INFLUENCE OF THE SURFACE PROPERTIES ON THE BENDING STRENGTH OF SHOT PEENED CARBURIZED STEEL

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ABSTRACT

Shot peening method has been found out to be very effective for improvement of surface structure anomalies created on surface of gas carburized steel, and this method is widely applied to gas carburized gears for automotive use. For further improvement of strength of shot peened gears, bending tests were carried out by using specimens, electro-polished or paper finished after gas carburizing and shot peening, in order to find out how the bending strength is influenced by the surface properties. As a result, it was found out that both static bending strength and fatigue strength are greatly influencd by the depth of surface structure anomalies, surface roughness and residual stress.

KEYWORDS

Carburizing, Shot peening, Fatigue strength, Static bending strength, Surface roughness, Surface structure anomalies, Residual stress.

INTRODUCTION

Higher strength of gas carburized gear is strongly requested for meeting requirements of high power engine and compact transmission. It has been well known that non-martensitic structure or so-called "surface structure amomalies" formed on surface of gas carburized steel is adversely affecting the strength of steel.[1][4] For improvement of this surface structure anomalies shot peening method was found out to be very effective and this method is widely applied to gas carburized gear for automotive use.[1]~[4] In order to meet request for much higher engine out-put, further inprovement of shot peened gear strength is strongly requested. This paper describes about results of engineering observation of quantitative relationship between various surface characteristic factors of residual stress, surface structure anomalies, surface roughness and so on, and static and fatigue bending strength of gear or specimen treated with shot peening after gas carburizing.

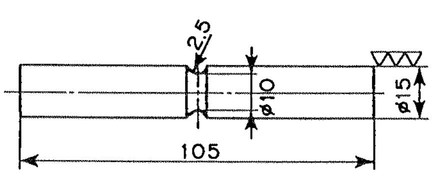
EXPERIMENTAL PROCEDURE

Chemical composition of tested steel is shown in table 1. Cr-Mo steel and Ni-Cr-Mo steel were used in this study. Afetr normalizing these materials were processed to 15mm dia. bar, notched specimen and module 4 spur gear shown in Fig.1.

Table.1 Chemical composition(%)

		C	Si	Mn	P	S	Ni	Cr	Mo
Cr-Mo steel	A1	0.20	0.23	0.85	0.030	0.017	0.03	1.15	0.15
	A2	0.19	0.28	0.79	0.007	0.018	0.03	1.12	0.17
	A3	0.22	0.27	0.75	0.017	0.015	0.07	1.05	0.15
	A4	0.20	0.19	0.83	0.011	0.017	0.06	1.12	0.11
Ni-Cr-Mo steel	B1	0.22	0.27	0.57	0.022	0.018	1.61	0.50	0.19
	B2	0.19	0.10	0.29	0.003	0.018	2.01	0.28	0.77

Notched specimen



Spur gear

Module	:	4
Pressure Angle	:	14.5°
Number of teeth	:	27
Pitch Dia	:	108.0
Base Dia	:	104.5599
Width of tooth	:	15

Fig.1 shape of specimens

For gas carburizing, continuous gas carburizing furnace was used with target of total case depth 1.0mm. Heat treatment condition is shown in Fig. 2. After gas carburizing, these specimens were applied with shot peening, partial paper finish or electro-polishing. These surface treament conditions are shown in table 2. Fig.3 shows hardness distribution of specimens treated with shot peening after gas carburizing. Shot peening made surface hardness higher, and the stronger shot peening, the higher surface hardness.[5] Fig.4 shows residual stress distrribution of specimens applied with various surface treatments indivioually or in combination after gas carburizing.[6] Static bending test, low cycle bending

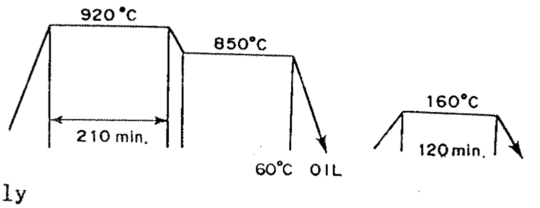


Fig.2 Heat treatment

Table.2 Surface treatment condition

1. Shot peening

	arc height	coverage	diameter of shot	hardness of shot
Conventional	0.47A	300%	0.8mm	HRC 53
Heavy peening	0.30C	300%	0.8mm	HRC 53

