THE RELATION BETWEEN SHOT PEENING CONDITIONS AND FATIGUE STRENGTH OF CARBURIZED GEARS

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ABSTRACT

The relation between shot peening conditions and fatigue strength of carburized gears was investigated. The fatigue strength of the gears closely corelates to arc height value and integral value of residual stress in the direction of depth. The total kinetic energy of shot is represented by arc height value. The kinetic energy makes retained austenite to change into martensite and produces compressive stress field. For that reason fatigue cracks are considered to be prevented from not only initiating but also propagating by the compressive stress. These results indicates that shot peening of higher arc height is more effective to improve fatigue properties of the carburized gears.

KEYWORDS

Arc Height, Residual Stress, Carburizing, Gear, Fatigue, Crack, Retained Austenite,

INTRODUCTION

Shot peening technology has been applied to improvement of carburized gears for vehicles. In the case of transmission gears, by shot peening, the fatigue strength can be increased 1.3 times over that of not peened gears.In spite of its effects, peening parameters that should be controled strictly have not yet been clear. In this report, authors investigated the relation between the shot peening parameters and the fatigue strength of carburized gears to establish equation that can determine the best condition to obtain satisfied strength of the gears.

EXPERIMENTAL PROCEDURE

Measurement of Arc Height Value

All experiments were carried out with a impeller type peening facility. Arc height value of Almen strip A gauge was measured under the conditions within coverage, rotation of the impeller, and diameter of shot shown in Table 1. Coverage was measured by observation of the surface of the gauge with a microscope.

Table 1 Peening conditions

Parameter	Extent
Rotation of impeller (rpm)	1500～2800
Coverage (%)	25～1920
Peening time (sec)	15～480
Diameter of shot (mm)	0.4～0.8
Arc heigit (mmA)	0.21～0.79

Shot Peening to Test Gears and Fatigue Test

Peening conditions for test gears are shown in Table 2. Dimensions of test gears are shown in Table 3. They are modification of 3rd drive and driven gears for front engine -front wheel drive vehicles. Test gears were shot peened following carburizing,quenching and tempering. After shot peening,the gears were put to fatigue test with a torque circulation gear tester. Fatigue strength was expressed by input torque or tooth root stress.

Table 2 Peening conditions for test gears

Condition	Shot diameter (mm)	Rotation of impeller (rpm)	Peening time (sec)	Coverage (%)
1	0.8	2000	300	545
2	0.8	2000	120	218
3	0.8	2000	480	873
4	0.8	1500	300	333
5	0.8	2800	300	750
6	0.4	2000	300	750
7	0.6	2000	300	545
8	0.8	2800	480	1200
9	0.4	2800	480	1920

Table 3 Gear dimensions

	Drive Gear	Driven Gear
Pressure Angle	17.5 degree	
Module	1.5	
Number of Teeth	33	41
Helix Angle	34 degree	
Center Distance	67 mm	

Measurement of residual stress

Residual stress of the peened gears was measured by a X-ray diffraction facility. Measurement was done at the part of the gear shown in Fig.1, in the direction of depth by electro-polishing.

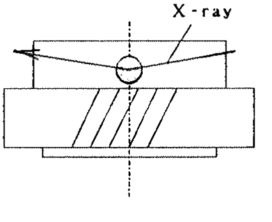

Fig.1 Measurement of residual stress

RESULTS

The Relations among Peening Parameters

Large peening velocity and small diameter of shot shorten the time until 100% coverage.(Fig.2) Arc height value is saturated after the peening time of 120 sec, however the peening of large velocity and large diameter of shot increases the final arc height value.(Fig.2)

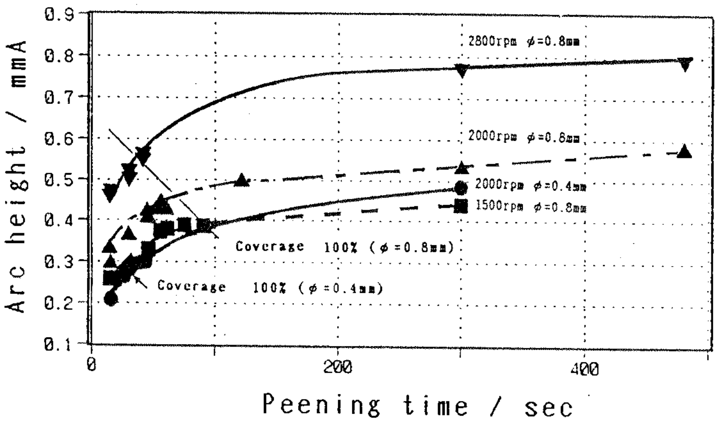

Fig.2 Influence of peening time, peening velocity and shot diameter on arc height and coverage

