Fatigue Strength of Work Softening Layer Produced by Shot Peening

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Introduction

Shot peening is a sort of cold working, so peened surface of metal has been generally work-hardened. But prestrained metal surface shows work-nonhardening or work-softening after shot peening. This phenomenon generally happens under combined cold deformation [1,2] and the cace of shot peening was already reported in the proceedings of 2nd ICSP for compressive prestrained steel [3].
In this report, we described the result of fatigue test for work-nonhardened and work-softened steel specimen which was prestrained by rolling under various reduction ratio befor shot peening.

Experiment

Various experimental conditions are shown in Table 1. Hardness distribution in affected layer produced by prestrain (rolling) or shot peening was measured by micro hardness instrument on the perpendicular to rolled or peened surface along three lines.
Surface residual stress was measured by the method : 2θ-$\sin^2\psi$. Harf width of (211) on diffraction pattern was calculated from the value of ψ = 0°, 30°, 45°, 60°.

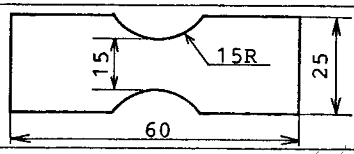
peening equipment	centrifugal type	
shot	cast steel (HV 800)	
	diameter D (mm)	2.2
peening condition	velocity V (m/s)	20
	peening time:coverage	100%
material	material: C:45 % C steel	
		
	thickness t (mm)	4
pre-strain	rolling reduction (%)	10,20
fatigue test	alternate bending $\pm\sigma$ (cpm)	2000
surface residual stress measurement	X-ray diffraction to (211) $\sin^2\psi$ method	

Table 1 Experimental conditions

Experimental result

Nomenclature and combined working condition are shown in Table 2. Prestrain used in the experiments is rolling, so the behaviors of rolled specimen for various reduction ratio and for shot peening after rolling were shown in Fig.1 about surface residual stress, surface hardness and harf width. The surface residual stress decreases as rolling reduction increases for only rolling, but it is constant value for shot peening after rolling (Fig.1 (a)).

nomenclature	specimen
O	annealed
P1	shot peening D:2.2 mm,V:20 m/s,Fc*
R1	rolling : reduction 10 %
R1P1	shot peening after R1 rolling
R1P1G	polished after R1P1
R1P1E	0.3 mm chemically etched after R1P1
R2	rolling : reduction 20 %
R2P1	shot peening after R2 rolling
R2P1G	polished after R2P1
R2P1E	0.3 mm chemically etched after R2P1

*Fc : full coverage time

Table 2 Nomenclature and combined working condition.

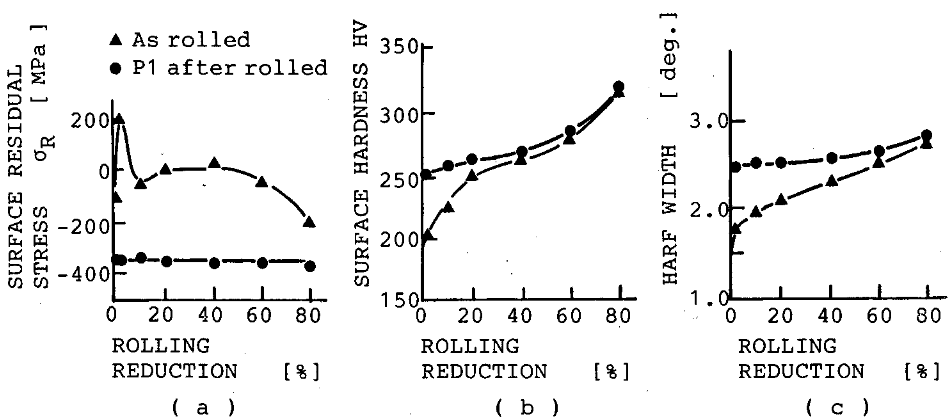


Fig. 1: Surface residual stress, surface hardness and harf width vs rolling reduction.

Surface hardness and harf width versus various rolling reduction were similler in shape to both only rolled and shot peened after rolling, and the difference in both curves decreases as reduction ratio increases (Fig. 1 (b),(c)).

