Work-Softening Induced by Shot Peening for Austenitic Stainless Steel

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ABSTRACT

This paper describes on the relation between the residual stress and the work-softening induced by shot peening for austenitic stainless steel. Shot peening are performed by steel shot and a centrifugal peening machine. Measuring items are surface roughness, hardness distribution, half width, residual stress and its distribution by X-ray diffraction. Results are as follows: (1)Diffraction angle and magnetic characteristic are changed by compressive deformation and shot peening. (2)Hardness distributions change from work-hardening to work-softening by shot peening as similar to other metals. (3)Half width in the work-softened zone decreases and then this suggests the recover of the crystal structure from prestrained state by shot peening. (4)Surface residual stresses induced by shot peening are not related with prestrain and work-softening. (5)The maximum work-softening ratio was 7.1 % in this experiment.

KEYWORDS

Shot peening, austenitic stainless steel, hardness distribution, work-hardening, work-softening, half width, residual stress, residual stress distribution.

1. INTRODUCTION

Austenitic stainless steel is used not only in mechanical industry but also in many fields such as atomic energy, medical equipment and chemical or foods industries. Although shot peening is an effective working process for these fields(1)(2)(3), the effects of shot peening on austenitic stainless steel are not fully clarified yet.

Work-softening phenomenon generally happens under combined heavy cold deformation for FCC or BCC metals such as steels, copper, aluminum and brass, and is completely different from Bauchinger effect. This phenomenon appears on the prestrained metals by shot peening as already reported (4)(5), but is not reported yet for materials which show the transformation by cold deformation.

This paper describes on the work-softening and other related factors produced by shot peening for austenitic stainless steel.

Shot peening are performed by steel shot and a centrifugal peening machine. Measuring items are surface roughness, hardness distribution, half width, residual stress and its distribution.

2. EXPERIMENTAL CONDITIONS AND PROCEDURES

Experimental conditions about shot peening, prestrain, specimen and residual stress measurement are shown in Table 1.

Table 1. Experimental conditions

Peening	Equipment	Centrifugal type	
	Shot	Material: steel	
		P1	D: 0.92 mm, 700 HV
		P2	D: 2.2 mm, 450 HV
		P3	D: 2.2 mm, 880 HV
	Velocity V	35 m/s	
	Peening time	T_f: full coverage time	
	Impact angle	Normal to the peening surface	
Prestrain	Compression ε	10, 20, 35 %	
Specimen	Material	SUS304: annealed, 210 HV	
	Size	ϕ18×18 mm	
Residual stress measurement	X-ray diffraction, (220) plane, $\sin^2\psi$ method, Iso-inclination method		

Residual stresses are calculated from the following equation.

$$\sigma_R = -\frac{E}{2(1+\nu)} \cot\theta_0 \frac{\partial 2\theta}{\partial \sin^2\psi} \qquad (1)$$

Where E = 192 GPa and ν = 0.28.

In order to produce the work-softening by shot peening, compression was performed as the primary deformation. Johnson wax # 111 was used as the lubricant between a specimen and anvils. This lubricant was dried for 12 hours, and then the specimen was compressed very slowly to avoid the thermal effect.

3. EXPERIMENTAL RESULTS

3.1 Influence of the primary deformation

As mentioned above, after the primary deformation, the work-softening is induced by the secondary deformation. Therefore, after primary deformation, the items such as hardness and surface residual stress were measured.

Specimens are deformed uniformly as shown in Fig. 1, and the maximum value of the barrel ratio R_b is 2.6 % where the compressive strain is 35 %.