Arc height value increases rapidly within the coverage of 20-30%, but after that, the arc height value increases slowly. The larger the peening velocity and the diameter of shot, the higher the arc height value.(Fig.3) The relation between the rotation of the impeller and the arc height value is shown in Fig.4.

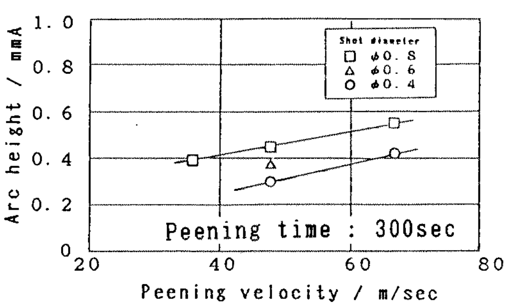

Fig.3 Effect of peening velocity and shot diameter on arc height

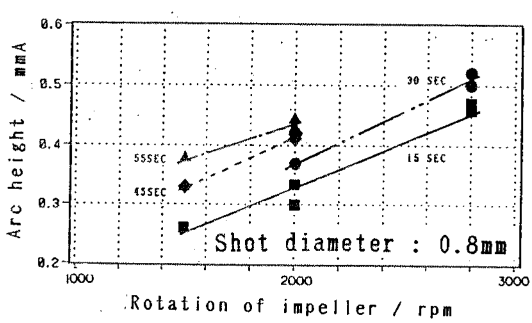

Fig.4 The relation between rotation of impeller and arc height

Hardness of Test Gears

The surface hardness of test gears before peening was 57 HRC, and internal (tooth root) hardness was 32-34 HRC. The effective case depth (HRC 50) was 0.2 -0.25mm at tooth root.

Fatigue Test

Fig.5 shows results of fatigue test. In all tests, fatigue fracture ocurred at the root of the drive gear. The peening conditions and fatigue strength at 10^5 cycles are shown in Table 4.

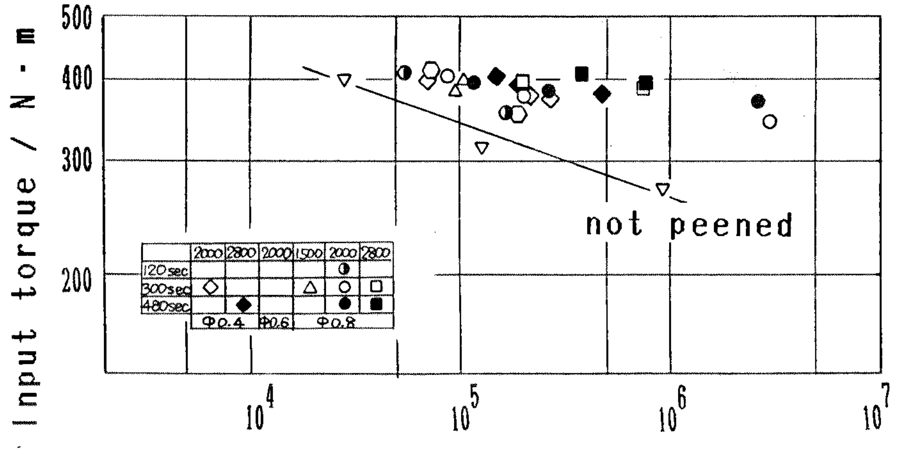

Fig.5 Results of fatigue test

Table 4 Fatigue strength at 10^5 cycles and the peening conditions

Condition	Shot diameter (mm)	Rotation of impeller (rpm)	Coverage (%)	Fatigue Strength(N · m)
1	0.8	2000	545	392
2	0.8	2000	218	372
3	0.8	2000	873	392
4	0.8	1500	333	372
5	0.8	2800	750	412
6	0.4	2000	750	392
7	0.6	2000	545	382
8	0.8	2800	1200	431
9	0.4	2800	1920	412

