FATIGUE STRENGTH OF GEAR STEELS SHOT PEENED IN EXTREMELY HIGH INTENSITY CONDITIONS

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ABSTRACT

For case hardened gear steels shot peening treatment in extremely high intensity conditions can generate the white etching layers in the surface region, which are recognized as the adiabatic shear bands. In this work the morphology and characteristics of the white layer was studied on the 600% hard peened specimen. It was revealed that the white layer has a half bowl shape. The effect of the white etching layers on fatigue strength and surface damage as pitting was also investigated by means of rotating beam fatigue tests and gear bench tester. Although no deletrious effects of the white layers was found in the fatigue tests, it should be avoided to form them on gear surface because of the possible risk of gear teeth chipping.

SHOT PEENING, FATIGUE STRENGTH, TRANSMISSION GEAR, ADIABATIC SHEAR BANDS, PITTING, SURFACE DAMAGE, RESIDUAL STRESS

INTRODUCTION

Transmission gears for outbord-motors are usually shot-peened to prevent them from surface damages like pitting caused by the relatively high pressure load accompanied with traction forth. For a longer life of gears it is desirable that the residual compressive stress in the near-surface region is as high as possible. However, an extremely severe condition of shot-peening treatment can result in lower fatigue strength of gear teeth. One of the reasons for the negative effect of the over peening on fatigue strength is thought that the white-etching bands, which is often found in the carburized layer peened in an extremely high intensity condition, can be a fatigue crack initiation site. There are a lot of reports on the white-etching bands occuring in high strain rate deformation [1-8] in which the bands have been labeled as transformed phases, called the adiabatic shear bands but few studies are found on shear bands formation during shot peening treatment of case-harded steels and their influence on mechanical properties.
The objective of this work was to manifest the relationship between existence of the adiabatic shear bands and the fatigue strength in carburized gear steels.

EXPERIMENTAL PROCEDURE

Material and Specimen

For rotating beam fatigue tests a 20mm dia. bar stock in the alloy steel JIS SCM415 (CrMo-steel) (Table 1) was used. After the material was lathed to the cylindrical specimens with a circurated notch (Kt = 3.0) they were carburized and oil-quenched from 850 C followed by tempering at 190°C with a resulting surface hardness of HRA 80 and an effective case depth at Hmv 550 of 0.55mm. The "unpeened" specimen was used with "as heat treated" surfase.
Real gears provided for the IAE bench tests were made of either the JIS SCM 415 or the high Mo steel whose chemical compositions are also shown in Table 1.

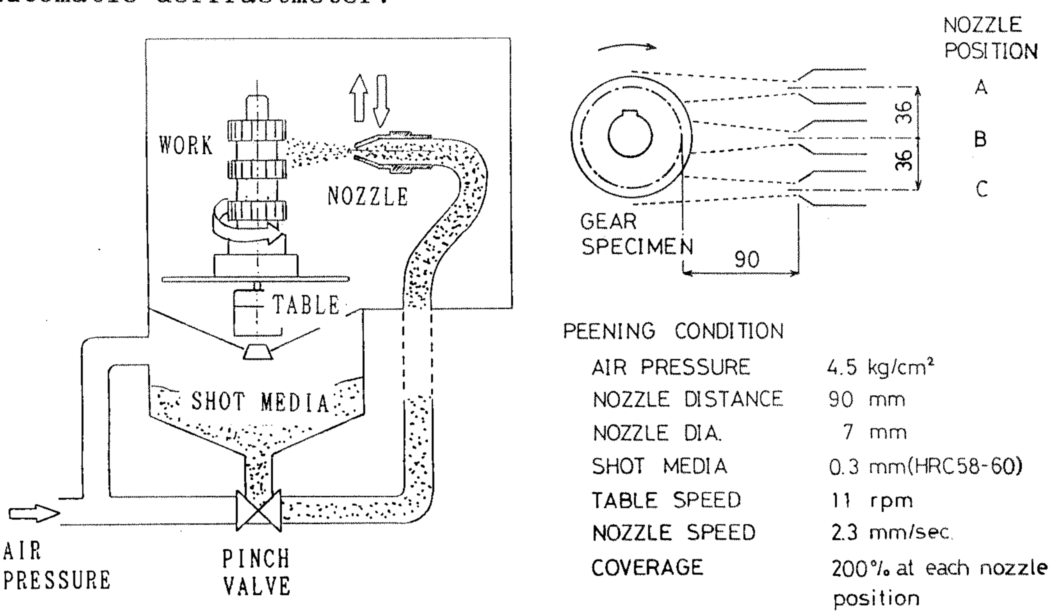
Table 1 Chemical Compositon of the Material Tested [wt%]

