) shows the microstructure of the area including no spheroidized carbide of the Q3T1 sample (×3000). At the spheroidized carbide area, the prior austenite grains were refined. Figure 5(e) shows the microstructure of the spheroidized carbide area of the QTQTQT sample (×3000). Figure 5(f) shows the microstructure of the area including no spheroidized carbide of the QTQTQT sample (×3000). At the spheroidized carbide area, the prior austenite grains were refined. Figure 5(d) and Figure 5(f) are the area where the spheroidized carbide cluster cannot be seen. Here, the prior austenite grain size of Q3T1 sample was similar to that of QTQTQT sample. This indicates that the spheroidized carbide area is important for the prior austenite grain formation in both samples.
(a) Microstructure of the Q3T1 sample (×1000)

(b) Microstructure of the QTQTQT sample (×1000)
(c) Microstructure of the spheroidized carbide area of the Q3T1 sample (×3000)

(d) Microstructure of the area including no spheroidized carbide of the Q3T1 sample (×3000)
(e) Microstructure of the spheroidized carbide area of the QTQTQT sample (×3000)

(f) Microstructure of the area including no spheroidized carbide of the QTQTQT sample (×3000)

Figure 5 Microstructure of the samples etched by picral.
3.3. Analysis of EPMA
We used EPMA in order to investigate the characteristic of spheroidized carbide. Figure 6 shows the result of EPMA observation of QTQTQT sample. The spheroidized carbide consists of Carbon and Chromium and the substrate was Iron. Furthermore, a few Iron was detected from the spheroidized carbide.

![EPMA Observation](image)

Figure 6 Result of EPMA observation (QTQTQT).

4. Conclusions
We prepared JIS SUJ2 steel bars which were 10 mm diameter. Specimens were quenched three times and tempered once (Q3T1) and quenched-tempered three times (QTQTQT). We measured Vickers hardness and the retained austenite. The specimen was etched by picral in order to observe the microstructure. We used EPMA in order to investigate the characteristic of spheroidized carbide. The conclusions are as follows.

1. The average of Vickers hardness of QTQTQT sample was slightly higher than that of Q3T1 sample.
2. The average of retained austenite of QTQTQT sample was lower than that of Q3T1 sample.
3. Spheroidized carbide area is important for the prior austenite grain formation.
4. The characteristic of spheroidized carbide was chromium carbide.

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