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EFFECT OF SHOT PEENING ON FATIGUE STRENGTH OF PHOSPHOR BRONZE C5191

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ABSTRACT

This paper deals with the effect of shot peening on the fatigue strength of phosphor bronze, which is widely used for springs of the electric appliances. Shot peening is performed for phosphor bronze with glass and steel shots by air blasting machine. The effects of residual stress, hardness and surface roughness are discussed, and the following results are obtained; (1) This bronze is the suitable material for shot peening owing to its characteristics such as the high work-hardenability. (2) The peening effect by steel shot is larger than by glass shot, and the more the shot size, the more the peening effect. (3) The influence of the surface roughness on the fatigue strength of this bronze is larger than the hardness and the residual stress. (4) The reduce of the cross sectional area of phosphor bronze is possible up to 40 % by shot peening in use as spring. (5) The maximum increasing ratio of fatigue strength is 131% compared with the unpeened bronze under peening conditions such as 0.3 mm steel shot, 0.2 MPa air pressure and 600 % area coverage.

KEY WORDS

Shot peening, phosphor bronze, fatigue strength, residual stress, hardness of work material, surface roughness, stainless steel, aluminum alloy.

1. INTRODUCTION

Since machine parts or components often break down under the low stress by cyclic load, they should be designed through considering not only their tensile strength but also their fatigue strength. Nevertheless, designers don't always understand correctly the influences of residual stress on the fatigue strength of the parts or components.

Shot peening is widely used for improving the fatigue strength of machine parts. These peening effects are produced by residual stress and work hardening. Many reports are published on steels as gears or springs, but there are few reports on the non-steel materials. Besides, the quantitative relationships between the fatigue strength and the peening conditions are not reported.

In order to clarify the peening effect on the fatigue strength of phosphor bronze, the influences of residual stress, hardness and surface roughness to the fatigue strength were discussed. The peening effect to the downsizing of the parts and the comparison of the characteristics of some work materials such as medium carbon steel, stainless steel and aluminum alloy were also discussed.

2. EXPERIMENTAL PROCEDURES

Table 1 shows shot peening conditions and Table 2 shows conditions on residual stress measurement. The materials and the size of specimen are shown in Fig.1. Although peening conditions that affect directly on the fatigue strength are shot size, peening time and shot velocity, the effects of the former two conditions were mainly discussed in this experiment.

The fatigue tests were run by the alternate bending fatigue machine at 25 HZ. The estimation of the fatigue strength was decided at 10^7 cycles, and the estimation of downsizing was decided at 10^6 cycles.

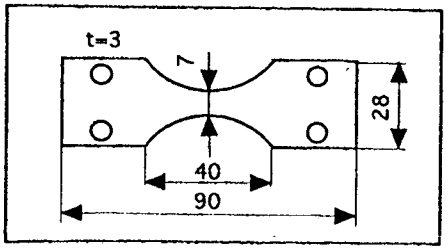
Surface roughness Ra were measured by profilometer. Hardness distributions were obtained from perpendicular section to the peened surface with micro Vickers hardness tester.

Table 1 Shot Peening

Equipment		Direct pressure type	
Air pressure (MPa)		0.2	
Shot	Material	Steel (900 HV)	Glass (550HV)
	Size (mm)	0.39	0.39, 0.27, 0.09
	Specific gravity	7.8	2.9
Area coverage (%)		0, 50, 100, 300, 600, 1000	
Distance from nozzle(mm)		300	
Diameter of Nozzle (mm)		5.0	

Table 2 Residual stress measurement

Work material	C5191	S45C	SUS304	A6063
Stress constant (MPa)	-491	-297	-639	-167
X-ray tube	Co-K α	Cr-K α	Cr-K α	Cr-K α
Diffraction plane	(222)	(211)	(220)	(311)
Dia. of projection area (mm)	0.3, 0.5, 1.0, 2.0			
ψ angle (deg.)	0, 21, 30, 38, 45			
Peak angle	$\sin^2\psi$ method (Half width)			



Phosphor bronze: C5191 (100HV)
Medium carbon steel: S45C (180HV)
Austenitic stainless steel: SUS304 (220HV)
Aluminum alloy: A6063 (45HV)

Fig. 1 Specimen

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Influence of shot size on the fatigue strength

The influences of shot size on the fatigue strength of phosphor bronze are shown in Fig.2. In the case of shot peening by air peening machine, the change of shot size causes not only the changes of the weight and the dent density, but also the change of shot velocity owing to the difference of its accelerating characteristics. The results, therefore, are affected by their factors. The fatigue strengths of all peened materials are remarkably increased compared with unpeened one and the maximum increasing ratio was 95 %.

