Size Effect on Fatigue Strength of Shot Peened Carburized Steel

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Introduction

There has been an increasing need for stronger and more reliable carburized transmission and axle gears because of motor vehicles getting lighter and engines becoming bigger.
As a result, carburized gears strengthened by shot peening have come into wide use. But it is not a well known fact that the influence of size of shot peened carburized steel is very big on the fatigue strength.
This paper discusses how the sizes and stress concentration of the shot peened carburized steel affect fatigue strength in a rotating bending fatigue test.

Experimental procedure

Clean steel used in this study was produced by means of R-H vacuum degassing, ladle refining and submarged nozzel continuous-casting to decrease non-metallic inclusions.
Chemical composition of Cr-Mo steel (JIS SCM420H & SCM822H) used in this study is shown in Table 1.
The Cr-Mo steel bars were machined to the shape shown in Fig. 1 and then gas carburized to the total case depth of 1.3 mm.
The condition of heat treatment is shown in Fig. 2.
Shot peening treatments are summarized in Table 2.

Table. 1: Chemical composition (%)

	C	Si	Mn	P	S	Cr	Mo	O_2
SCM822H :	0.21	0.25	0.80	0.014	0.004	0.98	0.37	12ppm
SCM420H :	0.22	0.29	0.88	0.007	0.004	1.11	0.18	13ppm

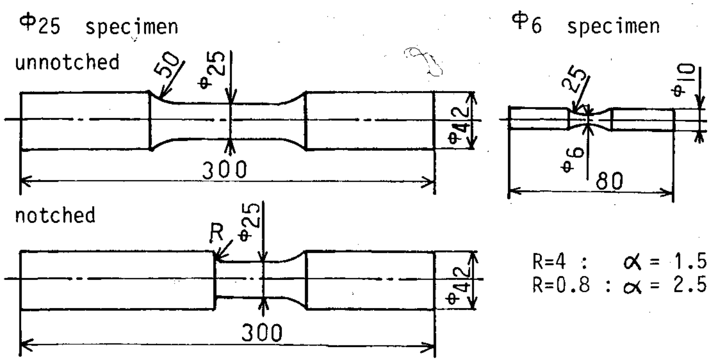

Fig. 1: Shape of specimens

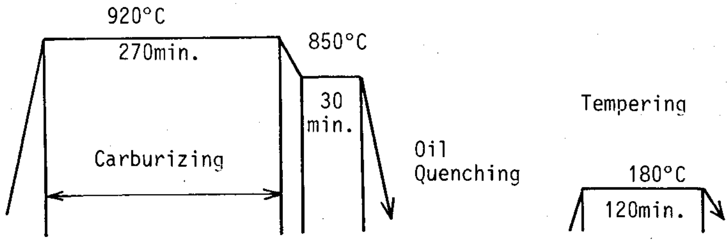

Fig. 2: Heat treatment

Table 2: Shot peening treatment

Peening Intensity Arc Height, mm	:	0.15 A	0.30 A	0.40 A	0.60 A	0.26 C
Shot Size, mm	:	0.40	0.60	0.80	1.00	1.40
Coverage, %	:			300		
Shot Hardness	:			HRC 50-56		

Experimental Results

1) Influence of shot peening on the surface structure anomalies

It is a well known fact that the surface structure anomalies often called "soft skin layers" are caused by internal oxidation occuring during gas carburizing process and that the anomalies reduce the fatigue strength of carburized parts.
Fig. 3 shows the surface structure anomalies of gas carburized Cr-Mo steel.

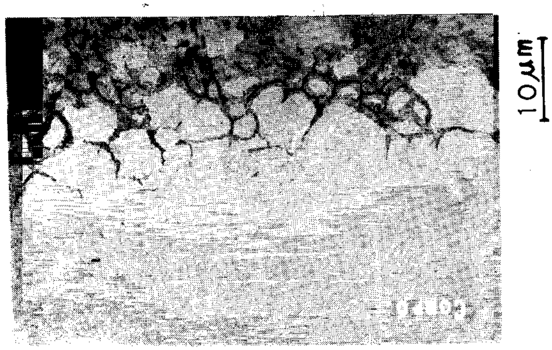

Fig. 3: SEM photograph of the surface structure anomalies.

Changes in near-the-surface distribution of hardness, residual stress and retained austenite as a result of shot peening were investigated with the results shown in Fig. 4, 5 and 6.
The difference in residual stress distribution before and after shot peening is as follows:
In a non-peened carburized steel specimen, a surface tensile residual stress (as measured without being etched) was observed instead of normal compressive stress because of surface structure anomalies.
As Fig. 5 shows, shot peening however transformed the tensile residual stress into compressive stress, and in lower peening intensity (arc height), surface stress became more compressive and area of maximum compressive stress came nearer to the surface.