	C	Si	Mn	P	S	Ni	Cr	Mo	Cu
Steel A1	.18	.31	.81	.015	.014	.07	1.17	.15	.12
Steel A2	.18	.23	.85	.026	.018	.11	1.17	.15	.12
Steel B	.20	.06	.74	.010	.020	.02	1.03	.76	.01

A1:JIS SCM415 for rotating beam specimens
A2:JIS SCM415 for gear specimens
B :High Mo Steel for gear specimens

Shot Peening

Specimens were shot peened by means of the air-pressure nozzle type machine which is equiped with a rotating table and a nozzle travelling mechanism.(Fig.1-A) As the peening media 0.3 mm dia. hard steel shots (hardness: HRC 58-62) were used with an initial velocity(nominal shot speed) of about 100 m/s. The table rotating speed and nozzle travelling speed were set up so that the whole specimen surface can be covered in an one way vertical movement of the nozzle, defining the coverage of 100%. For the gear specimens in peening coverage of 600% peening in coverage of 200% was repeated three times changing the nozzle position in the same horizontal plane (see Fig.1-B) to get a complete coverage on gear teeth surface as well as roots and bottoms of the gear teeth.
Measurements of the residual stress, the amount of retained austenite and the half-value width were carried out using the fullautomatic deffractmeter.



A B

Fig.1 Shot Peening Facility (schematic):A and Peening Procedure for Gear Specimens:B

Quantitative Assessment of Pitting Damage

For the gear type specimens the pitting damage was assessed quantitatively by means of the image analyser determining the specific pitting area for each gear tooth during tests. The grade of the pitting damage(GPD) was defined as the sum of the specific pitting area for the testing gear.[9]

RESULTS

Microstructure

Fig.2 shows the microstructure of cross section of the rotating beam specimens. In the "as heat treated" specimen oxide layer of grain boundary was seen in less than 20 micrometer depth, while the hard peened specimens exhibited more compact oxide layer and smoothed surface with slightly deformed grains. The white-etching layers in arc shape were found in hard peened specimens, of which the number increased with the peening coverage.

