Effect of Shot Peening on Micropitting Fatigue of Bearing Steel

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The effect of shot peening on rolling contact fatigue (RCF) under insufficient lubrication conditions was evaluated using an X-ray diffraction analyzer that can rapidly measure tri-axial residual stress and obtain diffraction ring patterns that provide information on crystal orientation. Two-cylinder RCF test was carried out to compare shot-peened (SP) and non-peened (NP) specimens. The residual stress in the specimens was measured using the cosα method for a tri-axial stress state. The degree of crystallographic preferred orientation was defined as the non-uniformity of the diffraction intensity distribution (S/S_0). The hoop component (σ_x) and the axial component (σ_y) of the residual stress for the SP specimen before the RCF test were both about -2000 MPa. However, both components decreased with increasing number of loading cycles, and by 10^3 cycles the values were close to those for the NP specimen. It is considered that this stress relaxation is caused by repeated contact between surface asperities. On the other hand, S/S_0 increased earlier for the SP specimen than for the NP specimen, and its value after test was larger. This result suggests that shot peening process makes contact surface easy to occur preferred orientation.

The radial component (σ_z) of the residual stress was smaller than σ_x or σ_y. During the RCF tests, the stress associated with contact between asperities is superimposed on the residual stress, and this combined stress acts on the contact surface. Thus, there is an increase in the shear stress due to out-of-plane stress deviations, leading to microcrack propagation. As a result, the micropitted area of the surface is much larger for the SP specimen than for the NP specimen. This causes excessive compressive residual stress that can lead to accelerated surface failure under insufficient lubrication conditions.

Although shot peening is generally considered to extend the fatigue life due to crack closure under compressive residual stress, the above results indicate that there is a case that shot peening treatment is not effective to prevent micropitting under insufficient lubrication condition.

Keywords: *rolling contact fatigue, micro pitting, shot peening, residual stress, rolling bearing*

1. Introduction

Shot peening is a surface processing technique that is used to produce compressive residual stress and a work-hardened layer, and is typically applied to improve the fatigue strength of steel. Some previous studies have shown that shot peening increases the rolling contact fatigue (RCF) life,[1,2] while there have also been reports that the effect depends on the peening and rolling contact conditions.[3]

We have previously examined the relationship among tri-axial residual stress, crystallographic preferred orientation and RCF under insufficient lubrication conditions using an X-ray diffraction ring analyzer.[4,5] In the present study, we applied this method to two-cylinder RCF tests to compare the RCF life for shot-peened (SP) and non-peened (NP) specimens.[6]

2. Experimental

2.1 Two-cylinder RCF test

Figure 1 shows a schematic of the two-cylinder RCF test device. The driven cylinder is rotated by the friction force exerted by the driving cylinder. Table 1 shows the test conditions and the specimen details.

Table 2 shows the shot peening conditions used in this study. Shot peening was applied after heat treatment only for the driving cylinder. The contact surface was then ground or superfinished to achieve a prescribed surface roughness. To evaluate the reproducibility of the test results, each RCF test was carried out twice.

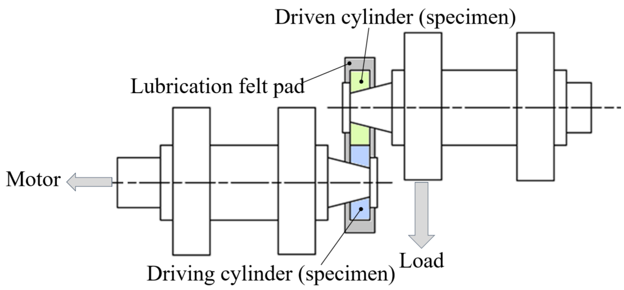


Figure 1 Schematic of RCF test with pair of cylinders.

Table 1 Conditions for two-cylinder test.

		NP	SP
Maximum contact pressure, P_{max} / GPa		2.77	
Rotational speed, N / min^{-1}		500	
Oil film parameter Λ		0.3	
Heat treatment		Quenching & Tempering	
Retained austenite, γ_R / % (before test)		8.2	1.5
Hardness, *HRC*	Driving	61.2	61.3
	Driven	61.4	61.5
Shot peening	Driving	Without	With
	Driven		Without
Roughness, R_a / μm	Driving	0.02	
	Driven	0.8	

Table 2 Conditions for shot peening process.

