Influence of Workpiece Conditions on Residual Stress Induced by Shot Peening

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ABSTRACT

In recent years, higher energy shot peening treatment, which gives higher compressive residual stress has been strongly required to improve the fatigue strength of carburized gears. And the high hardness shot media has been developed for high-energy shot peening treatment. However, the influence of the hardness and microstructure of the carburized workpieces on the compressive residual stress induced by shot peening using high hardness shot media has not been studied enough.

In this study, we investigated the influence of the case hardness on the maximum compressive residual stress induced by shot peening. As a result, the maximum compressive residual stress increased proportionally with the case hardness even when high hardness shot media is used for the shot peening treatment. The workpieces that are given more than 2000MPa compression residual stress has extremely higher fatigue strength than that applying the conventional heavy peening treatment.

KEY WORDS

Carburized steel, Residual stress, Hardness, Retained austenite, Fatigue strength

1. INTRODUCTION

Shot peening has been applied widely and generally to improve fatigue strength of carburized gear for automobile transmissions. Higher energy shot peening treatment, which gives higher compressive residual stress, has recently been required as a technique for miniaturizing carburized gear in order to improve automobile mileage.

Generally, the value of compressive residual stress induced by shot peening treatment can be highly-influenced by the workpiece hardness. It is known that the value of compressive residual stress increases as the workpiece hardness is elevated, when shot media that are harder than the workpiece are used[1), 2)]. However, for the carburized steels, even if the workpiece hardness is the same, the value of compressive residual stress induced by shot peening may differ greatly on any other condition of microstructure. Because the retained austenite (γ_R) which is the control factor that decides the carburized case hardness is included[3), 4)].

On the other hand, it is known that increasing the hardness of shot media is effective in terms of giving high compression residual stress[5)]. Thus, shot media with a higher level of hardness than the carburized case of workpiece have been developed[6)]. However, the influence of the hardness and microstructure of the carburized case on the compressive residual stress induced by shot peening using high hardness media has not been studied enough.

In this study, we investigated the influence of the carburized case hardness on maximum compressive residual stress ($|-\sigma_{Rmax}|$) induced by shot peening with high hardness shot media and examined the workpiece conditions which are necessary to maximize compressive residual stress. Then, bending fatigue strength of the workpieces that is given more than 2000MPa compression residual stress was compared with that of conventional heavy peening treatment.

2. METHODS

2.1 Test materials

The materials under testing in this study are of following three grades. JIS Low-alloy case hardening steel SCM420H (J), High Si Steel (Steel A) and High Si – low Cr steel (Steel B). Steel A that has higher Si content is a material with higher anti-temper softening than SCM420H. Steel B is suppressed carbide precipitation if carbon concentration would be much higher. And its composition is able to increase the amount of γ_R after carburizing disposal[7). These materials were machined to cylindrical bars (φ25 mm x 100 mm) as shot peening test pieces.

The conditions of carburizing disposal applied to each steel grade are shown in Table 1 along with the properties of test pieces. In this study, we obtained various levels of hardness by arbitrarily changing the subsurface carbon concentration, the amount of γ_R and tempering temperature through adjustment of the carburizing conditions.

The carburized case hardness of the workpiece was measured by using Micro Vickers hardness testing machines (load 2.94 N). The carbon concentration and the amount of γ_R were determined by using Electron Probe Micro-Analyzer (EPMA) and X-Ray diffractometer, respectively.

SCM 420H (J) scored 718 HV Vickers hardness of carburized cases (average hardness from the surface to the depth of 50 μm), 0.76 mass % for subsurface carbon concentration and approximately 20-vol % for the amount of γ_R.

The carburizing conditions for steel A were adjusted so that both subsurface carbon content and the amount of γ_R could be equal to that of SCM420H (J). Also, the case hardness of steel A were changed by tempering at 453 K (A1) and 413 K (A2) (A1: 718HV, A2: 798HV).

The carburizing conditions for steel B were also adjusted in order to obtain carburizing concentration of 0.50 % (B1), 0.85 % (B2) and 1.00 % (B3). Consequently, the amount of γ_R were 16.9 (B1), 25.8 (B2) and 41.0 (B3) vol%, respectively. The case hardness of B3 was as low as 692 HV due to a large amount of γ_R.