Their residual stress distributions are all "S" type as shown in Fig.3, which the maximum residual stress values are induced at inside and are all compressive stress about -450 MPa. The depths of the compressive stress layer are increased by 70 % increasing four times shot size.

Besides, their hardness distributions are "Work-hardening" type as shown in Fig.4. The hardness beneath the peened surface by smaller shot are not increased compared with the hardness by larger size shot. The difference of the depth of work hardened layer was three times.

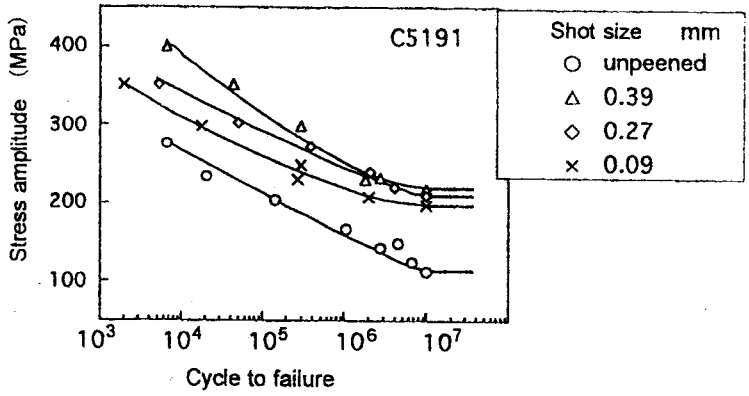


Fig. 2 Influence of shot size on fatigue strength of C5191 (Shot: glass, Peening time: Tf)

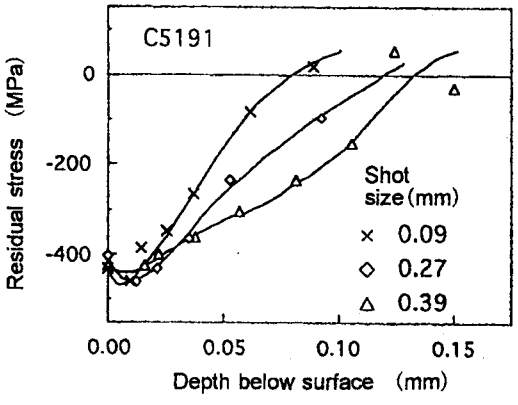


Fig. 3 Influence of shot size on residual stress distributions of C5191 (Shot: glass, Peening time: Tf)

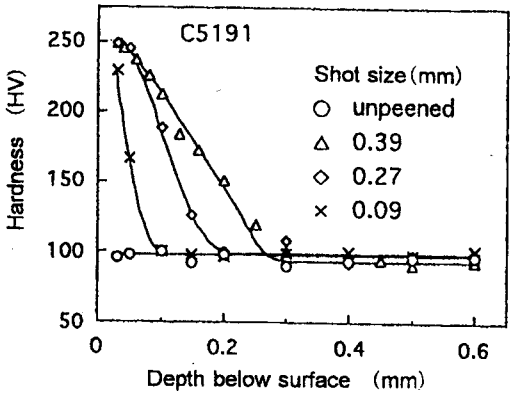


Fig. 4 Influence of shot size on hardness distributions of C5191 (Shot: glass, Peening time: Tf)

3.2 Effect of area coverage on the fatigue strength

Although peening time is full coverage in practice, shot peening was performed till 1000 % to clarify the effect of peening time on the fatigue strength of phosphor bronze. As shown in Fig.5, fatigue strength is remarkably increased till 300 % area coverage. From 300 % to 600 % coverage, the fatigue strength increases gradually, and at 1000 %, the over-peening phenomenon was not appeared.