Projection method	Gravity
Peening media hardness, *HV*	about 1200
Average particle diameter, *D* / μm	80
Projection pressure, *P* / MPa	0.4

Arc height, AH / mmN	0.171

2.2 X-ray diffraction measurements

Table 3 shows the X-ray diffraction measurement conditions. The measurements were performed using a μ-X360 residual stress analyzer (Pulstec Industrial Co., Ltd.). The analyzer consists of an X-ray tube, a two-dimensional X-ray detector and a signal readout unit. An imaging plate (IP) is used as the X-ray detector. Since micropitting occurs easily on the superfinished specimen due to low roughness,[7] the driving specimen was subjected to X-ray measurements. The residual stress in the specimens was measured using the cosα method for a tri-axial stress state.[8] Figure 2 shows relationship between the coordinate system for the cylinder and the location of the IP.

Preferred orientation of martensite is generated due to RCF progression. This causes a change in the circumferential intensity distribution in the X-ray diffraction ring pattern. The degree of preferred orientation of martensite is generated due to RCF progression. is defined as the non-uniformity of the diffraction intensity distribution (S/S_0), where S is the standard deviation of the diffraction intensity and S_0 is its value before RCF.

Table 3 X-ray diffraction conditions.

Characteristic X-ray	Cr-K_α
Diffraction plane (*hkl*)	α'-Fe (211)
Diffraction angle of unstressed material, $2\theta_0$ / °	156.158
Tube voltage, V / kV	30
Tube current, I / mA	1
X-ray irradiated area, S / mm	φ2
Incident angle, ψ_0 / °	0, 30
Exposure time, t / s	72

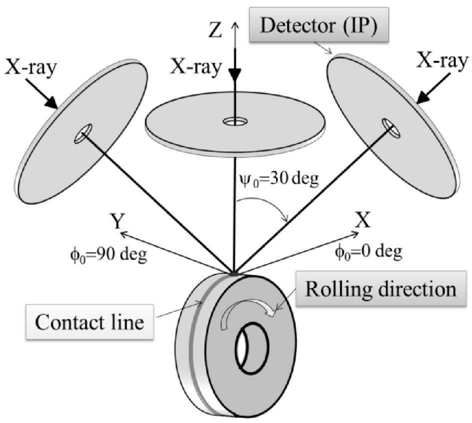


Figure 2 Relationship between coordinate system for cylinder and location of IP.

3. Results

3.1 Micropitting

Figure 3 shows optical microscopy images of the rolling contact surface for the SP and NP driving specimens after 10^6 cycles, where micropitted regions appear dark. The relative area of micropits (micropitting area ratio) in the images was calculated using image analysis. The mean micropitting area ratio after two tests was 4.5% for the NP specimen and 27.9% for the SP specimen, respectively.

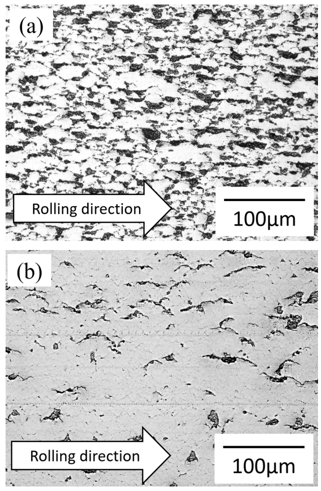


Figure 3 Optical microscopy images of RCF surface for (a) SP and (b) NP specimens. The number of contact cycles is 10^6.

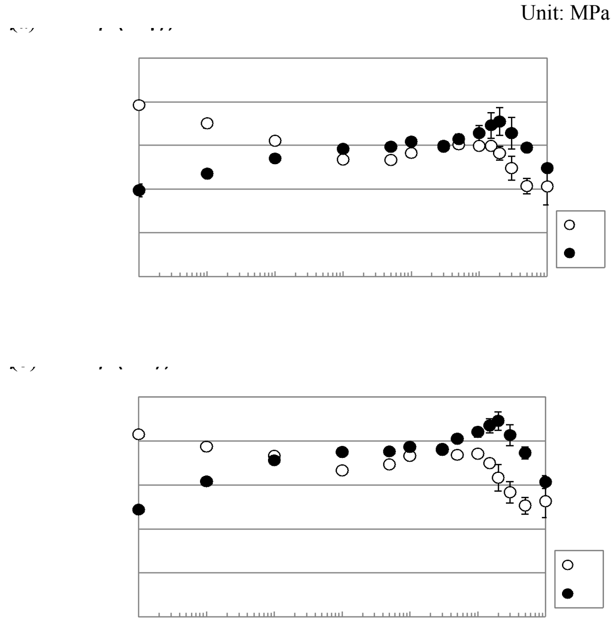
3.2 Residual stress

Table 4 shows the residual stress before test. Here, σ_{eq} is the von Mises stress calculated using six residual stress components. Figure 4 shows the relationship between the residual stress and the number of cycles. The hoop component (σ_x) and the axial component (σ_y) for the SP specimen before the RCF test are both about -2000 MPa. However, both components decrease with increasing number of loading cycles, and by 10^3 cycles the values are close to those for the NP specimen. It is considered that this stress relaxation is caused by repeated contact between surface asperities.