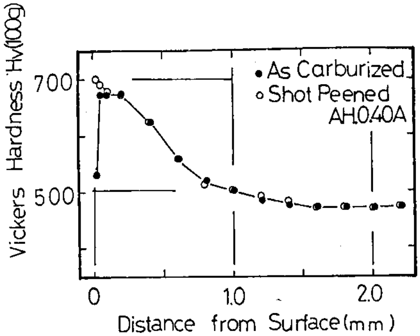

Fig. 4: Influence of shot peening on microhardness distribution.

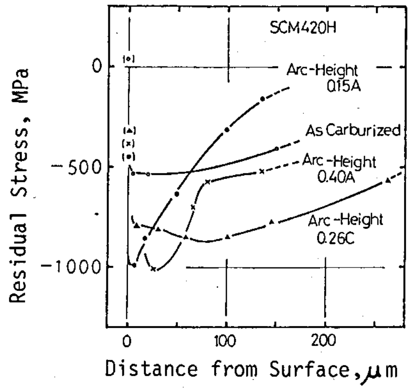

Fig. 5: Influence of shot peening on residual stress.

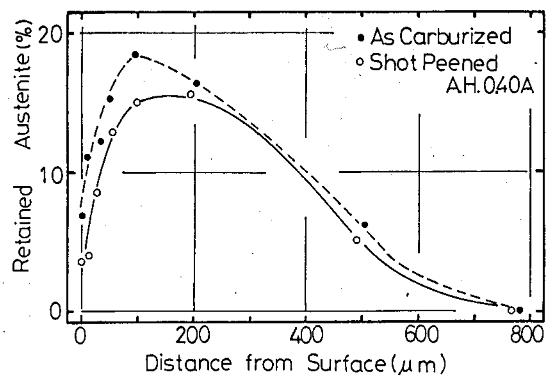

Fig. 6: Transformation of retained austenite by shot peening.

2) The results of a rotating bending fatigue test

Φ6 specimens: Fig. 7 shows a typical example of S-N curves. The fatigue limits are shown in Fig. 8, which shows shot peening increased the fatigue limits of Φ6 specimens by about 42-56%, and that the lower peening intensity specimens attained higher strength.

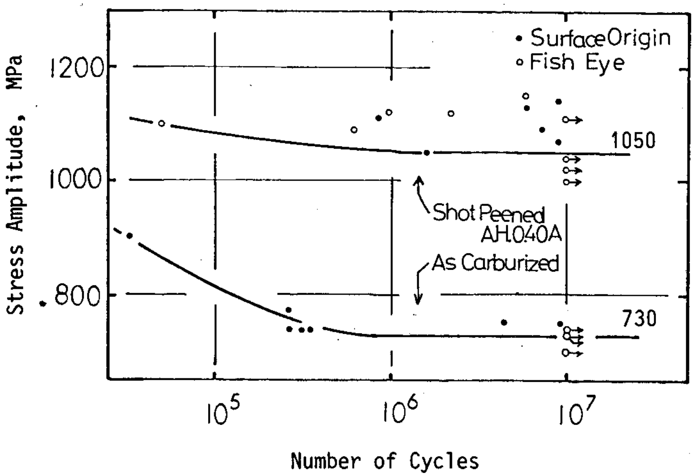

Fig. 7: S-N curves of shot peened (A.H.:0.40A) and as carburized specimens.

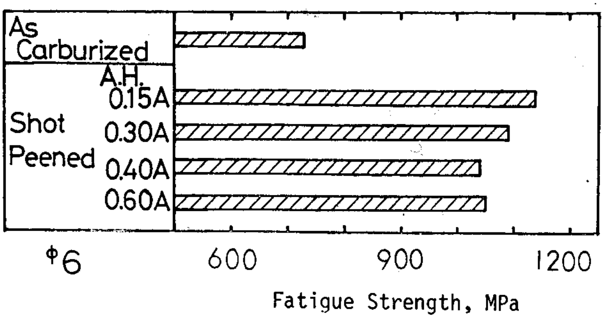

Fig. 8: Influence of shot peening on fatigue strength.

Φ25 specimens: Table 3 shows that the shot peening on Φ25 unnotched specimens was not so effective. However strength improvement of the Φ25 notched specimens with higher stress concentration is quite impressive, up as high as 49%.

Table 3: The results of the fatigue limits of Φ25 specimens.

