The effect of fine particle shot peening on the rolling contact fatigue strength

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Abstract
In this study, vacuum-carburized steels were shot-peened with fine particle shots under various conditions and their rolling contact fatigue strengths were evaluated using a thrust tester to determine the effect of fine particle shot-peening on the rolling contact fatigue strength. As a result, it was found that the surface roughness has a great effect on the rolling contact fatigue strength.

Keywords
Shot peening, rolling contact fatigue, residual stress, surface roughness

1. Introduction

The most expected effect of shot-peening is fatigue strength improvement. In Japan, the shot-peening process is mainly used for automotive products such as springs, which are represented by valve springs, and transmission parts. It is especially often used for carburized steel gears. It is said that the required fatigue strengths of gears include the dedendum bending and tooth flank contact fatigue strengths.
In recent years, a demand has been increasing for reduction of noises and vibrations generated by gears and, consequently, modules have been reduced in size. In addition, there is a tendency for the gear face width to get smaller for the sake of unit weight reduction, resulting in a radically increasing gear contact pressure.
In order to improve the contact fatigue strength of gears, tooth flanks of which slide against each other, it is necessary to not only maximize the compressive residual stress but also focus on the surface roughness.
As a smaller shot diameter is required to reduce the surface roughness, fine particle shots (approximately 50 to 100 micrometers in diameter) have been developed lately.
Then, in this study, a rolling contact fatigue test was performed to determine the effect of fine particle shot-peening conditions on the contact fatigue strength of material of automotive transmission gears.

2. Test Methods

The test used in this study was a thrust rolling contact fatigue test where a disc specimen was rolled with steel balls pushed onto it. The disc specimen was made of chromium molybdenum steel (SCM420H) with a chemical composition shown in Table 1, machined into a diameter of 60mm and a thickness of 7mm and vacuum-carburized, quenched and tempered using a heat pattern shown in Figure 1. The heat treated specimen had a surface hardness of HV780 and a case depth of 0.8mm.
The steel balls were made of high-carbon chromium bearing steel (SUJ2 defined by JIS) with a diameter of 9.53mm.

Table 1. Chemical composition of disc specimen （wt%）

C	Si	Mn	P	S	Cu	Ni	Cr	Mo
0.2	0.2	0.65	0.025	0.015	0.15	0.06	1.04	0.16

The disc surface was shot-peened using a SINTOKOGIO’s direct pressure shot-peening machine. Shots with a diameter not larger than 100 micrometers were used as fine particle shots; SINTOKOGIO's AMO beads (50 micrometers in diameter) and F shots (80 micrometers in diameter). Normal-sized C3 shots, 0.3mm in diameter, were also used for comparison. Table 2 shows the shot-peening conditions used for the test and Figure 2 illustrates the shot-peening method.

Table 2. The condition of shot peenig.

No.	Type of shot	Diameter of shot (mm)	Hardness of shot (HV)	Air Pressure (MPa)	Archight
NP	Not peened				
A-P1	Amorphous shot (Shot A)	0.05	900	0.1	0.143mmN
A-P3				0.3	0.220mmN
A-P5				0.5	0.242mmN
F-P1	Atomized shot by gas (Shot F)	0.08	1200	0.1	0.244mmN
F-P3				0.3	0.377mmN
F-P5				0.5	0.476mmN
C3-P1	CCW (Shot C3)	0.3	800	0.1	0.506mmN
C3-P3				0.3	0.792mmA
C3-P5				0.5	1.056mmA

