

Rolling Contact Fatigue Life of Case-Hardened Steel Treated by Shot Peenings with Shot Diameters of 0.05 mm and 0.30 mm

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Abstract. In order to investigate the influence of different shot peenings on the rolling contact fatigue life of case-hardened steel, the thrust type rolling contact fatigue test was performed with a ball-on-disk contact tester. In this study, the case-hardened steel disks were treated by the fine particle peening with a shot diameter of 0.05 mm and the normal shot peening with a shot diameter of 0.30 mm. The surface hardness and the surface compressive residual stress of the test disks were increased by these peenings. On the other hand, the surface roughness of the test disks was increased by the normal shot peening, and was decreased by the fine particle peening. The rolling contact fatigue test showed that the rolling contact fatigue life of the test disks was improved by the fine particle peening, and was not improved by the normal shot peening. The rolling contact fatigue life of the test disks became longer as their surface roughness became smaller. Therefore, it follows from this that the fine particle peening, which can provide the increase in surface hardness and the decrease in surface roughness, is good for the increase in the rolling contact fatigue life of case-hardened steel.

Introduction

Shot peening (SP) is a surface treatment method widely used to improve the fatigue life of metallic components in the aerospace and automobile industries. In the SP, the material surface is impacted with a multitude of small hard shots projected at high velocity, and then the change in the mechanical properties on the shot-peened surface is caused. In particular, the SP below 0.2 mm shot diameter and 0.15 mmA arc height is called fine particle peening (FPP). The FPP is reportedly effective for the control of surface topography in addition to the increase in fatigue strength [1], and has already been put to practical use in the surface treatment method for machine elements. The aim of this study is to investigate the influence of different shot peenings on the rolling contact fatigue (RCF) life. The surface properties of the test disks shot-peened with shot diameters of 0.05 mm and 0.30 mm were measured, and the thrust type RCF test of the test disks was performed.

Test Specimen and Surface Property

Test Specimen. In this study, the test disk and the steel ball were employed as test specimens in the thrust type RCF tests. The test disk with 60 mm in diameter and 7 mm in thickness was made of chromium molybdenum steel (Japanese Industrial Standards (JIS): SCM420H), and then it was finish-ground after case hardening. The steel ball with a diameter of 9.53 mm (3/8 inch) was made of high carbon chromium bearing steel (JIS: SUJ2), and its grade was G28 in conformity to the JIS [2].

Table 1 shows the SP conditions for the test disks. After finish grinding, the test disk was treated by the SP under different conditions shown in this table, rotating the test disk at a constant speed of 30 rpm. The SP employed in this study was air SP, and its shot distance was 150 mm. In this study, FPP and NSP (Normal shot peening) designate the SPs with shot diameters of 0.05 mm and 0.30 mm,

respectively. Additionally, the air pressures of these peenings were 0.1 MPa, 0.3 MPa and 0.5 MPa, and they are exhibited by P1, P3 and P5 placed after the specimens shown in Table 1, respectively. Here, NP represents the non-peened test disk.

Table 1 SP conditions for test disks

Specimen	Shot material	Shot diameter [mm]	Shot hardness [HV]
NP	---	---	---
A	Fe-based amorphous	0.05	900
S	Cast steel		1000
C	Conditioned cut wire (A)	0.30	800
CH	Conditioned cut wire (B)		930

Peening time: 12 [sec], Coverage: 300 [%]