Residual Stress

Residual stress curves in the direction of depth are shown in Fig.6, Fig.7 and Fig.8. Fig.6 shows that the larger the diameter of shot, the deeper the site of the muximum residual compressive stress. Peening of large velocity makes compressive stress field deeply below the surface.(Fig.7) Peening time and coverage do not influence on the stress field.(Fig.8)

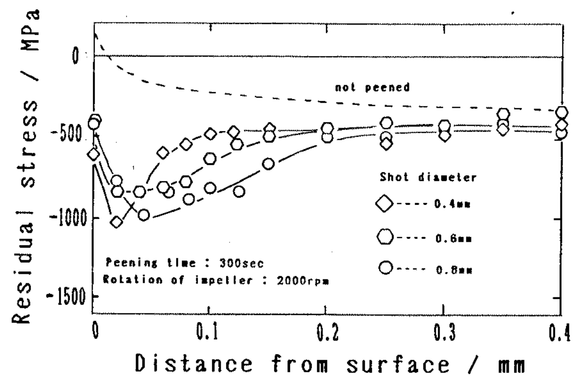

Fig.6 Effect of shot diameter on residual strees

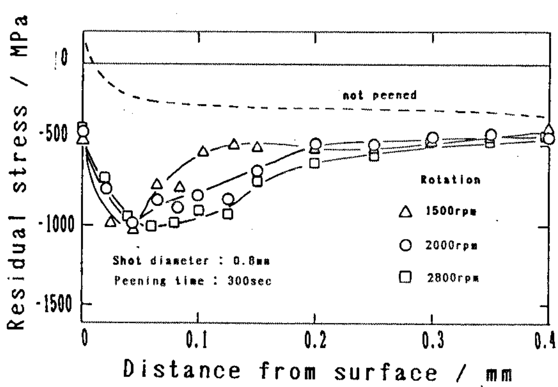

Fig.7 Effect of peening velocity on residual stress

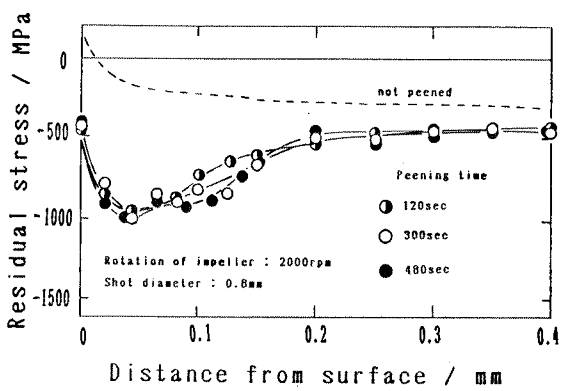

Fig. 8 Effect of peening time on residual stress

DISCUSSION

Effect of Peening Intensity on Fatigue Strength of The Test Gears

The relation between fatigue strength at 10^5 cycles /σw obtained from S-N diagrams shown in Fig.5 and the arc height value /H is shown in Fig.9. The fatigue strength is shown to have a close correlation with the arc height value. From this relationship, equation (1) can be obtained.

$$\sigma w = 810H + 1428 \quad (1)$$

The relation between fatigue life / Nf (input torque : 392 N·m)and arc height value / H is shown in Fig.10, and equation (2) can be obtained.

