COMBINED EFFECTS OF MICRO SHOT PEENING AND DEEP ROLLING ON THE FATIGUE LIFE OF THRUST BALL BEARINGS

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Keywords: Rolling contact fatigue, Residual Stress, Micro shot peening, Deep rolling, Thrust ball bearing

1. Introduction

Rolling bearings are widely recognized to be one of the most important of all mechanical elements. Size reductions and increased efficiency are demanding the provision of higher fatigue strength and wear resistance for rolling bearings, and micro structure control and surface modifications have been attempted with regard to bearing raceways and rolling elements. It is widely recognized that the application of compressive residual stress is an effective means of improving fatigue strength, since crack growth during rolling contact fatigue usually originates from subsurface regions [1].

Using manufacturing processes based on plastic deformation near the surface, such as a shot peening and deep rolling, it is possible to apply residual stress. Furthermore, shot peening with fine particles as the impact media, i.e. micro shot peening, results in higher residual stress near the surface without impact surface coarsening, and deep rolling is usually applied as the surface finishing process for flattening. Therefore, a combination of micro shot peening and deep rolling is a promising process for the surface modification of bearing elements [2].

The present study examines the applicability of a proposed surface modification process consisting of micro shot peening and deep rolling to the improvement of the fatigue properties of thrust ball bearing raceways. The changes in residual stress during a rolling contact fatigue experiment and the relationships between residual stress distribution and fatigue life were evaluated.

2. Experimental Methods

2.1 Surface modification

A commercial-grade chromium alloy steel washer for a thrust needle roller bearing (type 2542, ϕ 42×ϕ 25×t 3 mm) was used for the specimen. The end surface of the specimen was polished with diamond slurry (size 1 μm), then a heat treatment (200 deg., 3 hours) was applied to eliminate residual stresses in advance of the micro shot peening process. The micro shot peening was carried out using a newly developed direct gas injection system consisting of a double-walled nozzle that makes it possible to control the flow rate and flow speed individually. To reduce impact surface coarsening, glass beads (550 HV, 50 μm in diameter) were used for the impact media. The peening conditions are listed in Table 1. After the micro shot peening, deep rolling was applied to the surface using a hardened alloy steel roller with a diameter of 36 mm and a tip radius of 4 mm. The deep rolling conditions are listed in Table 2.

Table 1 Micro shot peening conditions

Treatment time	Flow speed pressure	Flow rate pressure	Nozzle distance
100 sec	0.6 MPa	0.3 MPa	100 mm

Table 2 Deep rolling conditions

Contact load	Revolution speed	Feed rate	Roller contact angle
600 N	550 rpm	0.044 mm/rev	90 deg.

Additional polishing was applied to the surface after the deep rolling, since the surface roughness after the deep rolling was greater than that of the bearing raceway. The estimated polishing thickness was less than 1 μm. The residual stress and the hardness of the testing surface were evaluated using an X-ray diffraction and a micro-Vickers indentation technique. Optical microscope images and surface profiles of the surfaces are shown in Fig. 1. Concavities resulting from the shot peening process were still present on the surfaces.