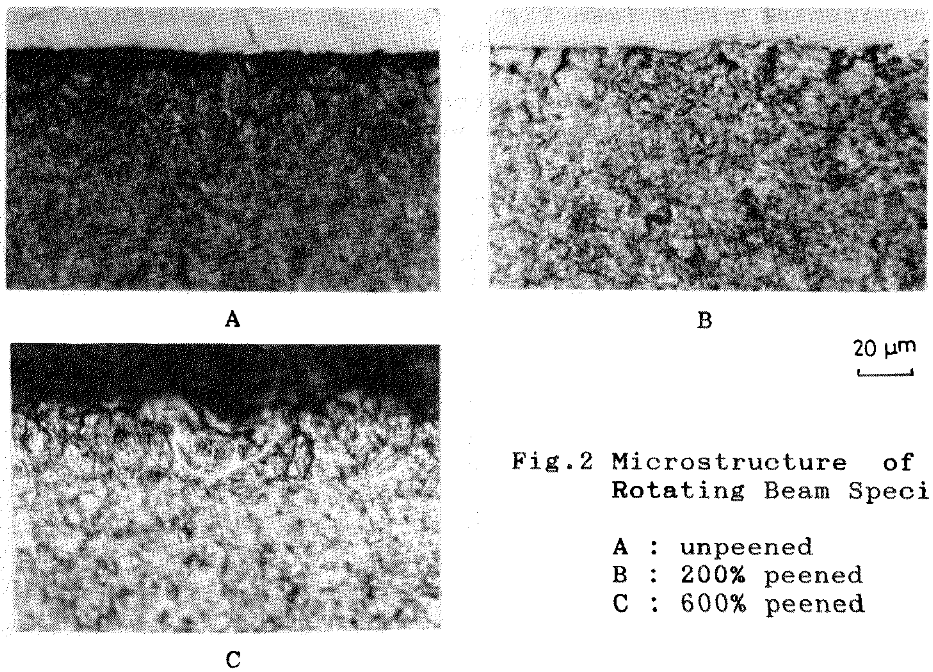


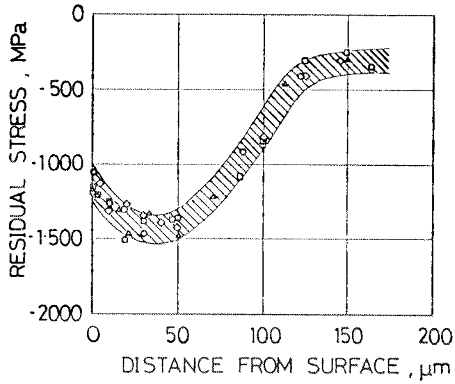
Fig.2 Microstructure of the Rotating Beam Specimens

A : unpeened
B : 200% peened
C : 600% peened

Peening Parameters

The residual stress-, retained austenite-, and half value width profile as a function of distance from surface are shouwn in Fig.3 for the fatigue specimens peeneed in coverage of 100 to 600%. Although the compressive stress at surface had tendency to increase with the peening coverage for every specimens, there was no essential change in the peek stress level scattering around 1450MPa. The depth of the peek compressive stress position seems to increase from 20 to 50 micrometers with increase of the coverage. The amount of retained austenite was remarkablly reduced within about 50 micrometers from surface. The profile of the half-value width exhibited the minimum peek at 50 micrometers from surface through the all peening conditions.
Fig.4 shows change of the surface roughness as a function of coverage. The surface roughness was improved with increase of coverage.

A



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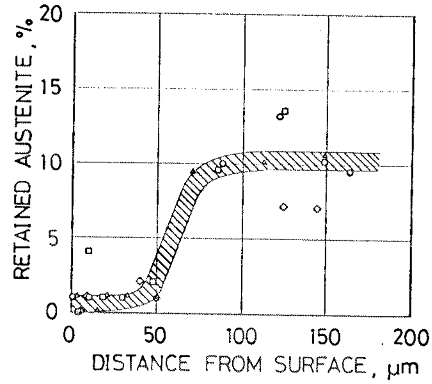

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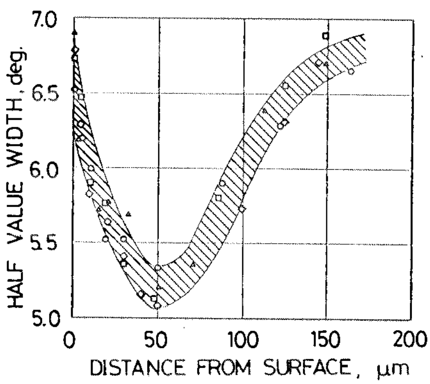


Fig.3 Profile of Peening Parameters

coverage	%
○	100
□	200
△	400
◇	600

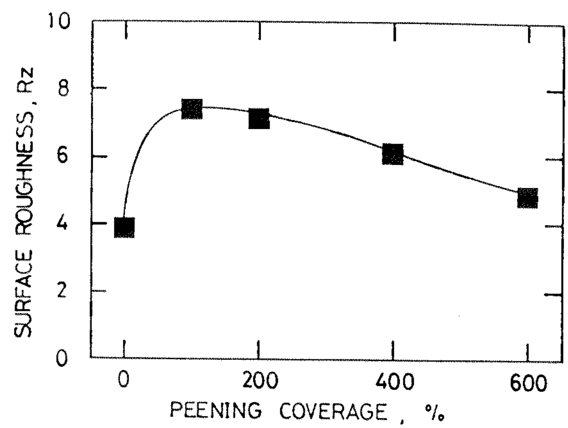


Fig.4 Relation between Surface Roughness and Peening Coverage

Result of Fatigue Tests

Rotating beam fatigue tests at room temperature were carried out for the as heat treated, 200%- and 600%-peened specimens. Fig.5 shows the S-N curves comparing the three conditions, where the vertical axis is the nominal stress amplitude at the notch root. The fatigue strength at 107 cycles for the peened specimens was 190 to 200% of that for the unpeened ones. The 600% series had 9% higher fatigue strength than the 200% series.