$$Nf = 10^{1.52H+4.14} \quad (2)$$

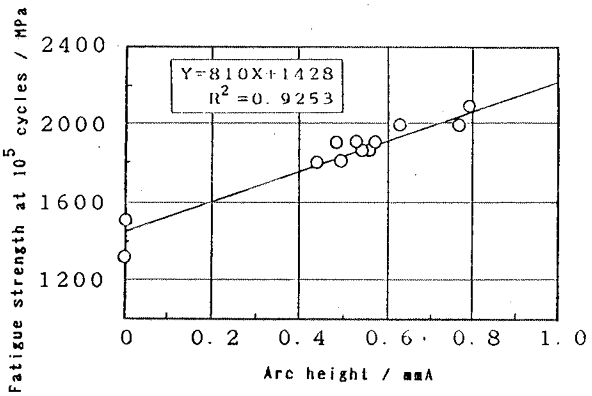

Fig.9 The relation between arc height and fatigue strength

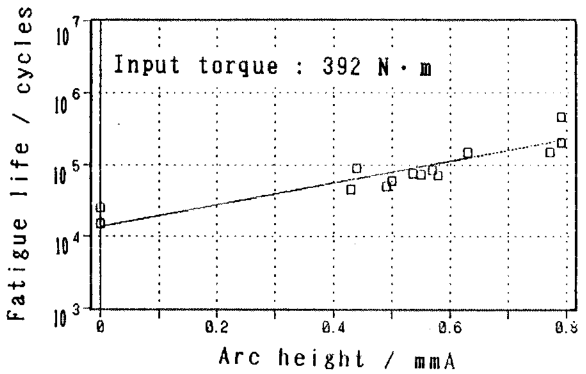

Fig.10 The relation between arc height and fatigue life

From the relationships mentioned above, it can be said that the arc height value is a very available parameter to evaluate fatigue strength of carburized and shot peened gears.

<u>Effect of Residual Stress on Fatigue Strength</u>

Residual compressive stress cancel tensional applied stress at the tooth root, and it is considered to prevent crack propagation. If micro cracks exist from the early fatigue process, residual stress must influence fatigue strength and fatigue life. Fig.11 shows relation between integral value of residual stress and fatigue strength of the test gears. Integral value / σR is obtained by integration of residual stress from the surface to depth of 0.4mm. Actually fatigue strength has a close correlation with the integral value of residual stress. This relationship can be written as equation (3).

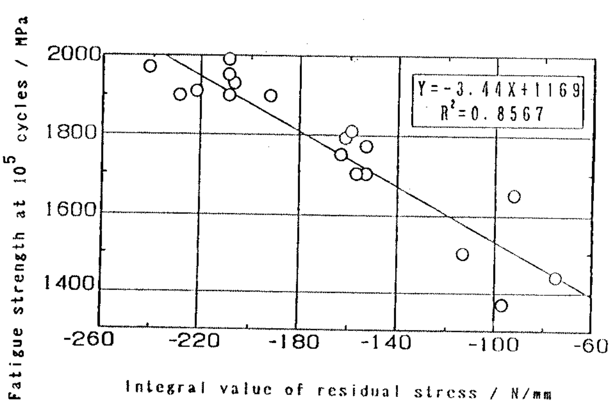

Fig.11 The relation between integral value of residual stress and fatigue strength

$$\sigma W = -3.44\sigma R + 1169 \quad (3)$$

This result indicates that fatigue strength is determined by not only crack initiation but also crack propagation.

Relation between Shot Intensity And Residual Stress

The integral value of residual stress, shown in Fig.11, has a close correlation with arc height value, as shown in Fig.12. The relationship is written as follows.

$$\sigma R = -173H - 106 \quad (4)$$

During shot peening, retained austenite on the surface layer decreases.(Fig.13) [1] Kinetic energy of shot makes retained austenite to change into martensite and produces compressive stress field. On the other hand, the kinetic energy also makes Almen strip gauge to deform, and amount of the deformation can be measured as arc height value. Therefore these two parameters correlate each other. From these results, authors confirmed that arc height value is the parameter of shot intensity with which fatigue strength of carburized and shot peened gears can be evaluated.

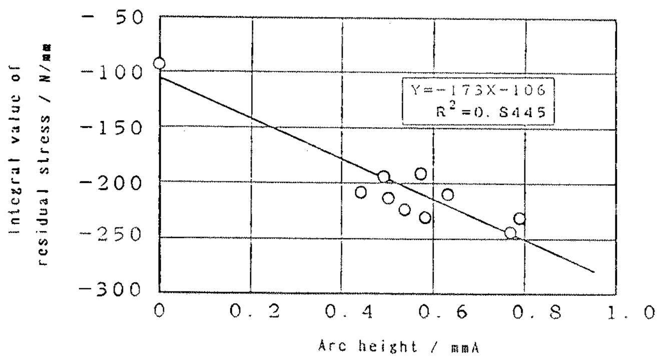

Fig.12 The relation between arc height and integral value of residual stress

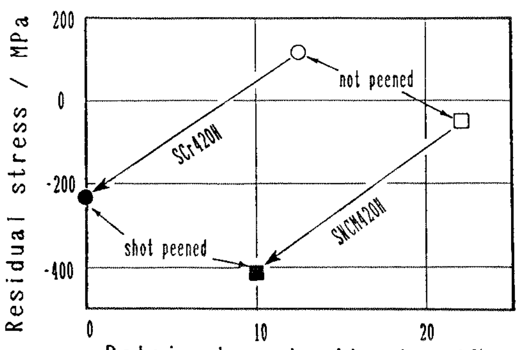

Fig.13 Reduction of retained austenite by shot peening [1]