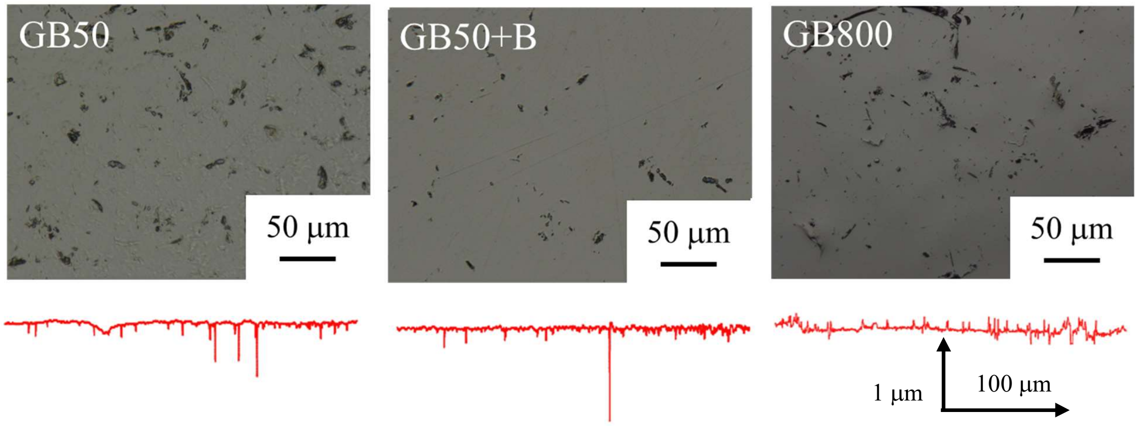
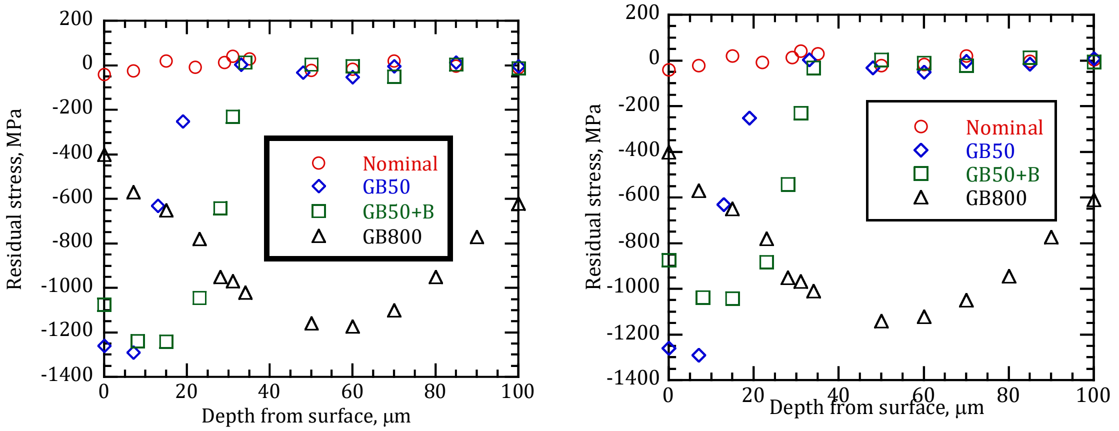


Fig.1 Optical microscope images and surface profile of shot peened and deep rolled surfaces

The residual stress distribution of the surface is shown in Fig. 2. An X-ray diffraction technique was used for the residual stress measurement. The measurement area was 1x1 mm^2 and the depth profile was obtained using electrolytic polishing. The residual stress of the non-peened (Nominal) surface was small and constant against the depth from the surface. The residual stress distribution of the surface peened with 800-µm glass beads (GB800) was isotropic and exhibited its maximum value of -1200 MPa in a depth range of 50 to 60 µm. The stress at the surface and at a depth of 100 µm was -400 MPa and -600 MPa respectively, and the zone affected by residual stress was relatively large. The maximum stress of the surface peened with 50-µm glass beads (GB50) was slightly larger than that of the GB800 peened surface and was exhibited at a depth of 8 µm. The residual stress was negligible at depths of more than 30 µm. As a result, the zone affected by residual stress in the GB50 peened surface was narrow and steep. The surface residual stress was -1250 MPa.

The shot peened and deep rolled (GB50+B) surface showed a different maximum stress depending on the measuring direction. The deep rolling resulted in an expansion of the zone affected by stress and a decrease in the maximum stress in the peripheral direction. Therefore, the surface stress decreased and the stress distribution was anisotropic.



Radial direction

Peripheral direction

Fig. 2 Residual stress distributions of shot peened and deep rolled surfaces

2.2 Rolling contact fatigue experiment

Rolling contact fatigue properties were evaluated with a thrust-type testing apparatus using 3-silicon nitride (Si_3N_4) balls with a diameter of 6.35 mm as the rolling elements. These balls were installed into the gage at equal intervals of 120 degrees on a pitch circle of diameter 34 mm. The surface-modified washer was mounted on a disc saucer located in the lower part of the apparatus. The gage was placed between the washer and a counter washer with a raceway groove. The counter washer was fixed to the end surface of a drive shaft located in the upper part of the apparatus. The contact load was applied by pushing up the disc using a dead weight through a lever. The testing conditions are listed in Table 3. The experiment was terminated when a vibration amplitude that was monitored during the experiment from an acceleration sensor mounted on the lever exceeded double the initial value.