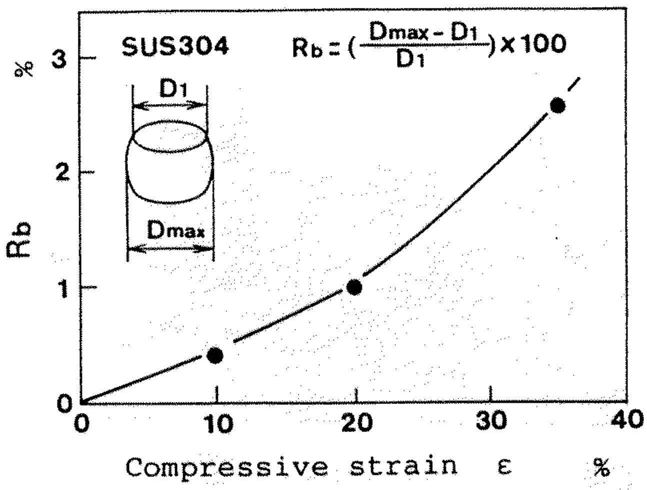

Fig. 1. Compressive strain vs R_b.

The influence of the compressive strain on the hardness of the specimen is shown in Fig. 2. The work-hardening ratio of the austenitic stainless steel increases about 100 % under 35 % compressive strain, and increasing ratio is much larger than medium carbon steel.

The influence of the compressive strain on the surface residual stress is shown in Fig. 3 where the residual stress approaches a saturated value.

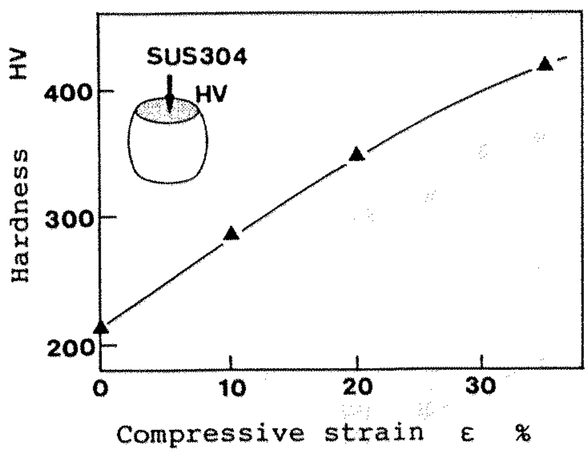

Fig. 2. Influence of compressive strain on hardness.

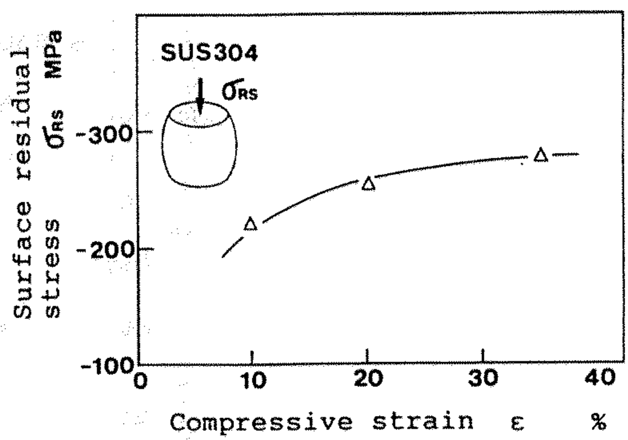

Fig. 3. Influence of compressive strain on surface residual stress.

The magnetic transformation of the austenitic stainless steel by the compressive strain or shot peening has already been confirmed qualitatively, but the structural transformation under the microscopic observation doesn't appear as shown in Fig. 4.