Hardness distributions of shot peened specimen after annealed, small rolled and hard rolled respectively were shown in Fig.2. The patterns are much different each other, then we separated into three types; (I) work-hardening, (II) work-nonhardening, (III) work-softening.

Annealed or small prestrained specimen befor shot peening shows "work-hardening" type (I), and medium prestrained specimen such as cold rolling or compressive prestrain shows "work-nonhardening" type (II) and this type consists of thin work hardened layer and non-hardened layer. Much prestrained specimen shows "work-softening" type (III) and this type also consists of two layer such as thin work hardened layer and softened layer, but the hardening ratio in the thin layer is small compared with matrix. The more intensity of shot peening the more softening layer.

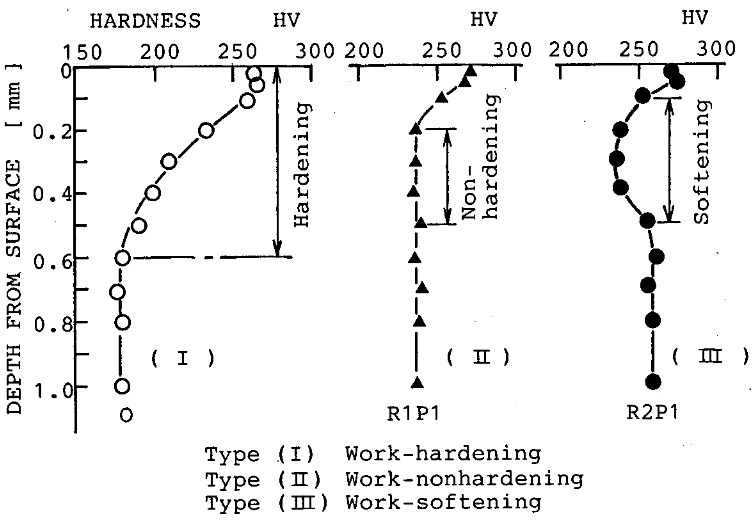


Fig. 2: Types of hardness distribution.

In the fatigue test, the specimens of these three types and surface soft types which were made by chemical etching were used. Etched specimen were made from type (II) and (III). Removing the surface layer, the maximum softening layer appears on the surface as shown in Fig.3.

Because of the remove of surface roughness produced by shot peening, specimens R1P1 and R2P1 were polished removing 30~40 µm by abrasive paper in which abrasive size is 10~15 µm. The surface residual stress of them were slightly decreased within 10 MPa. And then, their symbols change to R1P1G and R2P1G.

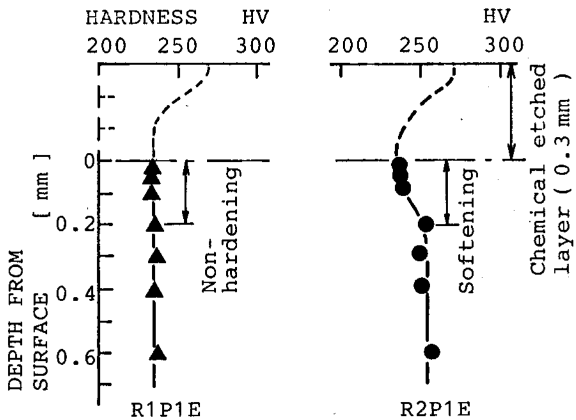


Fig. 3: Nonhardened and softened layer at surface.

From the fatigue test, we obtained many S-N curves as shown in Fig.4 and Fig.5. The result of work-nonhardening type (II) of medium prestrain involved rolling reduction 10 % before shot peening was shown in Fig.4. There is a slight difference of fatigue strength between R1 and O, but R1P1 and R1P1G are exceedingly different from them. R1P1 is as peening after rolling, and R1P1G is removed surface roughness by polishing from R1P1. The difference between both specimens is only surface roughness, and their surface residual stress are about same. From the results, therefore, it is clear that specimen of work-nonhardening type (II) has fully increased strength.