In addition, sub-zero treatment (SZT) at 193 K×7.2 ks to A2 and B3 was applied prior to the tempering treatment in order to increases the case hardness (A2-S:877HV, B3-S:853HV) by decreasing the amount of γ_R in carburized case.

2.2 Shot peening condition

Table 2 shows the shot peening condition. The shot media used for shot peening treatment were high hardness shot media (950HV) that are harder than the carburized case of workpiece. The shot peening treatments were performed by using direct-pressured air-peening-machine. And the experimental trials were carried out on the condition shown in Fig. 1.

Table 1 Carburizing properties of workpiece.

Steel	No.	Hardness control factor		Heat treatment		Hardness [HV]
		C [mass%]	γ_R [vol%]	SZT	Tempering Temp.[K]	
SCM420H	J	0.76	19.6	—	453	718
Steel A	A1	0.78	21.3	—		718
	A2	0.80	21.6	—	413	798
	A2-S	0.78	8.6	○		877
Steel B	B1	0.51	16.9	—	453	624
	B2	0.85	25.8	—		760
	B3	1.03	41.0	—		692
	B3-S	1.03	15.3	○		853

Table 2 Shot condition.

Shot hardness	950 HV
Shot dia.	0.3 mm
Air pressure	0.5 MPa
Coverage	300%
Arc height	0.365 mmA

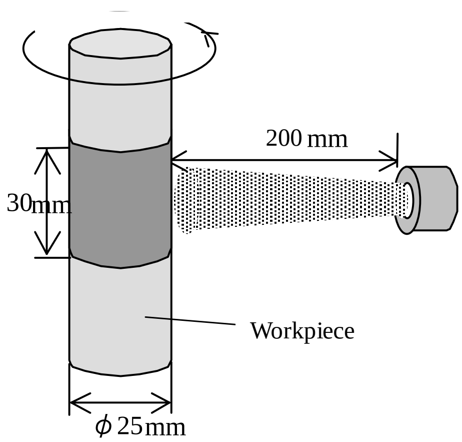


Fig.1. Testing method of shot peening.

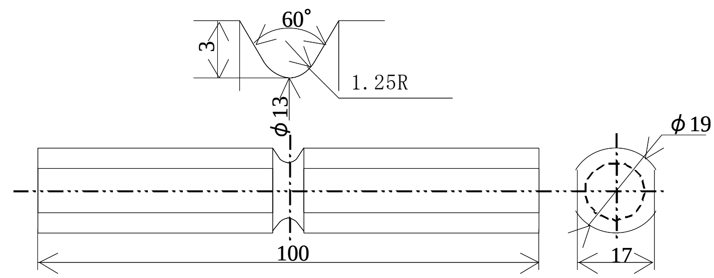


Fig.2. Shape of bending fatigue test piece.

Table 3 Bending fatigue test condition

Testing machine	Oil pressure servo exam. machine
Control method	Load control
Atmosphere	Room temperature
Determination of life	Rupture life

The residual stresses of the workpieces were measured by using X-ray diffraction method. Our discussion, in this study, focused on the maximum compressive residual stress ($|-\sigma_{Rmax}|$)[8] having the greatest effect on fatigue strength.

2.3 Fatigue Test

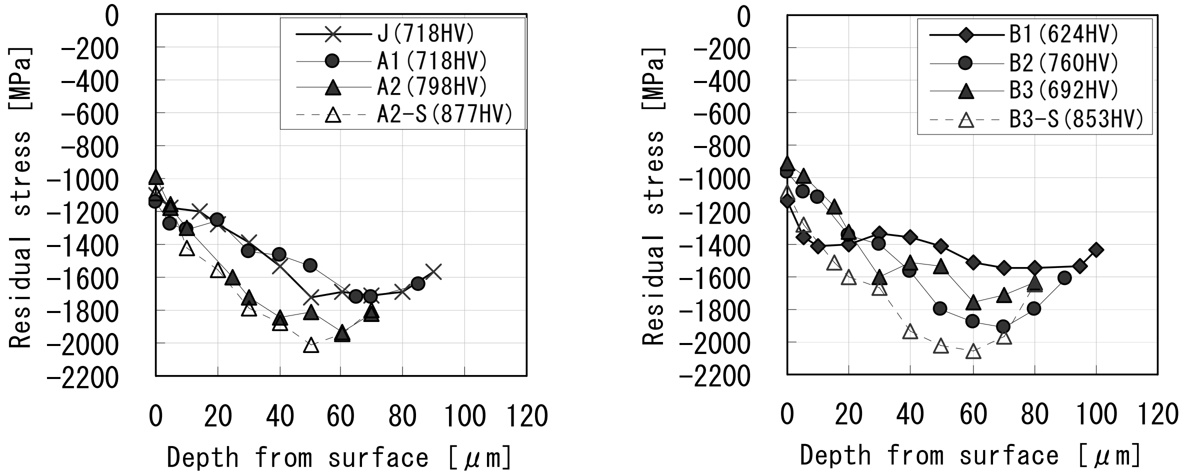
The fatigue strength was evaluated by the bending fatigue test on oil pressure servo machine with a stress ratio of 0.1. The bending stress at 10^5 cycles on S-N diagram had been chosen to represent the fatigue strength.