2. Paper finising

grain size	depth	direction
#400	300μm	axial or circumferential

3. Electro polishing

electrolyte	depth
ammonium chloride + glycerine + surfactant + H_2O	40μm

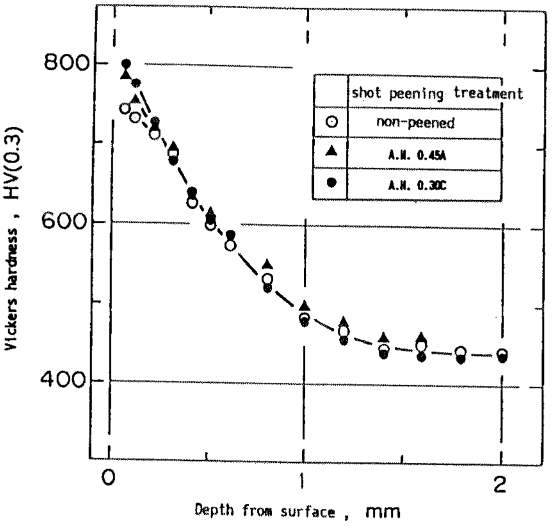


Fig.3 Influence of shot peening on microhardness distribution

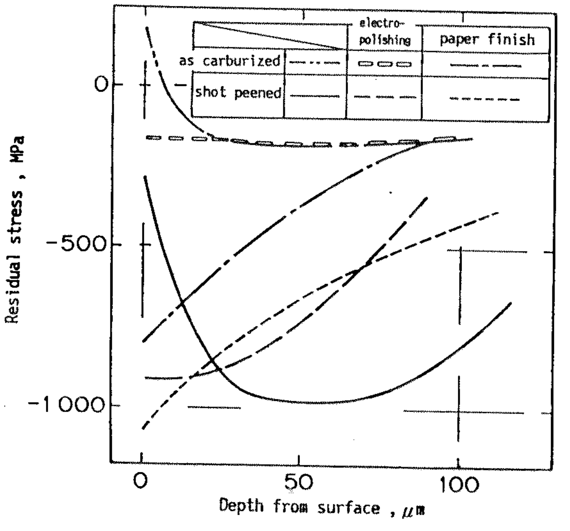


Fig.4 Influence of surface treatment on residual stress distribution

fatigue test and high cycle bending fatigue test were carried out by using specimens and gears applied with such surface treatments.

RESULTS AND DISCUSSION

1. Static bending strength

1.1 Static bending strength of specimens

ϕ 15mm specimens of A1 steel were machined from normalized steel bar and gas carburized. Static bending tests were carried out after treatment of shot peening, electro-polishing and paper finishing(axial and cross-wise direction).
Co-relation between static bending strength and surface roughness is shown in Fig.5. There are large variances of values for specimens remaining surface structure anomalies, but surface roughness and static bending strength are in linear relationship for specimens with surface structure anomalies removed by electro-polishing and paper finishing.
Multivariate regression analysis relative to the above test results was conducted with regression factors such as surface roughness, depth of surface structure anomalies, residual stress or surface hardness and following multivariate regression equation was obtained.

$$\sigma_1 = 2327 + 10.9/\sqrt{Rmax+Dan} - 0.389\,\sigma rs \quad (R=0.91)$$

Where;

σ_1	: Static bending strength (Mpa)
Rmax	: Max.surface roughness (mm)
Dan	: Depth of surface structure anomalies(mm)
σrs	: Surface residual stress(Mpa)
R	: Multiple correlation coefficient

(Regression factor)
Case depth, Surface hardness, Core hardness, Surface residual stress, Max. compressice residual stress, Surface retained austenite volume, Max. retained auetenite volume, Max. surface roughness, Depth of internal oxidation, Depth of non-martensitic structure

By addition of depth of internal oxidation to surface roughness, high relative coefficient was obtained and it was found out that static bending strength is greatly influenced by surface roughness, depth of internal oxidation and residual stress.
Co-relation between static bending strength and there regression factors is shown in Fig.6.