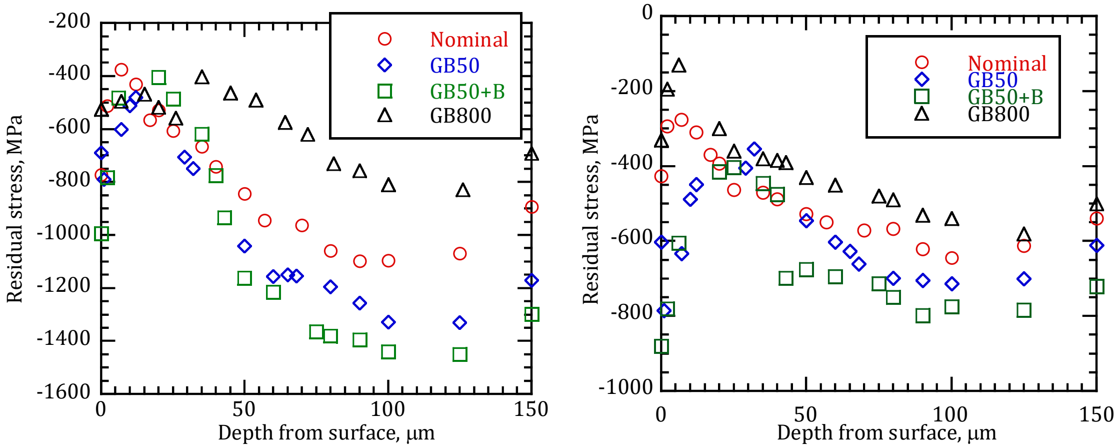
Table 3 Contact fatigue test conditions

Applied load	Rotational speed	Lubricant	Temperature	Relative humidity
980-2950 N	1500 rpm	PAO, 5 cSt @ 40 deg.	20-23 deg.	40-65%

3. Results and discussion

3.1 Change of residual stress distribution in rolling contact fatigue experiment

The rolling contact fatigue experiment at an applied stress of 4.5 GPa was interrupted at a testing time of 50 hours, and the residual stress distribution was measured. The residual stress profiles, shown in Fig. 3, were different from that of the initial state: The residual stress at the surface had decreased and the distribution had become anisotropic, and the shift of the zone affected by stress resulted in the maximum stresses' being located at a depth of around 100 μm. The order of the maximum stresses from largest to smallest was the GB50+B, then the GB50, then the Nominal, and then the GB800 surface. It was also found that the increase in the residual stress with the increase in the number of cycles and the difference in the stress depended on the direction in which the termination value was exceeded.



Radial direction

Peripheral direction

Fig. 3 Residual stress distributions of shot peened and deep rolled surfaces after 50 h of cyclic loading

3.2 Contact fatigue life

The relationship between the maximum contact stress and the number of cycles to failure determined from the vibration signal is shown in Fig. 4. The differences between the number of cycles to failure depending on the surface modification were small at the higher maximum contact stress of 6.62 GPa. In contrast, the number of cycles to failure for the GB50+B surface was several times larger than those for the other surfaces. Therefore, it was concluded that a combined surface modification consisting of micro shot peening and deep rolling is an effective means of improving the fatigue life of rolling contact elements.

Laser microscope images with contour maps of the raceway around the peeled-off regions are shown in Fig. 5. The depth of the peeling off varied from 70 to 120 μm, and was shallower than that for the maximum stress occurrence calculated from the contact mechanics. It appeared that the peeled-off depth increased with the increase in the number of cycles to failure.

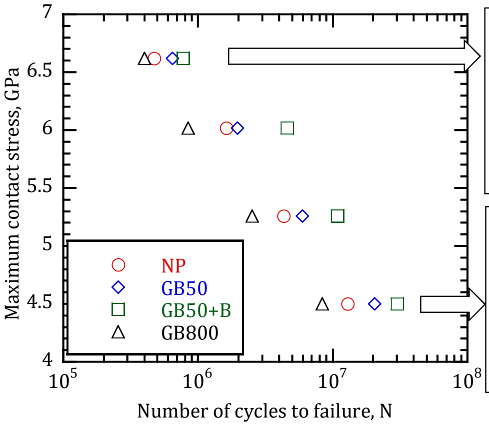


Fig. 4 S-N curve

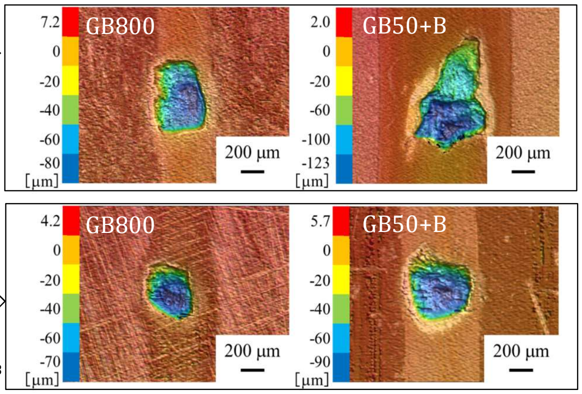


Fig. 5 Laser microscope images of peeled-off layers (Upper and lower images are from testing at a maximum contact stress of 6.62 and 4.52 GPa, respectively.)

4. Summary

The applicability of micro shot peening to the improvement of the fatigue life of surfaces subjected to cyclic loading was evaluated. As a result, it was found that there was an increase in fatigue life with micro shot peened surfaces. Furthermore, combining deep rolling with micro shot peening is an effective means of increasing fatigue life.

5. References

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