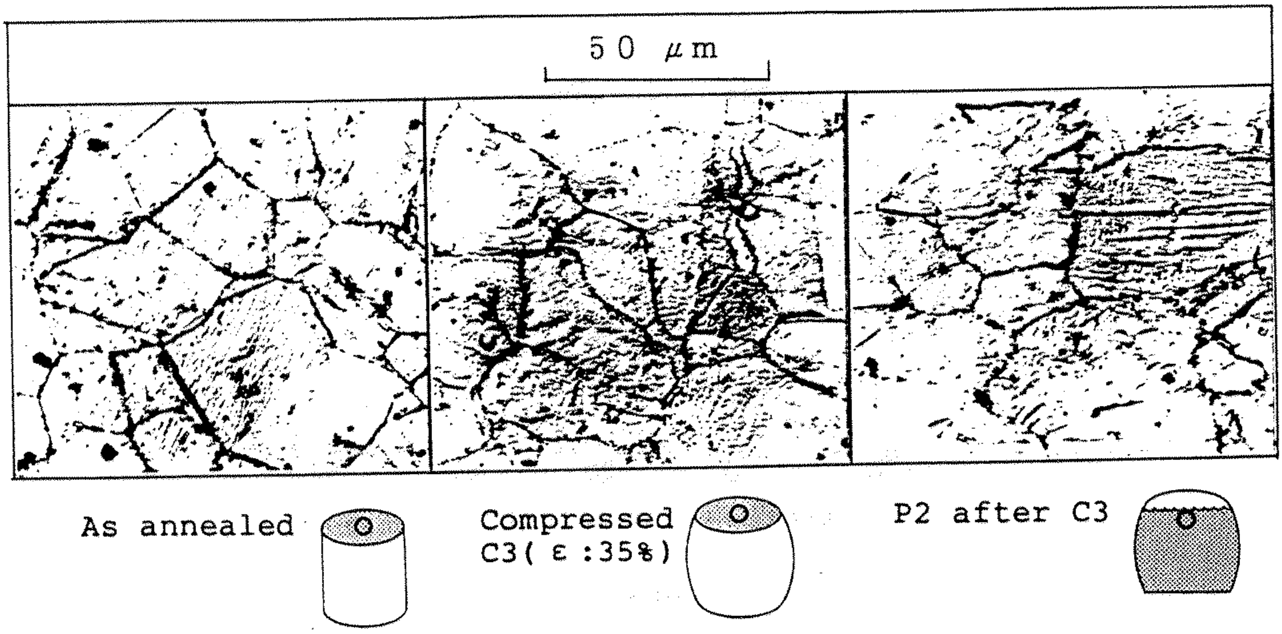

Fig. 4. Microstructure of austenitic stainless steel. (Etched by aqua regia)

3.2 Influence of shot peening as the secondary deformation

(a)Surface roughness

Figure 5 shows influences of shot peening on the surface roughness of the annealed and the strain hardened specimen compressed 10 %, 20 % and 35 % . The more the hardness, the less the surface roughness. Where the hardness of shot is much harder than the work, the surface roughness is inversely proportional to the square root of the hardness of the specimen (P1, P3). Where

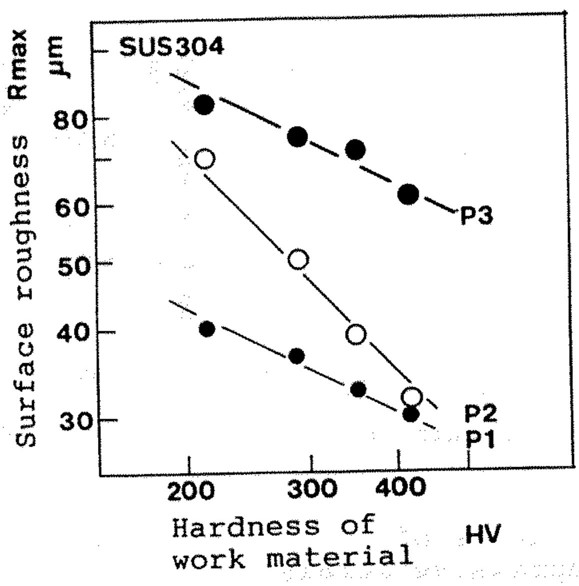

Fig. 5. Influence of work hardness on surface roughness.

the hardness of shot is similar to the work, the surface roughness is inversely proportional to the hardness of the work (P1).