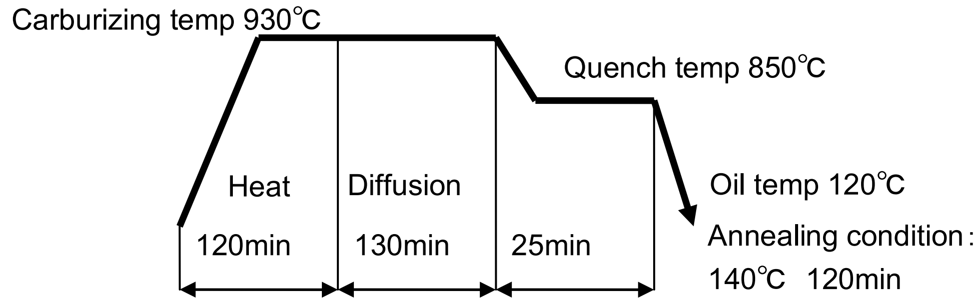

Fig 1. Heat pattern of vacuum carburizing

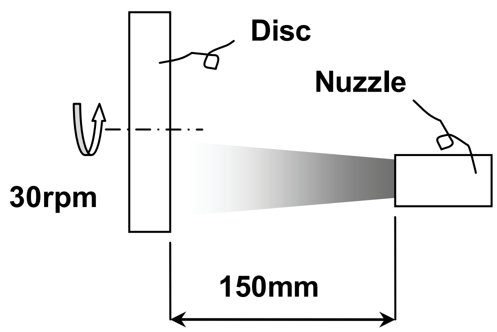

Fig2. Method of shot peenig

3. Test results

3.1 Evaluation after shot-peening

The compressive residual stress is said to be a parameter that contributes the most to the fatigue strength improvement as a result of shot-peening.

Figures 3, 4 and 5 show compressive residual stress profiles obtained with different types of shots.

The compressive residual stresses were measured with the sin2θ-ψ method using X-rays .

According to Figures 3, 4 and 5, a higher air pressure leads to a larger value of the maximum residual pressure and a deeper residual stress depth.
Figure 6 shows the maximum compressive residual stress obtained with different type of shots at an air pressure of 0.5 MPa as a function of the shot hardness. Figure 7 shows the surface roughness (arithmetic average roughness, Ra) obtained at that time.
It is found from Figures 6 and 7 that a higher shot hardness leads to a higher value of the maximum compressive residual stress and the highest surface roughness was obtained with F shots, which have the highest hardness.

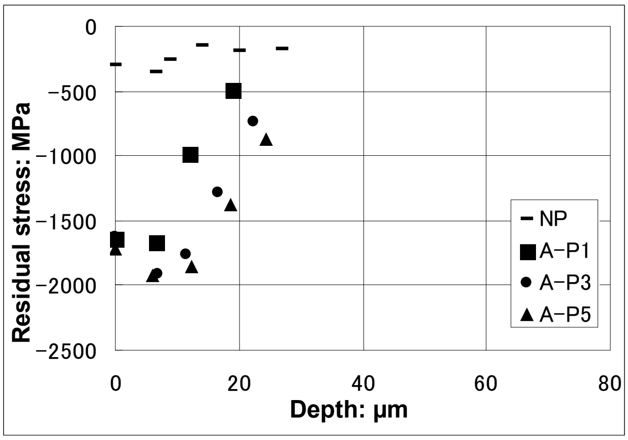

Fig3. Residual stress profile (AMO beads)

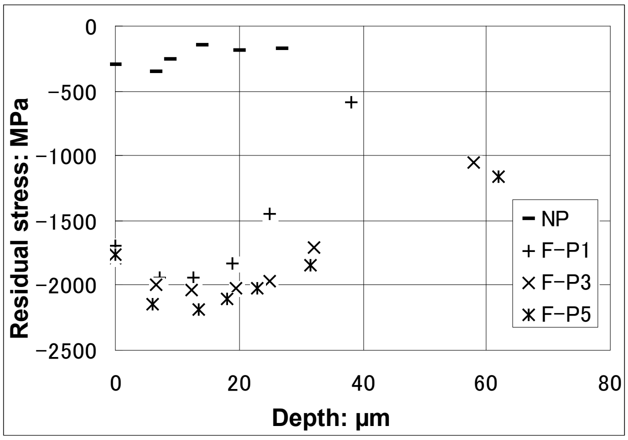

Fig4. Residual stress profile (Shot F)