The bar-piece as shown in Fig.2 were prepared as test pieces of fatigue test with the notch shape for a stress concentration factor 2, assuming the tooth root of the gear. The conditions of the fatigue test are shown in Table 3.

3. RESULTS AND DISCUSSION

3.1 Residual stress distribution after shot peening.

The residual stress distribution after shot peening treatment is shown in Fig. 3. The carburized case hardness of each workpiece before shot peening treatment was also shown in Fig. 3. Both SCM420H (J) and steel A1 (Fig 3 (a)), that have almost the same case hardness (718HV), have approximately the same residual stress distribution. Steel A2 (798HV), that is lower tempered, has higher $|-\sigma_{Rmax}|$ and shallower peak position than steel J and A1. For steel B (Fig.3 (b)) as well as steel A, $|-\sigma_{Rmax}|$



(a) SCM420H and Steel A (b) Steel B

Fig.3 Residual stress distributions of workpiece after shot peening.

increased with the case hardness. This tendency matched that of other experiments[1), 2)] which used shot media harder than the workpiece.

This relationship between $|-\sigma_{Rmax}|$ after shot peening and the carburized case hardness of the workpiece was approximately the same, even in the case of increasing the case hardness by decreasing the amount of γ_R though sub-zero treatment.

3.2 The influence of the workpiece hardness on $|-\sigma_{Rmax}|$

The relationship between $|-\sigma_{Rmax}|$ and the carburized case hardness of workpieces is shown in Fig. 4. For shot peening treatment using high hardness shot media harder than conventional shot media, $|-\sigma_{Rmax}|$ increased with the case hardness. This result indicates that $|-\sigma_{Rmax}|$ of carburized steel is not greatly influenced by the amount of γ_R but is influenced by the case hardness. Also, the workpieces with case hardness of 800 HV scored extremely high values of 2000MPa. Thus, it is necessary to increase the workpiece hardness while keeping lower hardness than shot media in order to get high compressive residual stress. It was found that adjustment of subsurface carbon concentration (0.70~0.85 mass%), low-temperature tempering treatment and sub-zero treatment were effective techniques for increasing the workpiece hardness.

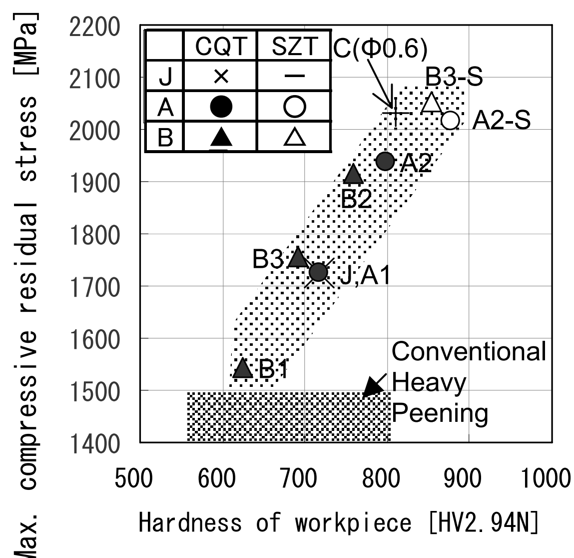


Fig.4 Relationship between the case hardness and $|-\sigma_{Rmax}|$.

In addition, as indicated in Fig.4 (symbol C), the effect of shot diameter on $|-\sigma_{Rmax}|$ is small. The fatigue tests were performed using shot media with φ0.6mm in diameter in this study.