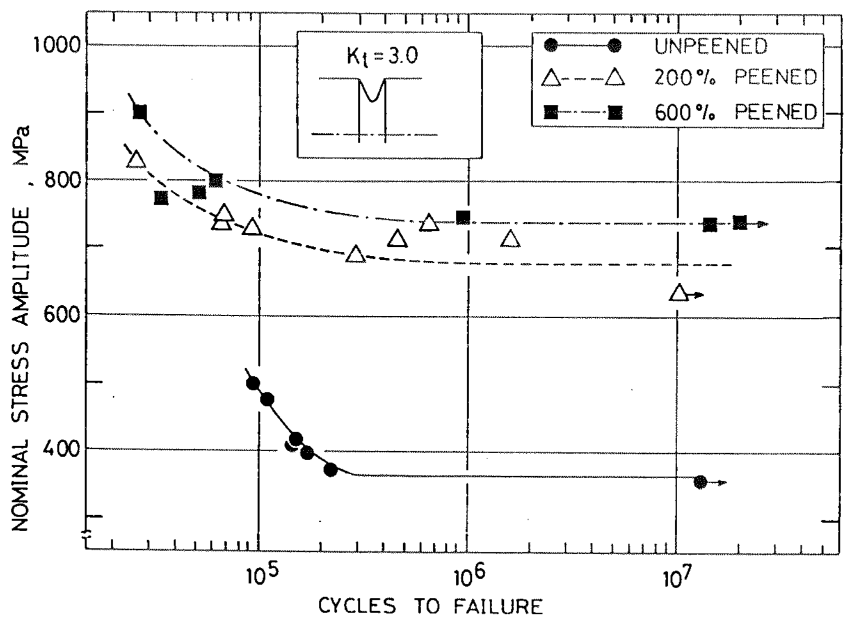
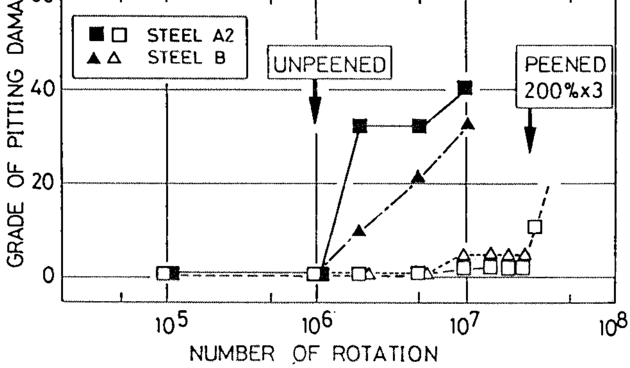


Fig.5 S-N Curves for Three Conditions : as heat treated, 200%- and 600% peened



Pitting Tests for Gear Type Specimens

Fig.6 shows result of the pitting tests by gear specimes comparing un-peened with 600% peened condition. For either material 600% peening exhibited a remarkable improvement of pitting resistance.

Fig.6 Result of Pitting Tests for Gear Specimens

DISCUSSION

Structure and Origin of the White-Etching Layer

Careful mechanical polishing of surface revealed the vertical view of the white-etching layer for the fatigue specimen peened in coverage of 600%. In Fig.7 distribution of white-etching rings was seen on the polished and Nital-etched specimen surface.
Fig.8 shows magnification of one of the rings in vertical view(A) and the cross sectional view (B). From those informations the three-demensional morphology of the white layer can be determined as (C) showing a half-bowl form.

