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# **Influence on shot peening and blast polishing for rotating bending fatigue strength of vacuum carburized steel with circumferential notch**

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## **Abstract**

In order to improve fuel efficiency in automobiles, weight reduction is necessary as well as improving engine efficiency. For transmission gears, thickness reduction is necessary for weight reduction. When the thickness is reduced, the cross-sectional area becomes smaller, and the load stress increases. Therefore, higher fatigue strength is required. Most gears carry out carburizing. Shot peening is often used to improve the fatigue strength of carburized heat-treated parts. After shot peening, compressive residual stress is introduced, but at the same time, surface roughness is increased. Therefore, the processing conditions of shot peening are very important. Blast polishing is a processing method in which resin media containing abrasive grains is sprayed at the workpiece. Compared to other polishing methods, the processing time is short. In addition, it is easy to apply to complex shapes.

In this study, shot peening and blast grinding were carry out on circumferential notch specimens to improve the fatigue strength of vacuum carburized materials commonly used in automotive transmission gears.

As a result, the fatigue limit of test pieces applied with double shot peening improved by 81% compared to unprocessed specimens, blast polished specimens which are carry out double shot peening achieved a 100% improvement in fatigue limit compared to unprocessed specimens. This is due to compressive residual stress and low surface roughness.

**Keywords** Transmission gear, Vacuum carburizing, Shot peening, Blast polishing, Fatigue strength, Circumferential notch

## **Introduction**

In order to improve fuel efficiency in automobiles, not only to improve fuel efficiency but also weight reduction. Gasoline-powered cars have transmissions, and electric cars have reduction gears. These are constructed with gears. These gears require high strength, and carburizing is generally applied. In order to reduce weight, tooth width and module reduction are required. Both requirements increase load stress due to a reduction in the cross-sectional area of the gear teeth. As a result, improvements in tooth root bending fatigue strength and tooth surface pitching strength are required.[1]

Shot peening is a method used to increase the strength of carburized gears. Shot peening is a processing method in which metal particles called shots are projected onto the workpiece at high speed. This is a processing method that is expected to improve fatigue strength by inducing compressive residual stress on the surface of the workpiece. On the other hand, when the shot hits the surface, dent is generated. Therefore, surface roughness generally becomes worse. Surface roughness affects fatigue strength, so the setting of shot peening conditions is very important.[2]

There are methods for improving surface roughness after shot peening, such as fixed grinding wheel and liquid honing. Both methods take a longer time than shot peening. Blast polishing is another method. Blast grinding is a processing method in which media containing abrasive grains is projected onto the workpiece. When this special media impacts the workpiece, the abrasive grains grind the surface to improve surface roughness. Even narrow areas such as the root of a gear tooth can be processed using small-diameter media.[3]

In this study, shot peening and blast polishing were carried out on circumferential notched test pieces of vacuum carburized material used in automotive transmission gears, and the effects on fatigue strength were investigated.

### Experimental Procedures

SCM420H is standardized in JIS is chosen for specimen which is a typical material for carburizing. Table 1 shows chemical composition of SCM420H.

Table1 Chemical composition of specimens

C	Si	Mn	P	S	Cu	Ni	Cr	Mo
0.21	0.25	0.85	0.019	0.016	0.01	0.02	1.10	0.16

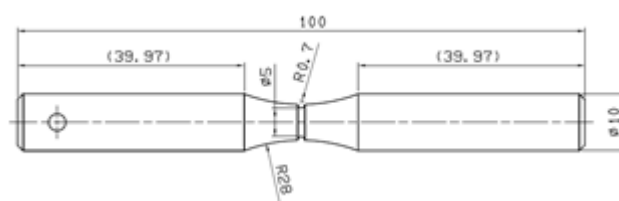


Fig. 1 Design of the specimens for rotating bending fatigue test

Fig. 1 shows design of the specimens. The specimens shape used in this study was a two-step notch test piece. A ring-shaped notch with a minimum diameter of 5 mm was created in the center of the sandglass-shaped test piece. The test piece shape used in this study was a two-step notch test piece. A circumferential notch with a minimum diameter of 5 mm was created in the center of the sandglass-shaped specimen.

The stress concentration ratio was  $\alpha = 1.76$  based on the FEM analysis results.