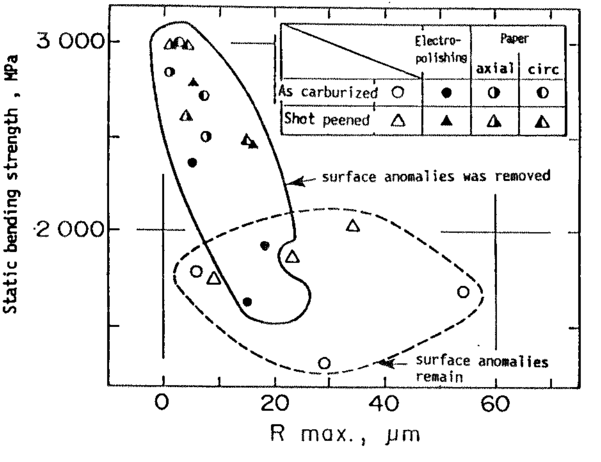


Fig.5 Relation between static bending strength and surface roughness

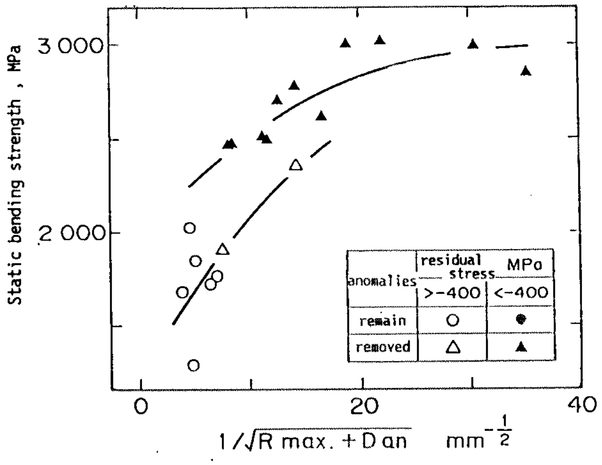


Fig.6 Relation between static bending strength and surface roughness (Rmax),surface structure anomalies (Dan)and residual stress

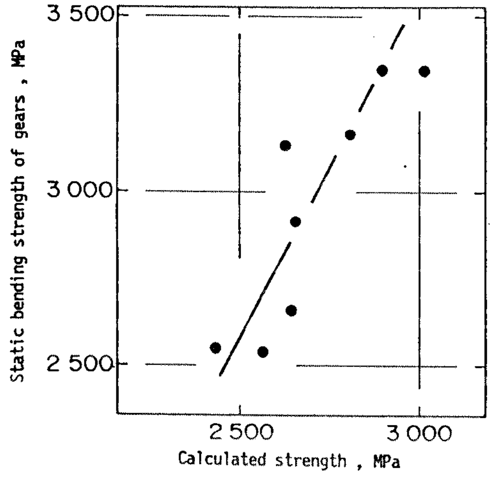


Fig.7 Relation between caculated and experimental static bending strength of gears

1.2 Static bending strength of gears

Gears(Fig.1) were machined from Al steel bars and static bending tests were carried out after application of gas carburizing and various surface treatments. Table 3 shows results of static bending gear tests.
There is not much difference of strength after only gas carburizing and shot peening, but further application of paper finishing or electro-polishing makes it possible to greatly improve the strength.
Calculated value of static bending gear strength was estimated according to above multivariate regression equation for specimens, after investigating the surface properties of tested gears, such as surface roughness, depth of internal oxidation, residual stress. Fig.7 shows co-relation between calculated value and experimental static strength. Their inter-relation is in linear and it was found out that static bending strength is greatly influenced by surface roughness, depth of internal oxidation and residual stress.

Table 3 Static bending strength of gears

(MPa)

			paper finish	electro-polishing (E.P.)	E.P. + paper finish
As carburized	$\overline{X}_3$	2 511	2 677	3 126	2 911
	σ	112	255	108	142
Shot peened	$\overline{X}_3$	2 533	3 162	3 342	3 342
	σ	22	62	143	162

2. Bending fatigue strength

2.1 High cycle fatigue strength

Notched test pieces were machined from different lot Cr-Mo steel(A2, A3,A4) and after gas carburizing, shot peening and or electro-chemical polishing apllied to conduct rotating bending fatigue test. S-N curves are shown in Fig.8. Fatigue strength was obtained higer by 20~40% by shot peening, 20~30% by electro-polishing and 40~60% by combination of electro polishing after shot peening compared with specimen of gas carburizing treatment only.
Multivariate regression analysis was conducted with regression factors such as surface roughness and depth of surface structure anomalies and following multivariate regression equation was obtained.