Since the layer has exhibited a quite high hardness (White layer: Hmv 1096 , Matrix: Hmv 726 in Average) and no extraordinal chemical composition compared to that of the matrix , it is thought to be the adiabatic shear band formed by collision of peening medium in a high velocity. Although these white layers were found more frequently in the specimens with larger peening coverage ,it is hard to understand that those white layers were formed by cyclic loading induced by repeated attack of media. One of likely assumptions is that the adiabatic shear was induced by collision of the peening media in velocities exceeding a critical value because the velocity of the peening media has a scatter and the probability of meeting with the high speed media is larger for higher coverage treatment.

The half bowl shape of the shear bands is thought to be created by axial-symmetry of elastic stress field in which the highest shear stress is located at the subsurface area directly below the center of the contact circle. The adiabatic shear is supposed to occur at the subsurface area and propagate to the edge of the contact circle in the surface.

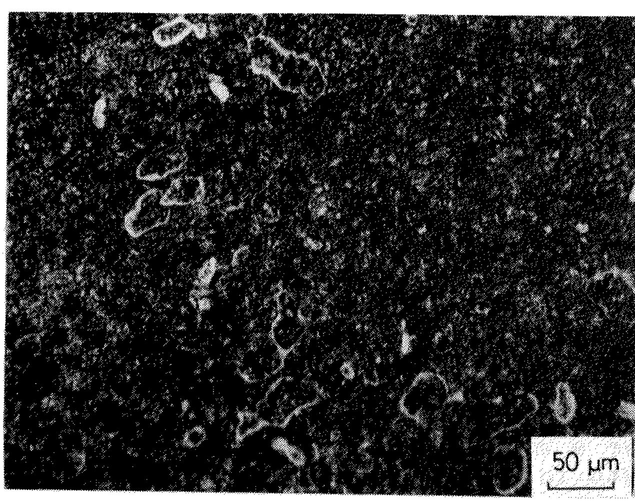


Fig.7 Distribution of the White Rings on the Specimen Surface

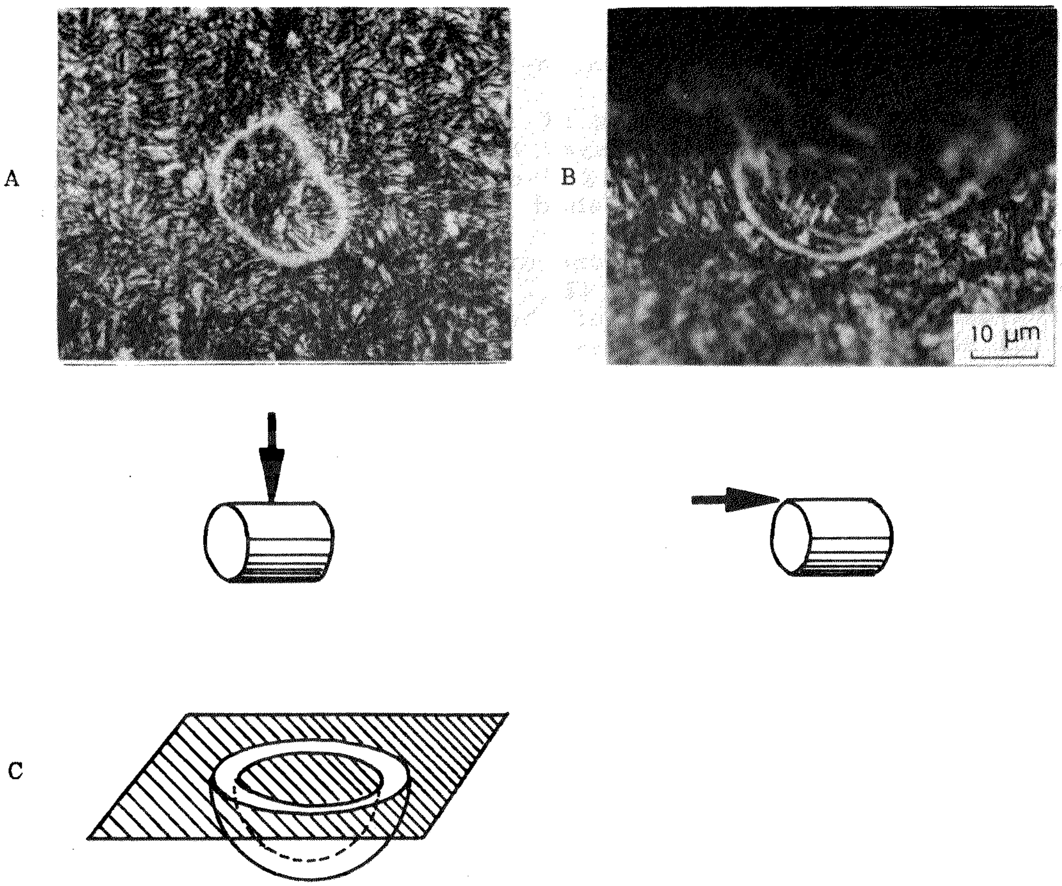


Fig.8 Morphology of the White Ring A:Vertical View, B:Cross Sectional View, C:Schematic Morphology

Influence of the White Layer on Fatigue Strength

The fatigue strength increased with increase of coverage whereas number of the white etching bands had been remarkablly larger in 600% than in 200% peening condition. Comparison of peening parameters between 200% and 600% condition exhibited there was no essential difference either in the residual stress profile or in the half-value width profile which represents the distribution of dislocation density. These facts suggest that the white layers have no deleterious influence on fatigue strength although a few SEM of the fracture surface revealed the white layer with the arc shape could be a crack initiation site.(Fig.9) Improvement of fatigue strength in higher coverages can be caused by improvement of surface roughness reducing the microscopical notch factor.