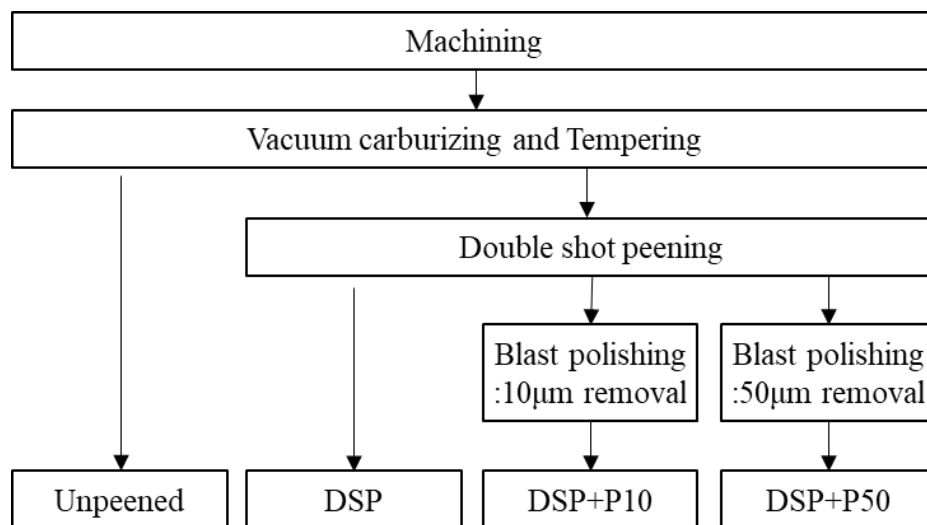


Fig. 2 Schematic diagram of heating phenomena by Burnishing

Fig.2 shows the procedure of specimens and description. Table2 and Table3 show shot peening condition of blast polishing conditions. All specimens were measured for hardness, surface roughness, residual stress. Residual stress was measured by XRD equipment using the  $\cos \alpha$  method. Residual stress measurement could not be evaluated at the notch bottom, which was the point of fatigue failure, because it was too narrow. Therefore, measurement was carried out on a flatter area. The residual stress measurement direction was set to be parallel to the longitudinal axis of the specimen.

Rotary bending fatigue testing machines were used for fatigue testing. The stress ratio was  $R = -1$ , and the test speed was 3000 rpm. The test environment was at room temperature under atmospheric conditions, and the number of test cycles was set at  $2.0 \times 10^7$ . The fatigue limit was set as the maximum load stress value among the stresses that did not failure until the number of test stops.

Table 2 Condition of shot peening

Item	1 <sup>st</sup> shot peening	2 <sup>nd</sup> shot peening
Media name	Conditioned cut wire	Cast steel shot
Diameter (mm)	0.6	0.1
Hardness (HV)	700	800
Air pressure (MPa)	0.30	0.15
Coverage (%)	300	300
Arc height	0.475mmA	0.250mmN

Table 3 Condition of blast polishing

Item	Blast polishing:10 $\mu$ m removal	Blast polishing:50 $\mu$ m removal
Media name	WAP-20C	WAP-20C
Air pressure (MPa)	0.20	0.20
Processing time (s)	6	42

Table 4 shows the result of surface roughness after processing. The surface roughness of the DSP treated with double shot peening was higher than that of the unpeened. This is due to dents formed on the surface by shot impact. The surface roughness of DSP+P10 and DSP+P50, which carry out blast polishing, was reduced compared to DSP. In particular, DSP+P50 had a smaller surface roughness than the unpeened specimen. This is due to the abrasive action by blast polishing.

Table 4 Surface roughness result

Item	Ra( $\mu$ m)	Rz( $\mu$ m)
Unpeened	0.32	2.24
DSP	0.67	4.48
DSP+P10	0.41	2.31
DSP+P50	0.28	1.56

## Results

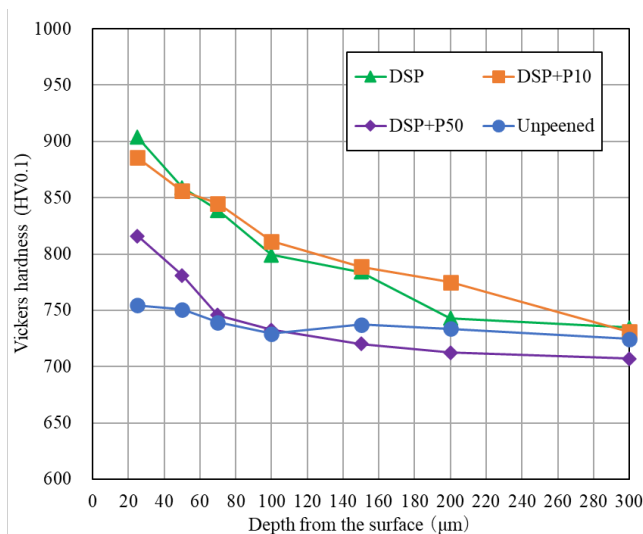


Fig. 3 Hardness distribution after processing

Fig. 3 shows the hardness distribution near the surface of each specimen. The hardness of DSP at a depth of 25  $\mu\text{m}$  exceeds 900 HV, which is more than 150 HV harder than the unpeened specimen. This is due to work hardening and work-induced martensitic transformation caused by plastic deformation by shot peening. Additionally, in DSP+P50, which underwent blast polishing, the hardness at 25  $\mu\text{m}$  was 820 HV. This was 80 HV lower than that of the double SP. This was due to the removal of the 50  $\mu\text{m}$  hardened layer induced by DSP by blast polishing.