$$\sigma_z = 396 + 5.83/\sqrt{Rmax+Din} - 0.340\,\sigma rm \quad (R=0.90)$$

Where;
σ_z : Bending fatigue strength(Mpa)
Rmax: Max. surface roughness(mm)
Din : Depth of internal oxidation (mm)
σrm: Max.compressed residual stress(Max)

(Regression factor)
Case depth, Surface hardness, Core hardness, Compressed residual stress, Surface retained austenite volume, Max. retained austenite volume, Max. surface roughness, Depth of internal oxidization, Depth of non-martensitic structure

Same as multivariate regression analysis of static bending strength, fatigue strength was found out to be greatly influenced by surface roughness, depth of internal oxidation and residual stress. But, in high cycle fatigue strength, Max. compressed residual stressas found out to be mostly affecting the strength which is different from

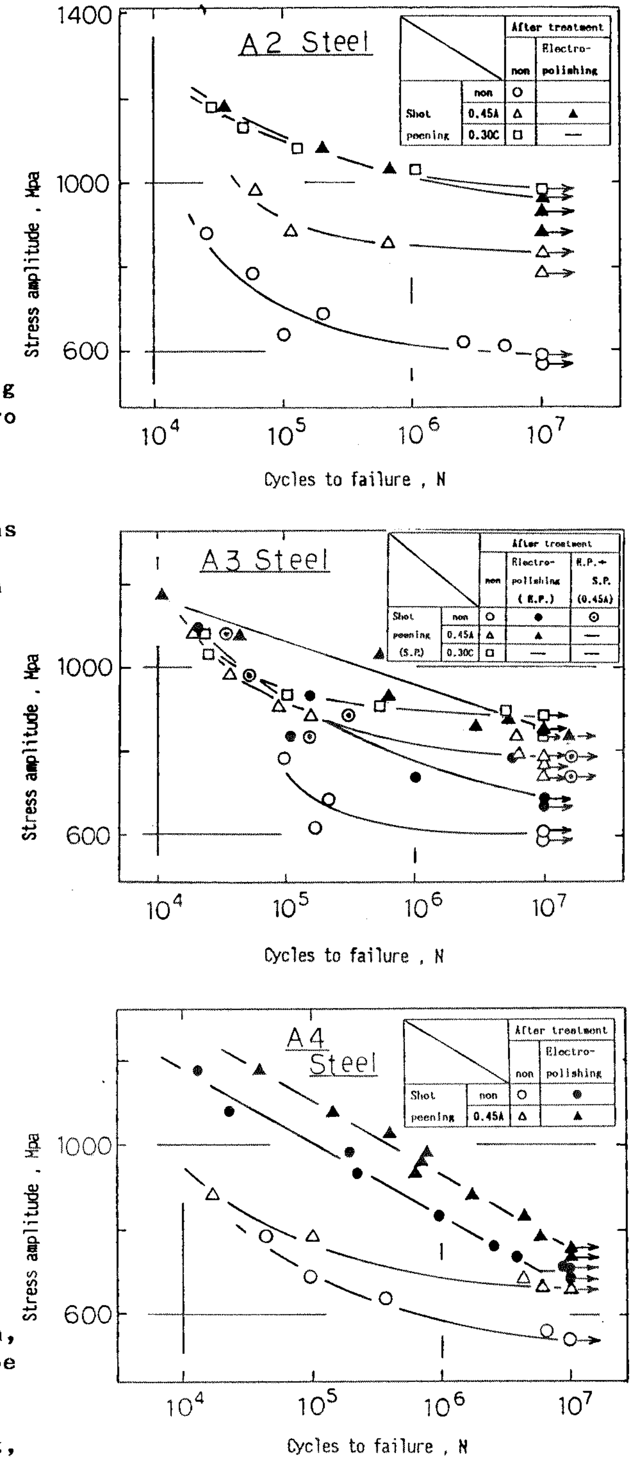


Fig.8 S-N curves of rotating bending fatigue tests

static bending strength.
Co-relation between calculated value by multivariate regression analysis and experimental value is shown in Fig.9.