(b)Hardness distribution

Figure 6 shows the hardness distributions produced by shot peening for various prestrained specimens under P1 (hard and small shot), P2 (soft shot) and P3 (hard shot) respectively. The type of the hardness distribution changes from work-hardening to work-softening with the increase of the prestrain, and the prestrained 20 % and 35 % shows work-softening. The influence of the shot hardness on the hardness distribution is little but the shot size is closely concerned with the depth of affected layer. The maximum ratio of work-softening was 7.1 % at 35 % prestrain and the depth below surface δ_s was about 0.3 mm, where the maximum work-softening happened.

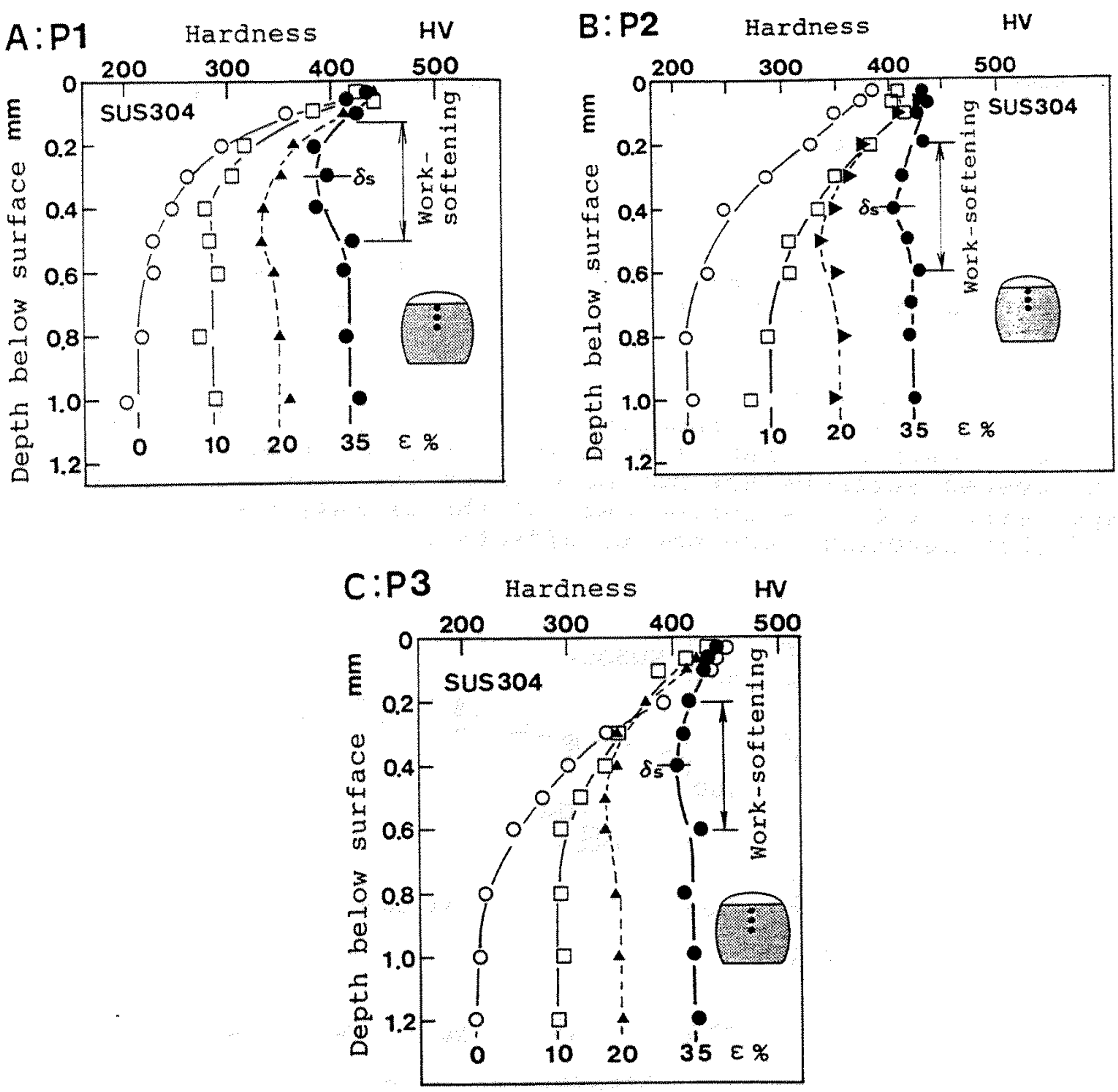

Fig. 6. Influence of prestrain on hardness distribution.

(c) Half width distribution