Table 4 Refined surface characteristics of the bending test piece

SP condition	—	As carburized	Shot media① 950HV-φ0.6	Shot media② 700HV-φ0.6
Surface carbon concentration	mass%	0.75	—	—
Hardness	HV	811	916	934
Effective case depth	mm	0.74	0.64	0.69
Max. residual stress	MPa	-199	-2030	-1490
Surface roughness(Ra)	μm	—	1.44	1.16

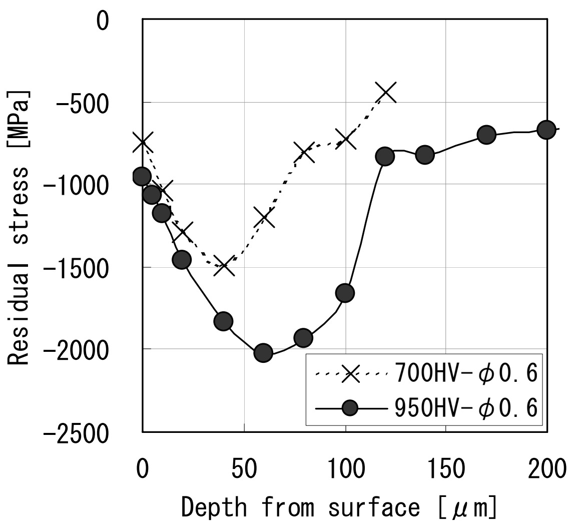


Fig.5 Residual stress distributions of the bending test piece

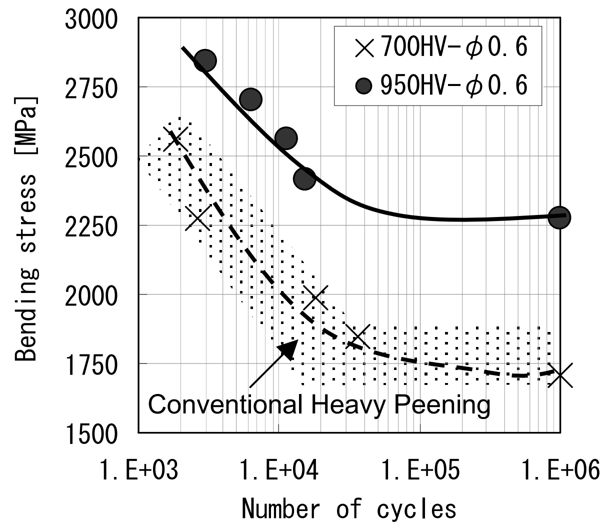


Fig.6 Bending fatigue properties

3.3 Bending fatigue strength

The bending fatigue tests were carried out to confirm fatigue strength of the material that has high compressive residual stress. The property of the workpiece before and after shot peening treatment is shown in Table 4 and the residual stress distribution is shown in Fig. 5. The results of a conventional heavy peening treatment (HSP) using approximately 700 HV generally applied to carburized gear were used as comparison material. Subsurface carbon concentration of the case is 0.75%C, and its hardness before shot peening showed levels as high as 811HV through low-temperature tempering treatment. For shot peened workpiece using high hardness shot media (950HV-φ0.6), hardness was almost equal and surface roughness (Ra) was larger than that of conventional HSP. However, as shown in Fig.5, compared to conventional HSP, residual stress distribution had an extremely high $|-\sigma_{Rmax}|$ at 2000MPa, and its peak position was deep. The result of the bending fatigue test is shown in Fig.6. The bending stress at 10^5 cycles of a workpiece that has 2000MPa indicated an approximately 30% higher than that of conventional HSP. Those results demonstrated that fatigue strength could be improved by giving high compressive residual stress of approximately 2000MPa.

4. CONCLUSION AND IMPLICATIONS

In this study, we investigated the influence of the carburized case hardness on the maximum compressive residual stress ($|-\sigma_{Rmax}|$) induced by shot peening with high hardness media. And we estimated the workpiece condition that can be gotten high compressive residual stress. The results are as follows.

1. $\left|-\sigma_{Rmax}\right|$ of carburized steel is not greatly influenced by the amount of retained austenite but is influenced by the carburized case hardness of workpiece. Increasing the workpiece hardness while keeping lower hardness than shot media is effective for getting high compressive residual stress.
2. The workpieces that are given more than 2000MPa compression residual stress has extremely higher fatigue strength than that applying conventional heavy peening treatment.

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