2.2 Low cycle fatigue strength

Notched specimens(Fig.1-a) of Cr-Mo steel(A1) and Ni-Cr-Mo steel(B1,B2) were machined and after carburizing, shot peening and or electro-polishing applied and low cycle bending fatigue tests were carried out.
One example of these test results is shown in Fig.10. There is not so much difference of strength by kinds of steel and the order of strength is,
gas carburizing only <gas carburizing + shot peening <gas carburizing + electro-polishing <gas carburizing + shot peening + electro-polishing.
Also multivariate regression analysis relative to fatigue strength at 5×10^3 cycles was conducted with regression facters such as surface properties and following multivariate regression equation was obtained.

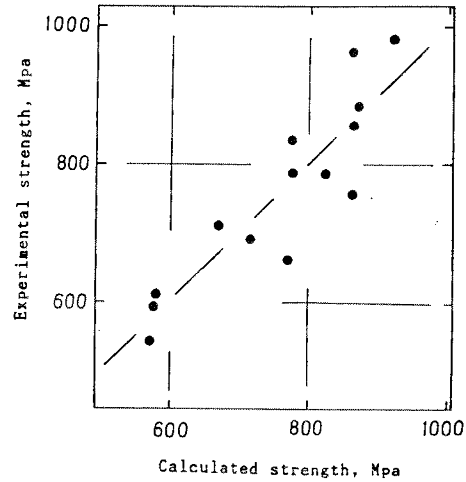


Fig.9 Relation between calculated and experimental bending fatigue strength

$$\sigma_3=1832+7.09/\sqrt{Rmax+Din}-0.295\sigma rs \quad (R=0.93)$$

Where;
σ_3 : Bending fatigue strength at 5×10^3 cycles(Mpa)

(Regression factor)
Case depth, Surface hardness, Core hardness, Compressed residual stress, Surface retained austenite volume, Max. retained austenite volume, Max. surface roughness, Depth of internal oxidization, Depth of non-martensitic structure

Alloying element is not affecting low cycle fatigue strength and high precision multivariate regression equation was obtained from surface roughness, depth of internal oxidation and residual stress. Low cycle fatigue strength is found out to be also greatly infuenced by surface roughness, depth of internal oxidation and residual stress.

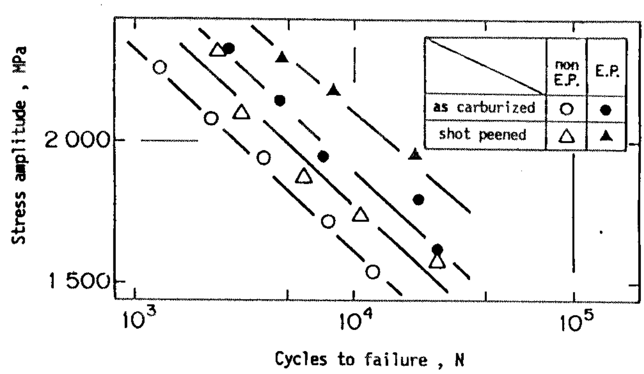


Fig.10 Results of low cycle bending fatigue tests

CONCLUSION

1. Static bending strength is greatly influenced by surface roughness, depth of internal oxidation and residual stress. Relative with surface roughness, depth of internal oxidation and residual stress, the following experimental equation was obtained.

$$\sigma_1=2327+10.9\sqrt{Rmax+Dan}-0.389\sigma rs$$

2. Same as static bending strength, bending fatigue strength is greatly affected by surface roughness, depth of internal oxidation and residual stress, relative with 10^7cycles fatigue strength and 5×10^3cycles strength, the following experimental equation was obtained.

10^7cycles fatigue strength : $\sigma_2=396+5.83/\sqrt{Rmax+Din}-0.340\sigma rm$

5×10^3cycles fatigue strength : $\sigma_3=1832+7.09/\sqrt{Rmax+Din}-0.295\sigma rs$

3. As stated above static bending strength and bending fatigue strength of gas carburized steel were both found out to be greatly affected by residual stress, surface roughness and depth of internal oxidation.
It has been made clear that strength can be greatly improved by treatment of shot peening aftert gas carburizing and further application of electro-polishing for removing internal oxidation and decrease the surface roughness.

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