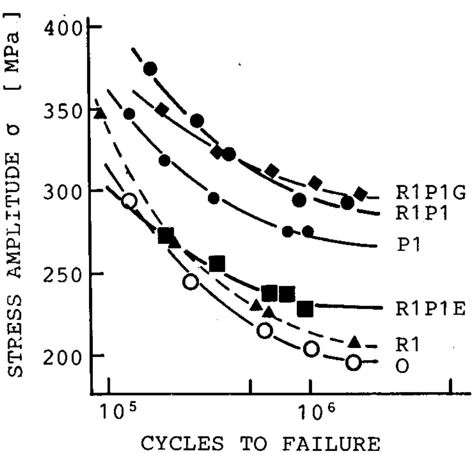


Fig. 4: S-N curves for work-nonhardening type (II). (prestrain: 10 %)

The strength of R1P1E is decreased compared with other R1P1 group, but better than R1 or O. The strength of R2P1E is also decreased compared with R2P1 group as shown in Fig.5, but the increased ratio to annealed specimen (O) is more than that of R1P1E.
The results of shot peened specimen prestrained 20 % produced by rolling reduction were shown in Fig.5. Although this type has work softening layer, the increased fatigue strengthes are similler to Fig.4, but quantitatively better than that. Then it is clear that specimen of work-softening type (III) also has fully increased strength.

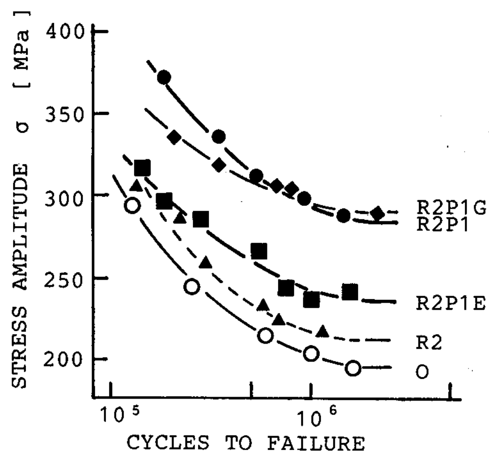


Fig. 5: S-N curves for work-softening type (III). (prestrain: 20 %)

From the other view point, we have examined two characteristics of fatigue strength for peened specimen. At the first, the features of R2 group specimens are shown in Fig.6. Within the range of alternate number $N = 10^5 \sim 10^6$, it is evident that the relations on log-log diagram between strength and number are straight line, therefore the formula is

$$\sigma = k \cdot N^m \qquad \text{Equ. 1}$$

where m is the slope of line and k is constant.

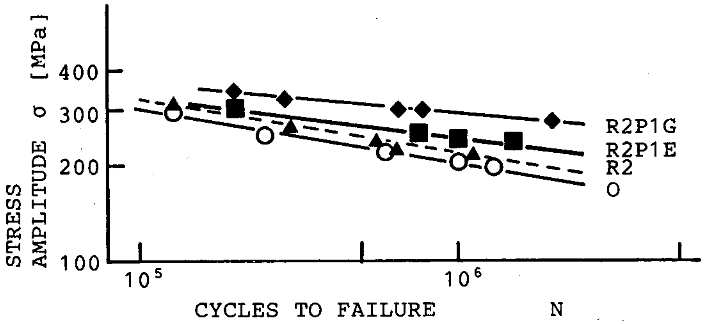


Fig. 6: S-N curves (log-log) for R2 specimens.

And then, we protted the values m against the surface residual stress and hardness of peened surface as shown in Fig.7. From the relations between m and surface residual stress as shown in Fig.7 (a), it is seen that the high residual stress group has smaller m than the low group. And then the slope on S-N diagram decreases with surface residual stress increase. Therefore, the high surface residual stress tends to have long alternating time in the same stress amplitude.
As shown in Fig.7 (b), the difference is clear for peened and non-peened group, but m is constant in the same group.