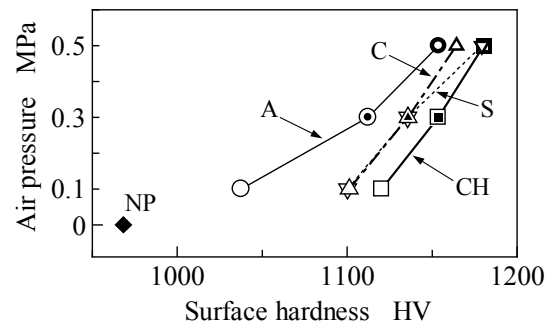


Fig.1 Relation between air pressure and surface hardness

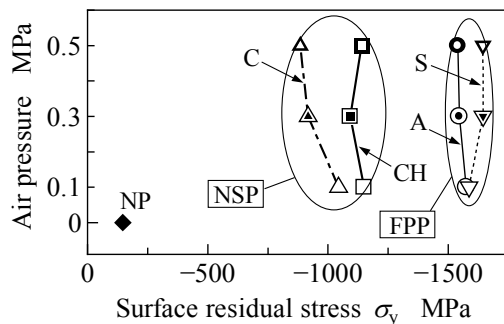


Fig.2 Relation between air pressure and surface residual stress

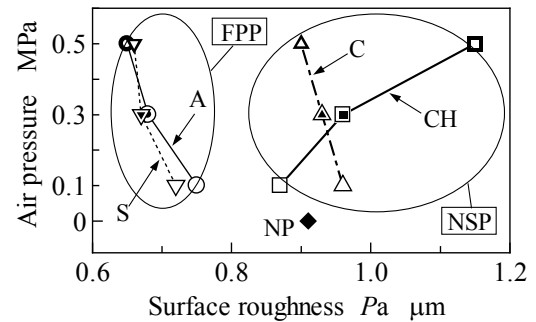


Fig.3 Relation between air pressure and surface roughness

Surface Property. Figure 1 shows the relation between the air pressure of the SP and the surface hardness of the test disks. The Vickers hardness was measured with a micro hardness tester under a measuring load of 0.98 N for 30 sec. The surface hardness of the test disks was determined from their hardness distributions below the disk surface. Here, the air pressure of the SP for non-peened disk NP was considered to be 0 MPa in Fig.1. As shown in Fig.1, the surface hardness of the test disks was increased by the SP. In particular, the surface hardness increased with the increase in air pressure.

Figure 2 shows the relation between the air pressure of the SP and the surface residual stress of the test disks. Their surface residual stress was measured according to the 2θ - $\sin^2\psi$ method [3] using $\text{CrK}\alpha$ -ray as characteristic X-ray. As in the case of the surface hardness, their surface compressive residual stress was greatly increased by the SP. The surface compressive residual stress of the test disks treated by the FPP was larger than that by the NSP.

Figure 3 shows the relation between the air pressure of the SP and the surface roughness of the test disks. Their surface roughness is the arithmetic average roughness P_a of profile curve on the disk surface, and it was measured by using a surface roughness measuring machine. From this figure, the surface roughness of the test disks treated by the NSP was equal to or more than that of non-peened disk NP. Many research indicate that the fatigue life of machine elements was improved by SP, while the increase in surface roughness due to SP caused the decrease in their fatigue lives [4]. On the contrary, the surface roughness of the test disks was decreased by the FPP in this experimental range. In the case of the FPP, the surface roughness became smaller as the air pressure became larger. Thus, it can be expected that the RCF life of the test disks is especially improved by the increase in surface hardness and surface compressive residual stress and the decrease in surface roughness due to the FPP.

Experimental Procedure and Experimental Result

Experimental Procedure. The thrust type RCF test was performed with a ball-on-disk contact tester. A test disk was fixed in the container of the tester, and a washer (Thrust bearing 51305) was fixed at the spindle of the tester. While, three steel balls were inserted between a test disk and a washer. A test disk, a washer and three steel balls were immersed in ATF employed as a lubricating oil. The kinematic viscosity of the ATF was $33.180 \text{ mm}^2/\text{s}$ for 313 K and $7.225 \text{ mm}^2/\text{s}$ for 373 K. In this test, the normal load between the test disk and the steel balls was given by dead weight, and the maximum Hertzian stress p_{\max} [5] between the test disk and the steel balls was adopted as the standard of the loading. The RCF test was performed at a spindle rotational speed of 1700 rpm under $p_{\max}=5.0 \text{ GPa}$. The orbital diameter of three steel balls on the test disk was 38.5 mm. In this study, the number of cycles of the test disk was taken as the number of times steel balls passed through an arbitrary point along the steel ball orbit on the test disk, and the RCF life N of the test disks was defined as the number of cycles when the tester was automatically stopped by the vibration increase due to the surface failure of the test disk. Eight RCF tests for each SP conditions were performed to gather statistical experimental data, since RCF life varies widely among RCF tests.