	Factor of Stress Concentration	Fatigue Limit (MPa) As Carburized	Fatigue Limit (MPa) Shot peened	Increase %
Unnotched	: 1.0	520	590	13
Notched R=4	: 1.5	500	590	18
R=0.8	: 2.5	350	520	49

Influence of specimen size on the fatigue strength and the position of the destructive origins

Table 4 shows the positions of the destructive origins. As is evident from Table 4, the surface of the shot peened specimens of both Φ6 and Φ25 has been strengthened resulting in relocation of destructive origins from surface toward center.
Here we will closely review the influence of size on the fatigue strength and relocation of destructive origins.
Fig. 9 shows two dotted lines (Φ6 & Φ25) which indicate the fatigue strength calculated from residual stress and vickers hardness and two straight lines which indicate the bending stress applied to the specimen.
It is noted that the inclination of the applied stress line of the Φ6 specimens is much sharper than that of the Φ25 specimens and the destructive origins of the Φ25 become deeper and come near the case depth (point A), hence smaller increase in fatigue strength.

Table 4: The position of destrutive origins and fracture probability.

Fracture origin		Size Φ6	Size Φ25
As carburized			
Surface	:	100%	77%
Inside	:	0%	23% (Core)
Shot peened			
Surface	:	48%	14%
Inside	:	52% (Case)	86% (Core)

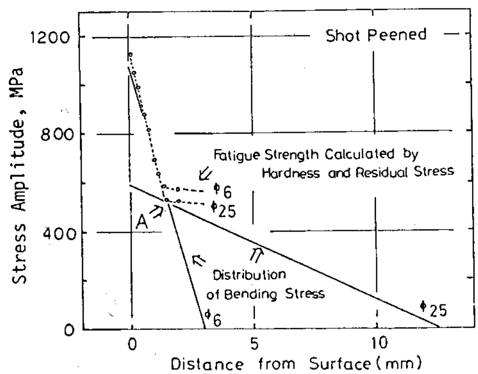

Fig. 9: The distribution of calculated fatigue strength.

Fig. 10 shows the relation between the calculated fatigue strength and specimen sizes.
On the other hand, even with in the Φ25 specimens, when they are notched, the inclination of the applied stress line near the surface become shaper, hence greater increase in fatigue strength as in the case of small size, unnotched specimens.

These results indicate that shot peening is the most effective when applied to small size parts about 6mm thick. And it is also true with larger parts having sharp notches.
Fig. 11 shows the P-S-N curves of carburized gears (module:4). An excellent result of 48% increase has been obtained in limited fatigue strength at 10 percent breakage probability.

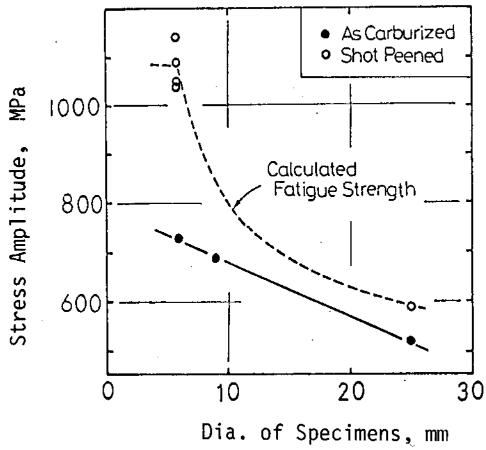

Fig. 10: Influence of specimen size on fatigue strength.

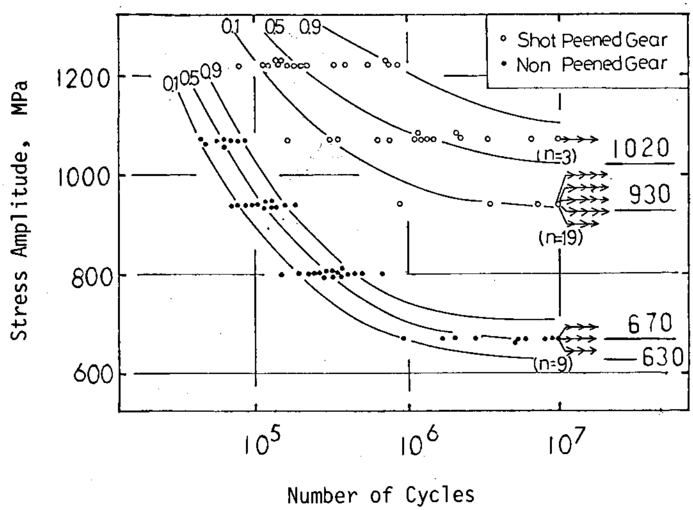

Fig. 11: P-S-N curves of carburized gears.

Influence of shot peening intensity (arc height) on the fatigue limit

Table 5 shows the relation between the arc height and the positions of the destructive origins of Φ6 specimens and Fig. 12 the S-N curves of specimens fractured only from surface origins.
As table 5 shows, in lower arc height specimens, a probability of inside destruction (generally called a fish eye) is higher and as Fig. 12 indicates the fatigue lives of the surface fractured specimens is longer in case of the lower arc height.
This suggests that the lower arc height treatment is more effective to improve the fatigue strength weakened by the surface structure anomalies.
And this is in agreement with the measured result of residual stress distribution (as mentioned Fig. 5).