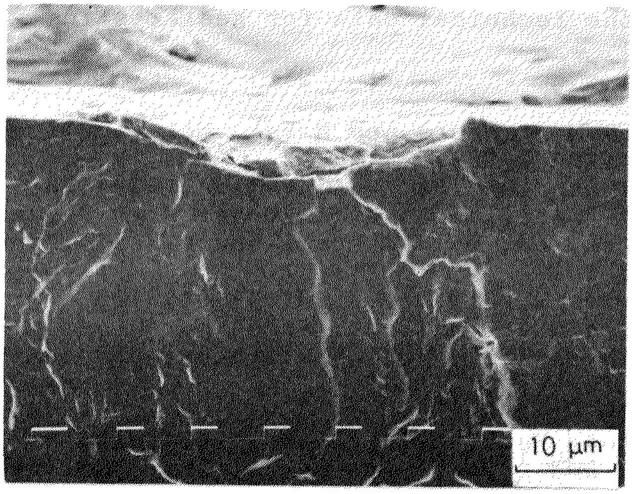


Fig.9 Fatigue Crack Initiation Site Probably at the Shear Band

For the gear specimens chipping of the teeth edge was seen during the pitting tests on 600% peened samples but it did not hinder the improvement of pitting resistance in the testing system. In practical use as a transmission, however, the small chips removed from the tooth-tips could be caught in teeth-gaps causing a fatal damage of the teeth surface because of the closed system.

CONCLUSION

(1)On the case-hardened CrMo-steels shot peening in extremely high coverage conditions up to 600% resulted in improvement of fatigue strength up to 200% and better pitting resistance as compared with unpeened condition. Although number of white-etching layer was found to increase with increase of coverage and a part of the layer can be the fatigue initiation site, no deleterious influence of them on fatigue strength was recognized.

(2)Morphology of the white layer was determined as the half-bowl shape. From the characteristics of the layer it was supposed to be the adiabatic shear bands formed by collision of peening media in high velocities over a critical value.

(3)For practical use such as treatment for transmission gears peening conditions should be chosen to avoid the white layer formation because during operation the white layers can be removed from tooth-tips to be caught in the teeth gaps causing a fatal damage on the gear surface.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation for the efforts of Mr.T.Takegami and Mr.S.Ono, Sanshin Industry Co., Ltd., who performed the specimen treatment and X-ray measurement, and also

Mr.M.Nakamura, Senior-Engineer of Kobe Steel Co.,Ltd., who allowed to use the technical data for gear testing.

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