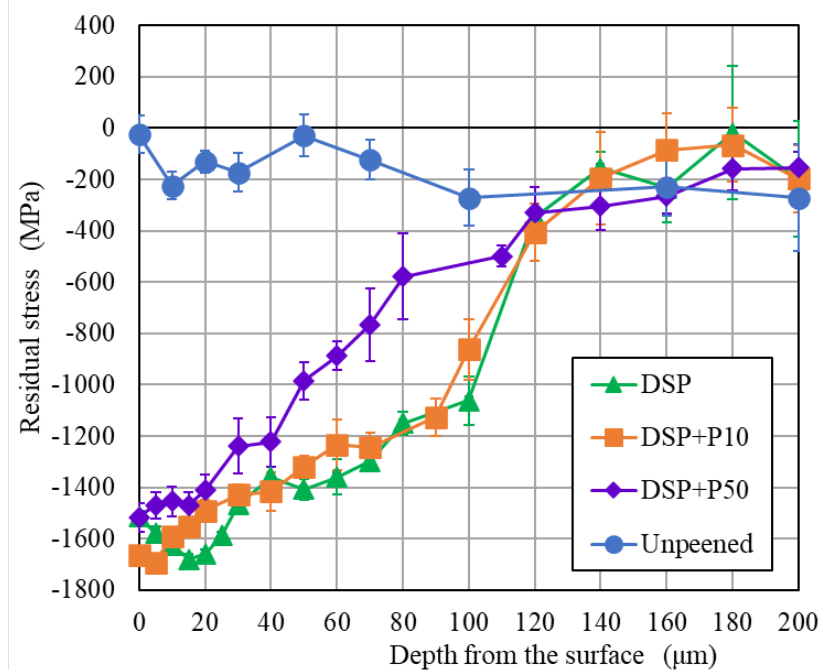


Fig. 4 Residual stress distribution

Fig. 4 shows the residual distribution after processing. The surface residual stress of DSP was -1512 MPa. The residual stress at a depth of 10  $\mu\text{m}$  was -1624 MPa, and the residual stress at a depth of 50  $\mu\text{m}$  was -1407 MPa. The surface residual stress of DSP+P10 and DSP+P50 after double shot peening and blast polishing was -1664 MPa and -1517 MPa,

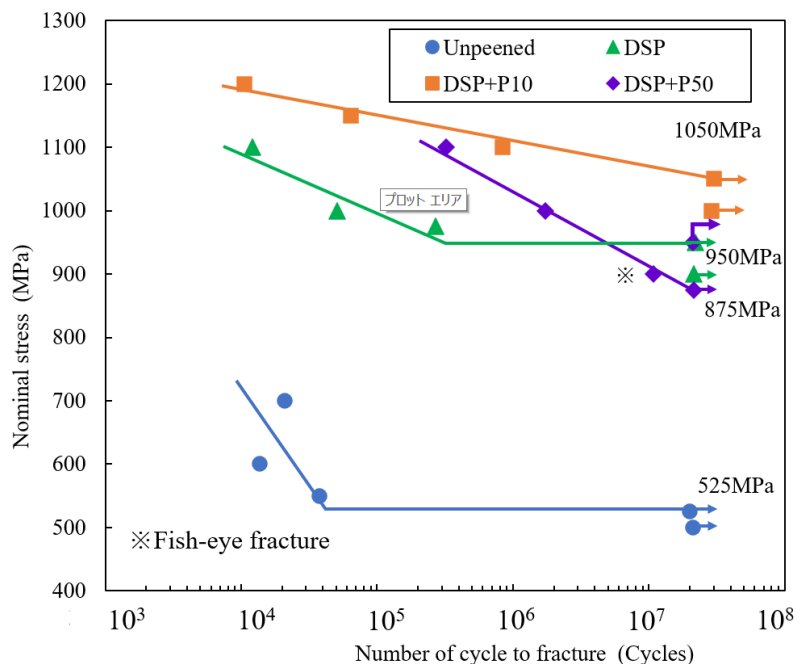


Fig. 5 S-N curve

Fig. 5 shows S-N curve for nominal stress. The fatigue limit for Unpeened was 525 MPa, for DSP it was 950 MPa, for DSP+P10 it was 1050 MPa, and for DSP+P50 it was 875 MPa.