Influence of Shot Parameters on Arc Height

Kinetic energy of shot is considered to make compressive stress field in the surface layer of carburized gears for the reasons mentioned above. The energy of shot /Ei and total energy of a shot peening treatment /Etotal are shown as equation (5) and (6).

$$Ei = 1/2\, mivi^2 \quad (5)$$

$$Etotal = \Sigma\, 1/2\, mivi^2 \quad (6)$$

Mass of the shot is proportional to the volume, so that mass of the shot can be written as cube of the diameter / D. Velocity of the shot can be written as square of rotation of the impeller / V . The summation of shot / Σ should be considered to be coverage / C. From these consideration, equation (7) is introduced.

$E_{total} \propto C\,D^3\,V^2$ (7)

Peening intensity represented by arc height must be saturated, so that the relation between total energy of a shot peening and arc height can be written as equation (8).

$H \propto \log(C\,D^3\,V^2)$ (8)

Fig.14 shows the relation between arc height value and logarithm of the total peening energy obtained from Table 1 and Table 2. This relationship can be written as equation (9).

$H = 0.024 \log(C\,D^3\,V^2) - 0.0112$ (9)

Arc height value closely correlates to logarithm of the total peening energy, and from this result, the propriety of equation (8) is certified. As a result of these analysis, authors made it clear that not only arc height vallue but also fatigue strength could be determined by coverage, diameter of shot and velocity of the shot, then determination of peenig conditions by equation (9) has been put into practice in production of transmission gears. These results also indicate that shot peening of higher arc height is more effective to improve fatigue strength of carburized gears.

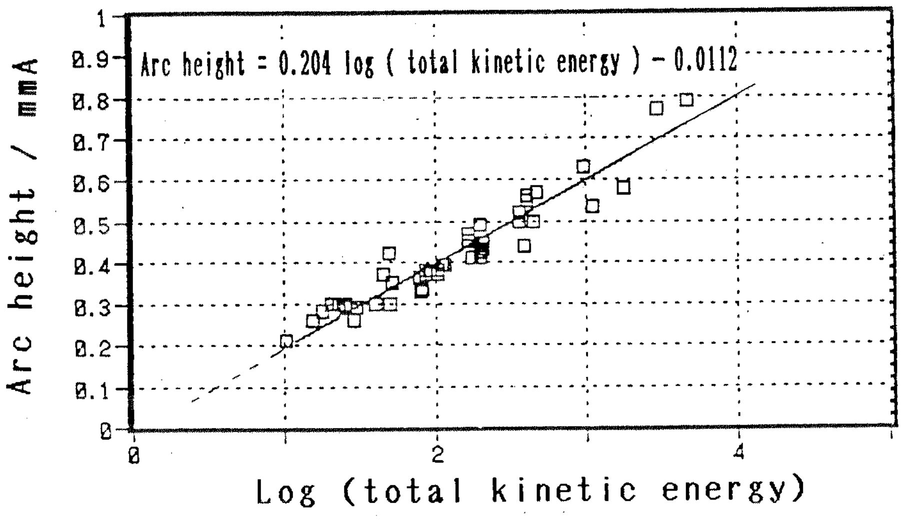

Fig.14 The relation between total peening energy and arc height

CONCLUSION

(1) Fatigue strength of carburized and shot peened gears closely correlates to integral value of residual stress and arc height value.
(2) The kinetic energy of shot makes retained austenite to change into martensite and produces compressive stress field in the surface layer of the carburized gears.
(3) Arc height value is shown to be a function of total kinetic energy of shot.

REFERENCE

[1] T.Matsumoto et,al.; Testu to Hagane (Japanese), vol.73, S462 (1987)