The half width distributions under P1 and P3 are shown in Figs. 7 and 8. Those distributions are similar to the hardness distributions, and the value of half width at the work-softened zone (δ_s neighbor) is lower than the other. Therefore, it suggests that the strain produced by the primary deformation are recovered by shot peening.

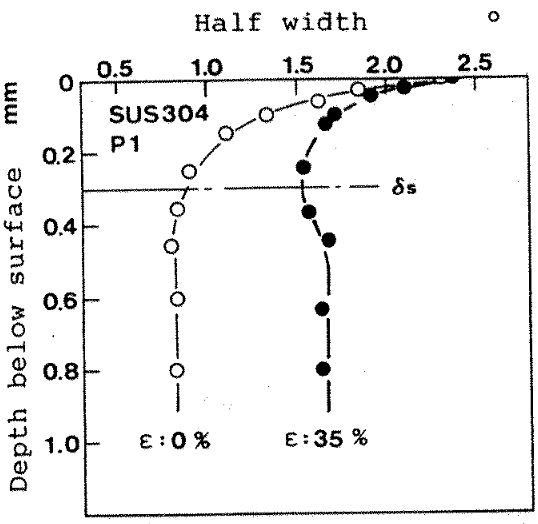

Fig.7. Influence of prestrain on half width. (P1)

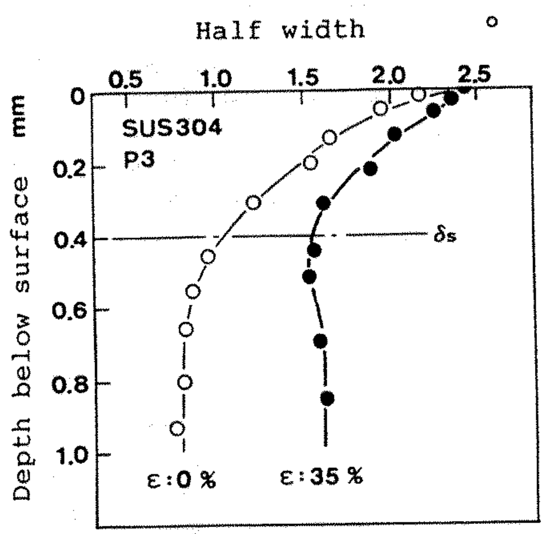

Fig. 8. Influence of prestrain on half width. (P3)

(d) Residual stress
Shot peening was performed under P2 and P3, and the results on surface residual stress are shown in Fig. 9. Residual stresses on the peened surfaces are not so changed for the all prestrained specimens and the influences of the primary compressive strain and shot hardness are not so affected.