Fig. 6 shows typical fracture surface observation results for each specimens. Except for part of DSP+P50, fatigued fracture initiated from the surface. Fish eyes were observed in the long-life region exceeding  $1.0 \times 10^7$  cycles for DSP+P50. The depth of origin of the fish eyes was approximately 90  $\mu\text{m}$ . The fatigue limit of DSP improved by approximately 81% compared to that of Unpeened. This is due to the high compressive residual stress induced by SP and the improvement in hardness near the surface. The fatigue limit of DSP+P10 was 100% higher than that of unpeened. The fatigue limit was further improved compared to DSP. This is due to the reduction in surface roughness and increase in surface residual stress caused by blast polishing.

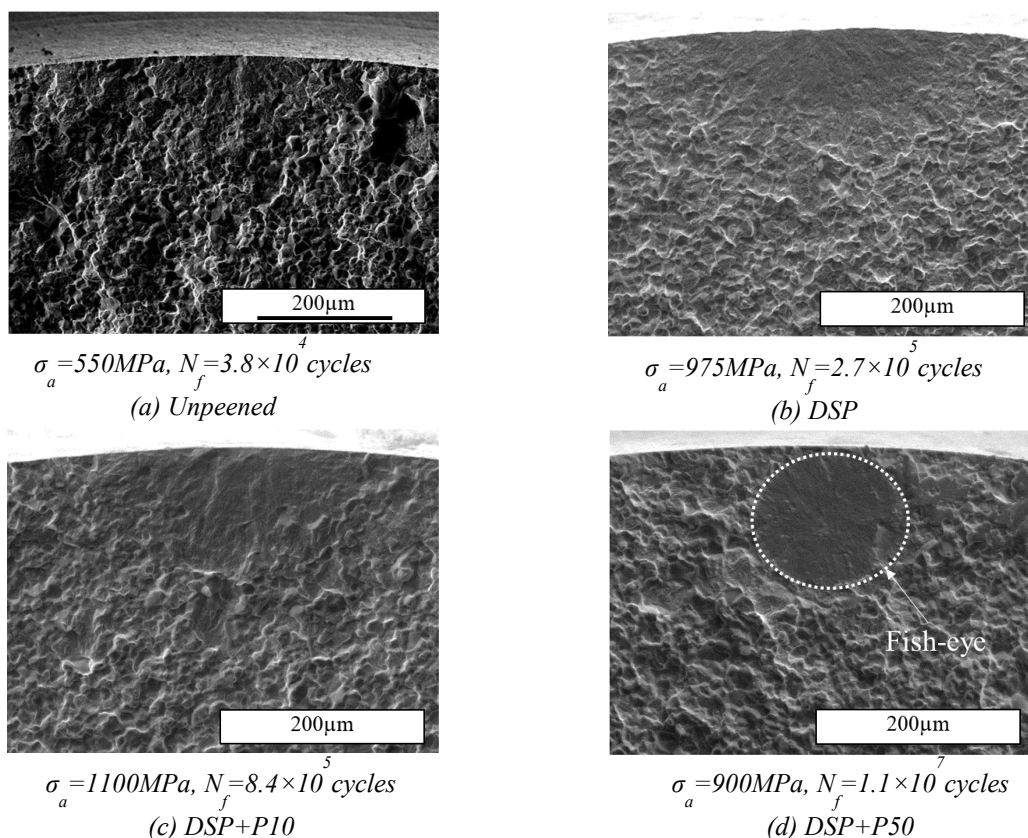


Fig. 6 observation result of fracture surface

On the other hand, the fatigue limit of DSP+P50 was approximately 67% higher than that of Unpeened. The fatigue limit improvement rate was lower than that of DSP. The fracture mode of DSP+P50 shifted to fish-eye fracture on the long-life side, and it is considered that fish-eye fracture occurred more easily due to the shallow depth of compressive residual stress induced by blast polishing.

### Discussion and Conclusions

- 1) Double SP was applied to vacuum carburized specimens. Surface roughness increased, but high hardness and high compressive residual stress were obtained.
- 2) Blast polishing of vacuum carburized specimens treated with double shot peening reduced the surface roughness that had increased due to shot peening. In addition, blast polishing caused a transition in the distribution of compressive residual stress. As a result, the compressive residual stress on the surface increased.
- 3) Vacuum carburized test pieces treated with two-stage SP showed an approximately 81% improvement in fatigue limit compared to vacuum carburized test pieces due to the generation of compressive residual stress and improvement in hardness near the surface.
- 4) The fatigue limit of vacuum carburized test pieces that carry out double shot peening with 10 μm blast polishing improved by 100%. This is due to a reduction in surface roughness and an increase in compressive residual stress on the surface caused by blast polishing.

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