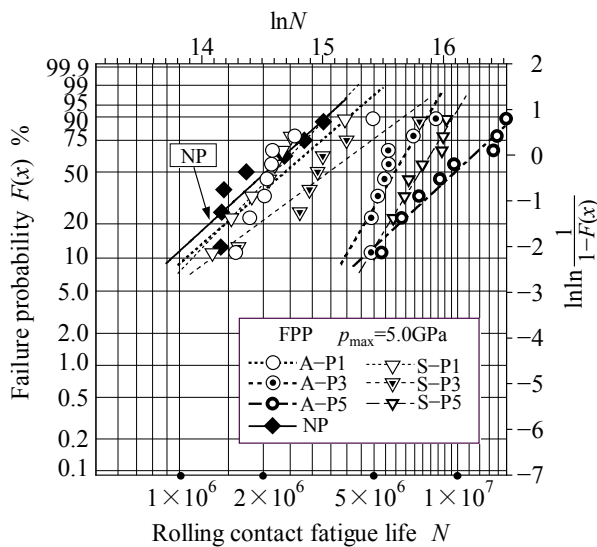


Fig.4 RCF lives of test disks treated by FPP

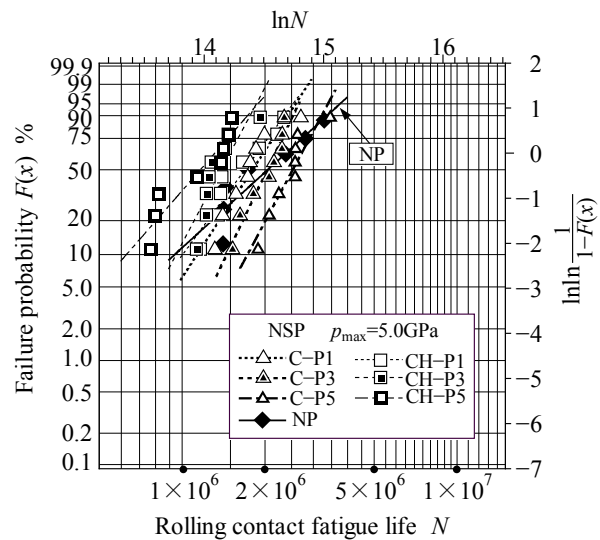


Fig.5 RCF lives of test disks treated by NSP

Failure Mode and RCF Life. As the result of the RCF test of the test disks, pitting occurred along the steel ball orbit on the test disk. The diameter of the pitting caused on the test disks was 0.5 mm to 1.5 mm, and the depth of that was 0.1 mm to 0.3 mm. During the RCF tests, the temperature of the ATF was in a range of 323 K to 348 K.

Figures 4 and 5 show the Weibull plots of the RCF lives of the test disks treated by the FPP and the NSP, respectively. As can be seen in Fig.4, the RCF lives of most test disks were improved by the FPP, and those increased with increasing the air pressure of the FPP. In contrast, those of most test disks treated by the NSP were shorter than or equal to those of non-peened disk NP, although the surface hardness and the surface compressive residual stress of all the test disks were increased by the NSP as shown in Figs.1 and 2. This may be because the surface roughness of the test disks was also increased by the NSP. From Fig.5, it can be understood that the RCF lives of test disk CH-P5 with the largest surface roughness in this experimental range were much shorter than those of non-peened disk NP. Consequently, the RCF lives of most test disks treated by the FPP were longer than those by the NSP in this study.

Relation between L_{10} Life and Surface Property. L_{10} life is defined as the basic rating life with 10 % failure probability, and is often used to estimate the fatigue of machine elements such as bearings and ball screws [6]. In this study, the L_{10} life of the test disks was obtained as the RCF life at 10 % failure probability in Figs.4 and 5. Figure 6 shows the relation between the L_{10} life and the

surface roughness of the test disks. It can be seen from this figure that the L_{10} life of the test disks has a tendency to increase with the decrease in surface roughness. The L_{10} life of the test disks with smaller surface roughness was the longest among those of the test disks. It can be said, therefore, that the RCF life of the test disk is easily affected by the surface roughness in the ball-on-disk contact test.

From Fig.4, the RCF lives of the test disks were greatly increased by the FPP with larger air pressure. The surface hardness of the test disks increased with the increase in air pressure as shown in Fig.1. Moreover, the L_{10} life of the test disks has a tendency to increase with the decrease in surface roughness as shown in Fig.6. Thus, both the surface hardness and the surface roughness are significant parameters in RCF. The FPP with larger air pressure in this experimental range provides the effect of both the increase in surface hardness and the decrease in surface roughness on case-hardened steel surface. Consequently, the FPP with larger air pressure is beneficial in improving the RCF life of case-hardened steel.

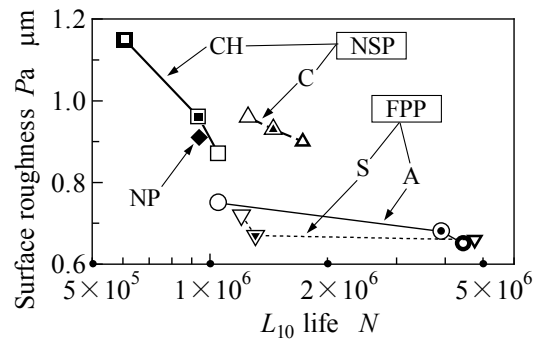


Fig.6 Relation between L_{10} life and surface roughness of test disks

Conclusion

This paper described the thrust type RCF test results of the case-hardened steel disks treated by the SPs with shot diameters of 0.05 mm and 0.30 mm. As the result of the RCF test, the RCF life of the test disks was not improved by the increase in surface roughness due to the NSP. While, that was improved by the increase in surface hardness and the decrease in surface roughness due to the FPP. Therefore, the FPP with larger air pressure, which provides the increase in surface hardness and the decrease in surface roughness, is effective in improving the RCF life of case-hardened steel.

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