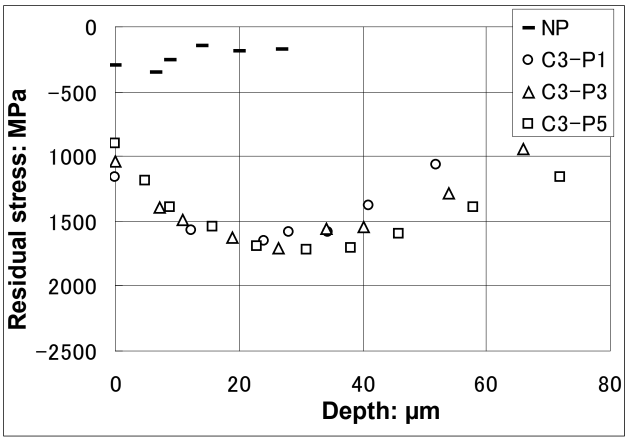

Fig.5 Residual stress profile (CCW)

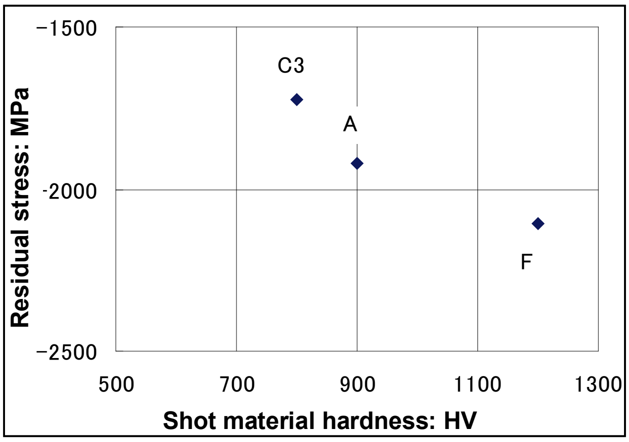

Fig6. Relationship between residual stress and shot material hardness

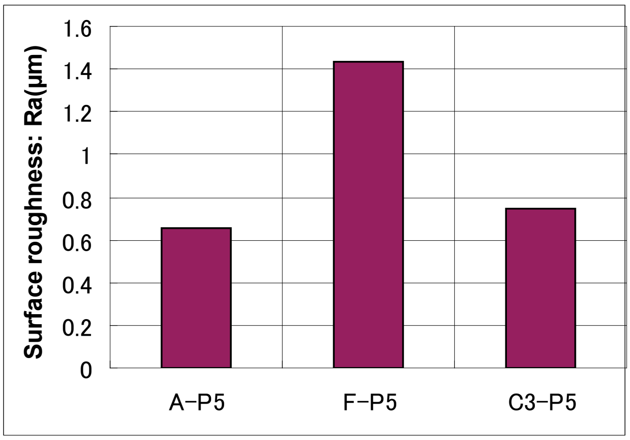

Fig7. Surface roughness : Ra (μm)

3.2 Results of the rolling contact fatigue test

In this study, a thrust rolling contact fatigue tester (offered by Tokyo Testing Machine) as shown in Figure 8 was used to evaluate the rolling contact fatigue life. A disc and three steel balls were installed in a test chamber filled with lubricant. A vertical load was applied to the steel balls. The rolling orbit diameter of the steel balls on the disc was 38.5mm. The test contact pressure between the disc and the steel balls was constant at 5.0 GPa as Hertz' maximum contact stress, pmax, and the spindle rotating speed was 1700 rpm. ATF was used as lubricant.