On this phosphor bronze, therefore, when the maximum fatigue strength is required, shot peening should be performed till 600 % coverage. But, as the long time peening causes the energy loss and the drop of the working efficiency, shot peening at 200% coverage may be suitable.

3.3 Comparison between the fatigue strength of phosphor bronze and other materials

Figure 6 shows the results of the fatigue strengths on four materials that were shot peened under the same conditions as shown in Fig.1. The increase of the fatigue strength of phosphor bronze was increased 131 %. As this influence is remarkably larger than those of other three materials, phosphor bronze 5191 is the suitable material for shot peening.

Figure 7 shows residual stress distributions of the materials peened under the same condition as shown in Fig.6. Generally, the more hardness increases, the more residual stress increases after shot peening. But the compressive residual stress of this bronze induced by shot peening is similar to stainless steel whose hardness is about 2 times to this bronze.

The influence of shot peening on the surface hardness of this bronze is much as shown in Fig.8. The increasing ratio of hardness is about 180 %, and this value is larger than that of stainless steel having large strainhardening exponent.

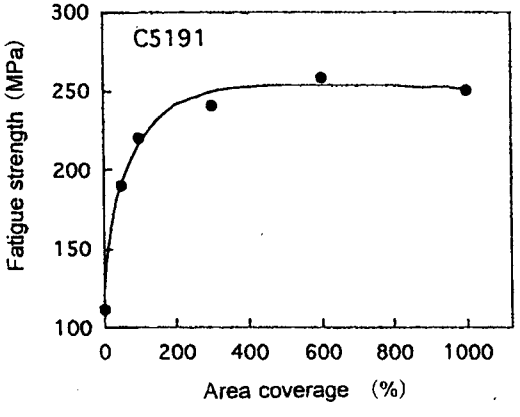


Fig. 5 Influence of area coverage on fatigue strength of C5191 (Shot: steel, size: 0.39mm)

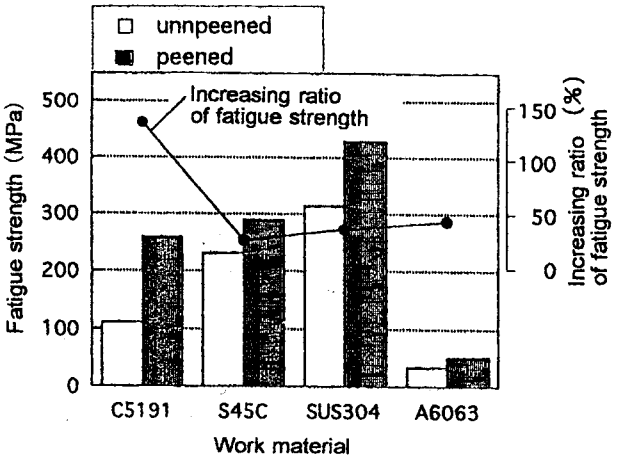


Fig. 6 Comparison of fatigue strength of four materials (Shot: steel, size: 0.39mm, Tf)

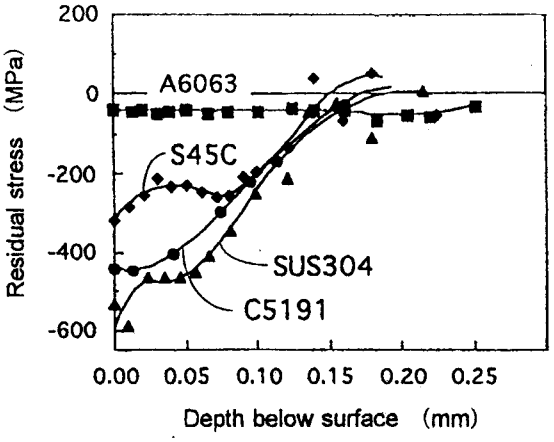


Fig. 7 Residual stress distributions of four materials (Shot: steel, size: 0.39mm, Tf)