Table 5: The positin of the destructive origins of Φ6 specimens

Arc height mm,A		Probability of fracture from surface and inside origin Surface origin	Inside origin
0.15 A	:	0 %	100 %
0.30 A	:	25 %	75 %
0.40 A	:	55 %	45 %
0.60 A	:	100 %	0 %

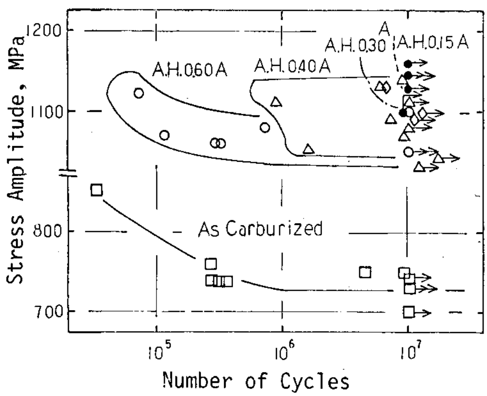

Fig. 12: S-N curves of specimens fractured only from surface origins.

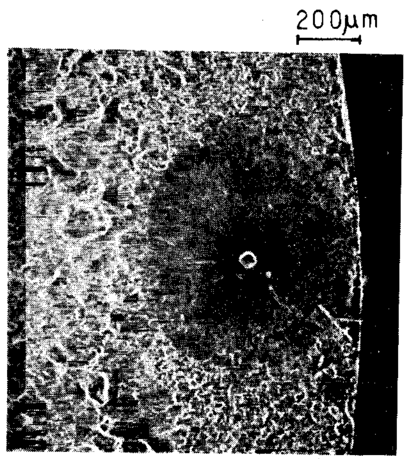

Fig. 13: Fracture surface.

Size and number of non-metallic inclusions

In the center of the fish eye, non-metallic inclusions are always observed. A typical inclusion-initiated fractured surface is shown in Fig. 13.

Fig. 14 shows the size of the inclusions observed in the fish eyes.
In larger specimens, larger inclusions were observed. The size of these inclusions are so large that normal microscopic observation cannot detect.
So we evaluate the size of the inclussions in the Cr-Mo steel by means of the acid dissolution method. Fig.15 shows the results.
This suggests the necessity of reducing the size and number of non-metallic inclusions to improve the fatigue strength.

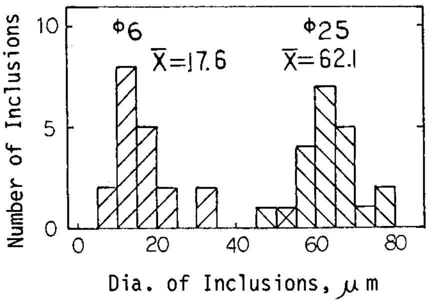

Fig. 14: The size of the inclusions observed in the fish eyes.

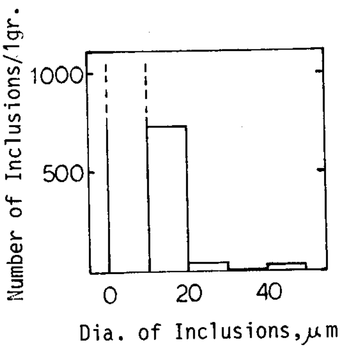

Fig. 15: The number of inclusions in raw material as found by acid dissolution method.

Conclusion

1) Weekened fatigue strength due to anomalies can significantly be improved by means of shot peening which help improve the hardness, residual stress and retained austenite of the material.
2) An increasing rate of fatigue limit by shot peening is much influenced by the inclination of the applied stress distribution. So the greater benefit of shot peening is obtained in small parts and/or more stress concentrated parts.
3) In case of small size specimens the condition or arc height of shot peening is very important. Lower arc height specimens obtained better fatigue limit because of higher compressive surface stress with the area of maximum compressive stress coming near the surface.
4) In the case of large size specimens, rarely existing large non-metallic inclusions always become the destructive origins. So, it is very important to reduce the size and number of non-metallic inclusions to improve the fatigue strength.

References

(1) S.Gunnarson; Metal Treatment and Drop Forging, June(1963)219.
(2) G.H.Robinson; ASM Book(1957).
(3) S.Hisamatsu; Kinzoku Zairyou, 15, 4(1975)77.
(4) S.Hisamatsu, T.Kanazawa; JSMS,29th Sympo.(1980)112.
(5) K.Shiwaku et all; SAE Paper,850364.