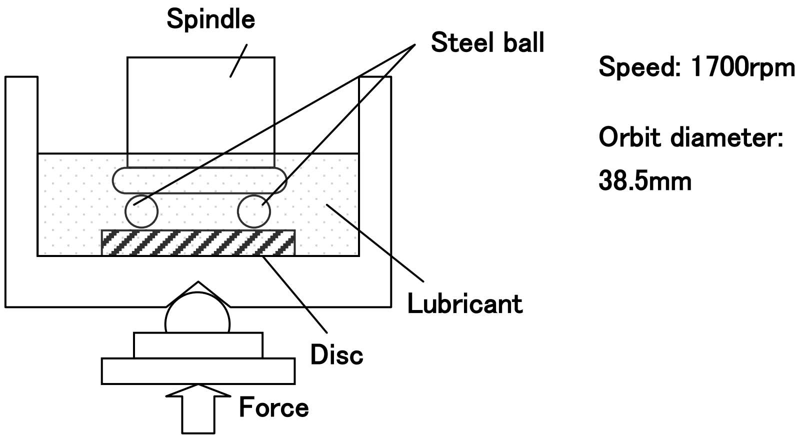

Fig8. Method of rolling contact test

Figure 9 shows the rolling contact fatigue life, N, obtained with the rolling contact fatigue test as examined with a Weibull distribution.

It is found from Figure 9 that a higher shot pressure leads to a longer life with any type of shots. The shot type resulting in the longest life was A-P5.
Then, the L10 life of the disc was determined from Figure 9. The L10 life means the rolling contact fatigue life, N, of the disc at the damage probability of 10%. Figure 10 shows the L10 life as a function of the surface roughness, Ra. It is found that a higher surface roughness essentially leads to a shorter L10 life with any type of shots.
Figure 11 shows the maximum compressive residual stress as a function of the L10 life of the disc. It is found that, with A shots, a higher compressive residual stress leads to a longer L10 life but, with F shots, a higher compressive residual stress leads to a shorter L10 life.

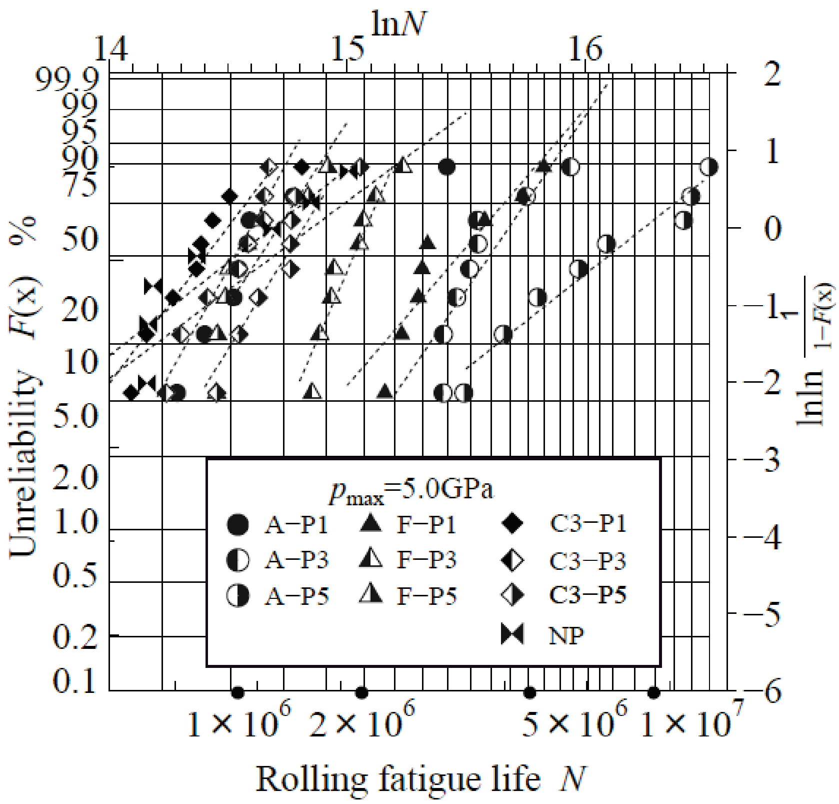

Fig9. rolling contact fatigue strength

This implies that a higher shot-peening pressure leads to a higher surface roughness, which affects the resultant L10 life more than the increase in compressive residual stress improves the fatigue strength.
SINTOKOGIO, LTD. and Daido Steel Co., Ltd. jointly published the DASP, a process for realizing the highest bending fatigue strength in the world, in September, 2008. It consists of a combination of material, heat treatment and shot-peening that leads to a surface roughness not lower than HV1000 and the maximum compressive residual stress not lower than 1800 MPa and realizes an excellent fatigue strength. As preconditions for DASP, (1) the material to be processed shall have a surface hardness not lower than HV750 (vacuum carburized steels are the most suitable) and (2) the shot hardness relative to the hardness of the material to be processed shall be >= 50HV and =< 250HV.
The F shots used in this study are harder than specified as a precondtion for DASP. Using F shots increases the compressive residual stress but worsenes the surface roughness, resulting in a shorter rolling contact fatigue life.
Therefore, the requirement for shots defined as a precondition for DASP is considered as effective to improve the rolling contact fatigue strength under the testing conditions used in this study.