Table 4 Residual stress before test.

	σ_x	σ_y	σ_z	τ_{xy}	τ_{xz}	τ_{yz}	σ_{eq}
NP	-755	-829	-281	12	-4	-4	519
SP	-2082	-2141	-758	31	13	-12	1332

Unit: MPa



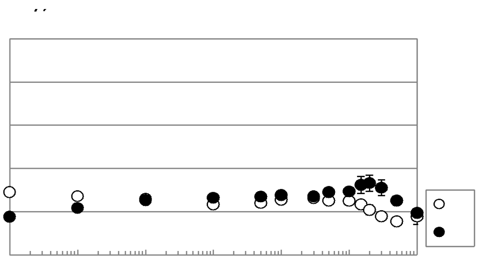


Figure 4 Relationship between residual stress and number of cycles for SP and NP specimens: (a) hoop component (σ_x), (b) axial component (σ_y), (c) radial components (σ_z).

3.3 X-ray diffraction rings and S/S_0

Figure 5 shows the X-ray diffraction ring patterns for the SP specimen before test and after 10^6 cycles. The images were obtained at an X-ray incidence angle of ψ_0 =30°. Before test, the X-ray diffraction ring intensity is uniform, indicating a random grain orientation. On the other hand, the intensity is nonuniform after 10^6 cycles, indicating a preferred orientation.

Figure 6 shows relationship between S/S_0 and the number of cycles for the SP and NP specimens. For the SP specimen, S/S_0 increases earlier than that for the NP specimen, and the value after test is larger. This result suggests that shot peening process makes contact surface easy to occur preferred orientation.

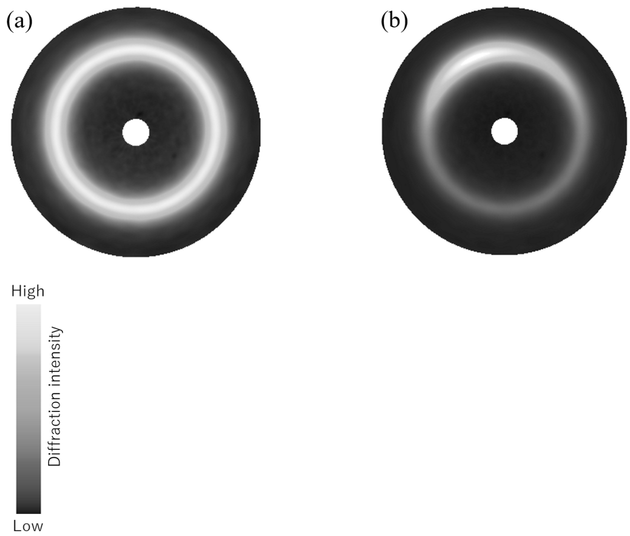


Figure 5 X-ray diffraction rings for SP specimen: (a) before test, and (b) after 10^6 cycles.

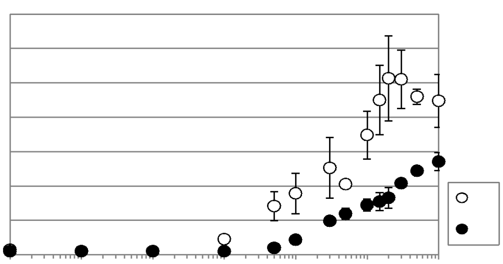


Figure 6 Relationship between S/S_0 and number of cycles for SP and NP specimens.

4. Discussion

During RCF tests, the stress caused by contact between asperities is superimposed on the residual stress, and this combined stress acts on the contact surface. Thus, there is an increase in the shear stress due to out-of-plane stress deviations, leading to microcrack propagation. Because the radial component (σ_z) of the residual stress is smaller than σ_x or σ_y, the relative area of the micropitted region is much larger for the SP specimen than for the NP specimen. This causes excessive compressive residual stress that can lead to accelerated surface failure under insufficient lubrication conditions.

5. Summary

Although shot peening process is generally considered to extend the fatigue life due to crack closure under compressive residual stress, the results of the present study indicate that there is a case that shot peening treatment is not effective to prevent micropitting under insufficient lubrication condition.

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