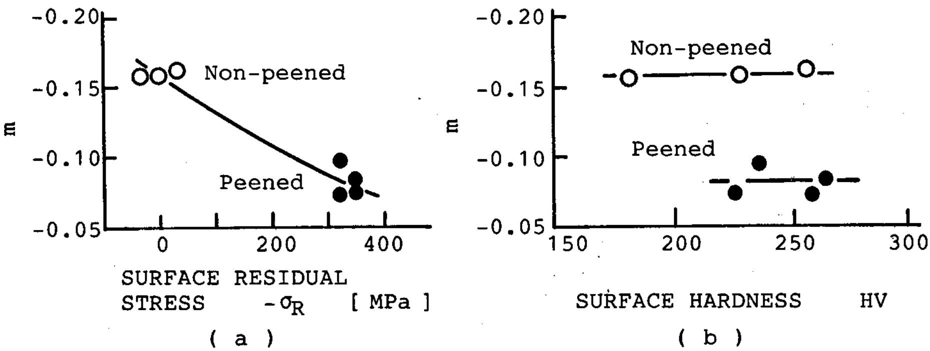


Fig. 7: Surface residual stress and surface hardness vs m.

Then we compared fatigue strength (σ) of various specimen with annealed one (σ_O) at $N = 10^6$, and plotted the increased strength ($\sigma - \sigma_O$) against surface residual stress and surface hardness as shown in Fig.8. It is evident, consequently, that the increased strength is affected by surface residual stress so much but not so affected by surface hardness. Therefore the high surface residual stress is effective for increasing of fatigue strength.

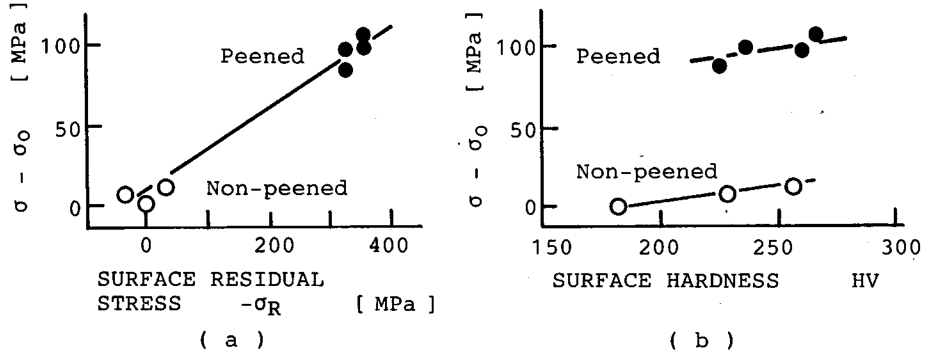


Fig. 8: Surface residual stress and aurface hardness vs increase of fatigue strength at 10^6 cycles.

Conclusion

We may summarize the conclusions as follows.

1) Hardness distribution in affected layer produced by shot peening involves such three types as (I) work-hardening type, (II) work-nonhardening type and (III) work-softening type.
2) The fatigue strength of the specimen which has the distribution of work-nonhardening or work-softening produced by shot peening is not weakened.
3) In the affected layer produced by shot peening, the ratio of the minimum hardness value to matrix was 8.0 % in this experiment.
4) The ratios of fatigue strength of shot peened specimens (σ) compared with annealed (σ_0) and prestrained (σ_S) at 10^6 cycles were shown in Table 3, and the maximum was 52.4 % in the case of σ/σ_0.

type		specimen	σ/σ_0(%)	σ/σ_S(%)
(I)	work-hardening	P1	34.6	—
(II)	work-nonhardening	R1P1	45.2	39.2
		R1P1G	49.0	42.9
		R1P1E	12.0	7.4
(III)	work-softening	R2P1	48.1	39.4
		R2P1G	52.4	43.4
		R2P1E	20.2	13.1

σ_0 , σ_S: strength of annealed and prestrained specimen

Table 3: The ratio of fatigue strength increase at 10^6 cycles.

References

(1) K. Iida, I. Aoki: " Study of Work Softening (1st Rep.)", J. of JSPE. 39-4 (1973) 441.
(2) K. Iida, K. Tosha: " On the Basic Properties of Shot Peening ". J. of JSPE. 41-8 (1975) 796.
(3) K. Iida: " Dent and Affected Layer Produced by Shot Peening ". Proc. 2nd ICSP (1984) 283.