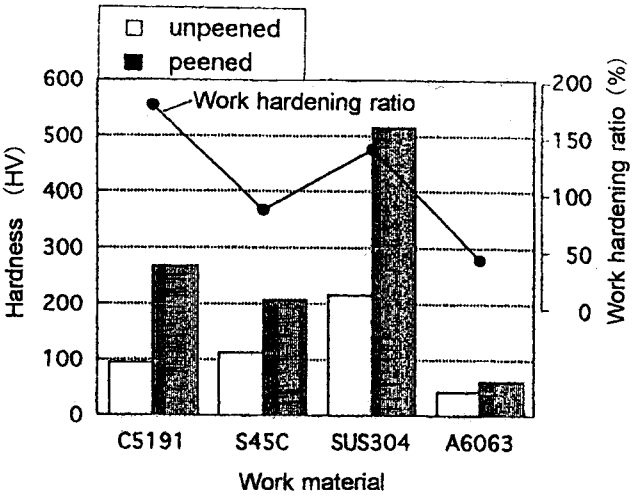


Fig. 8 Work-hardening of four materials (Shot: steel, size: 0.39mm, Tf)

Therefore, Phosphor bronze C5191 is very suitable for shot peening, because the large peening effect is obtained from high work hardenability.

3.4 Effect of residual stress, hardness and surface roughness on the fatigue strength

Fatigue strength is increased by residual stress and hardness and decreased by surface roughness [1), 2)], but those factors are produced at the same time and then affect at the same time. To discuss each factor independently, the following formula is obtained from the analysis using simultaneous linear equation.

$$\sigma_s = K \cdot \sigma_{RI}^{0.27} \cdot H_I^{0.28} \cdot R_a^{-0.33}$$

Where, σ_s : Fatigue strength
K : Constant
σ_{RI} : Integrated value of compressive stress beneath the peened surface
H_I : Integrated value of work hardened layer beneath the peened surface
R_a : Surface roughness

Judging from the exponential value, the influence of surface roughness is larger than other factors. This results may come from low hardness of phosphor bronze.

3.5 Effect of shot peening on the downsizing

In order to discuss the possibility for the downsizing, shot peening was performed for the specimens with the different width of the notched part under the same conditions. Figure 9 shows the results on the bending moment calculated from the fatigue strength at 10^6 cycles to compare them under the same load. The width of the peened specimen that shows the same strength as the unpeened specimen is 4.2 mm, and this means that the reduce of the cross sectional area of phosphor bronze is possible up to 40 % by shot peening.

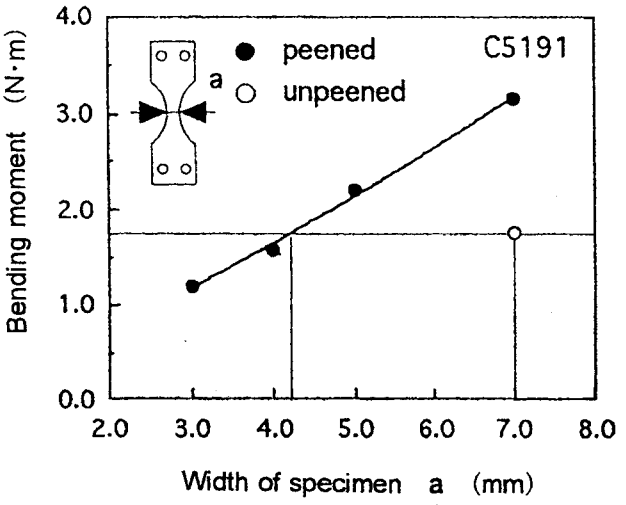


Fig. 9 Relation between width of specimen and bending moment (Shot: steel, size: 0.39mm, Tf)

4. CONCLUSIONS

In order to clarify the peening effect on the fatigue strength of phosphor bronze, the influences of residual stress, hardness and surface roughness to the fatigue strength are discussed, and the following results are obtained.

(1) This bronze is the suitable material for shot peening owing to its characteristics such as high work hardenability.

(2) The peening effect by steel shot is larger than by glass shot, and the more the shot size, the more the peening effect.

(3) The influence of the surface roughness is larger than that of work-hardenability and residual stress.

(4) The reduce of the cross sectional area of phosphor bronze is possible up to 40 % by shot peening.

(5) The maximum increasing ratio of peening effect for the fatigue strength is up to 131% compared with the unpeened material under the following peening conditions; steel shot (D: 0.3 mm), air pressure (P: 0.2 MPa), area coverage (T: 600%).

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