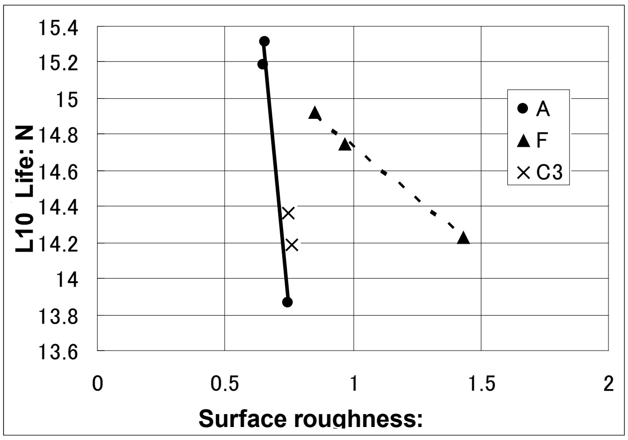

Fig. 10. Relationship between L10 Life and Surface roughness

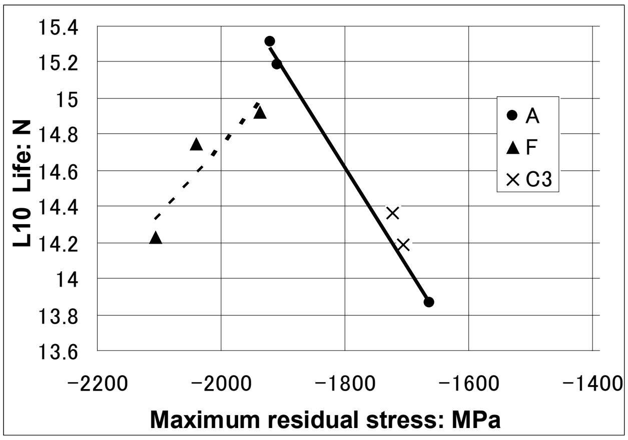

Fig. 11. Relationship between L10 Life and Maximum residual stress

4. Conclusion

In this study, a thrust rolling contact fatigue test was performed using a shot-peened disc and steel balls to determine the effect of fine particle shot-peening on the rolling contact fatigue life of carburized steels. The conclusions are described below:

- With any type of shots used for the test, a higher air pressure leads to a higher value of the maximum residual stress and a deeper residual stress depth.
- A higher shot hardness leads to a higher value of the maximum compressive residual stress obtained with each type of shots.
- F shots, which had the highest hardness, produces the roughest surfaces.
- The L10 life of the disc obtained with F shots, which ensure a higher value of the maximum compressive residual stress but with a higher surface roughness, was shorter than that obtained with AMO beads.
- Shot-peening with AMO beads, which satisfy the precondition for DASP, maximized the rolling contact fatigue life under the conditions used in the test.

6. Reference documents

1) Ryohei Ishikura, Takashi Karino, Yuji Kobayashi and Satoru Ujibashi: *"A Study on Superficial Structures of Carburized Steels and the Maximum Compressive Residual Stress Applied by Shot-peening"*; Electric Steel Making, Vol. 79 No.1, pp.25-35 (2008)
2) Yuji Kobayashi: "*Recent Trends of the Shot-peeing Technology*"; Idemitsu Kosan, the 32rd Heat Treatment Research Meeting , pp3-1～3-10 (2009)
3) Hajime Makab:*"Analysis of Reliability Data"*: Iwanami Shoten (1987) ,120