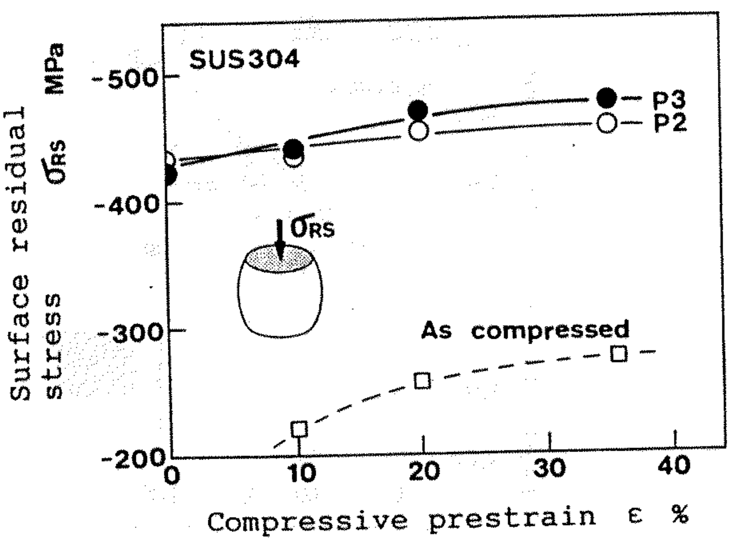

Fig. 9. Residual stress on the peened surfaces.

The difference of the prestrain on the residual stress distribution is larger in the core than in the surface layer. The compressive residual stress in the surface layer of the non-prestrained specimen turn into tensile stress at the depth about 0.7 mm for P3 and P2 and 0.5 mm for P1, but residual stress distributions of the prestrained are still compressive. The type of residual stress distribution is "S type" on P2 and P3, and is "C type" on P1 as shown in Figs. 10 and 11.

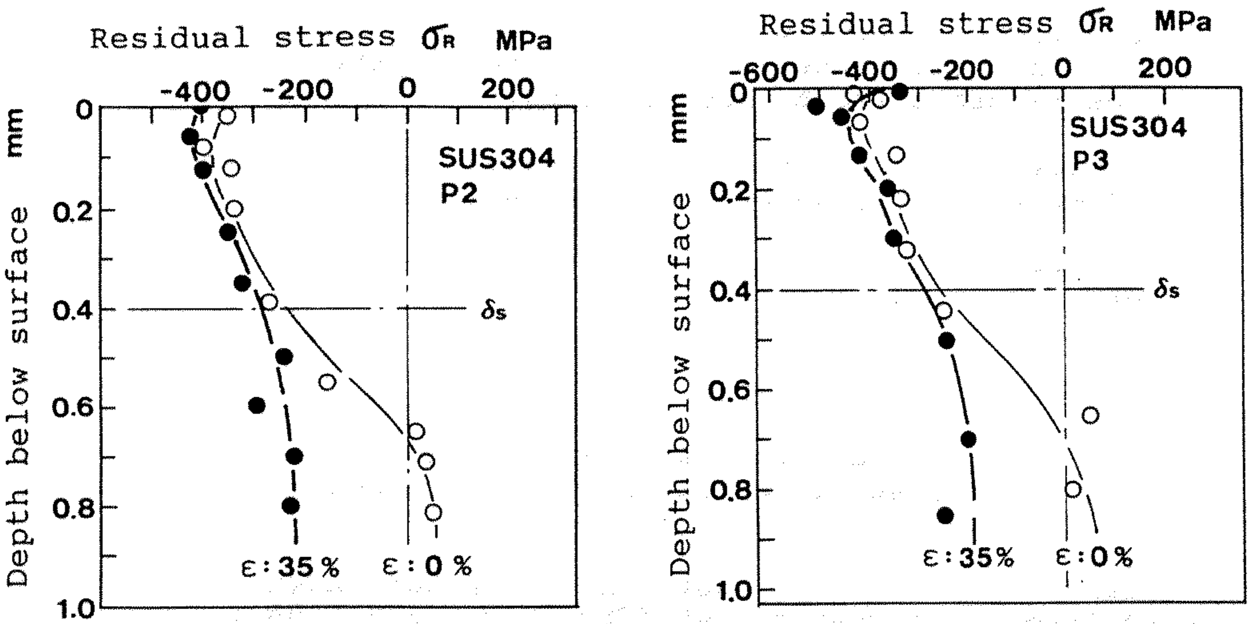

Fig. 10. Residual stress distributions.
(S types, P2 and P3)

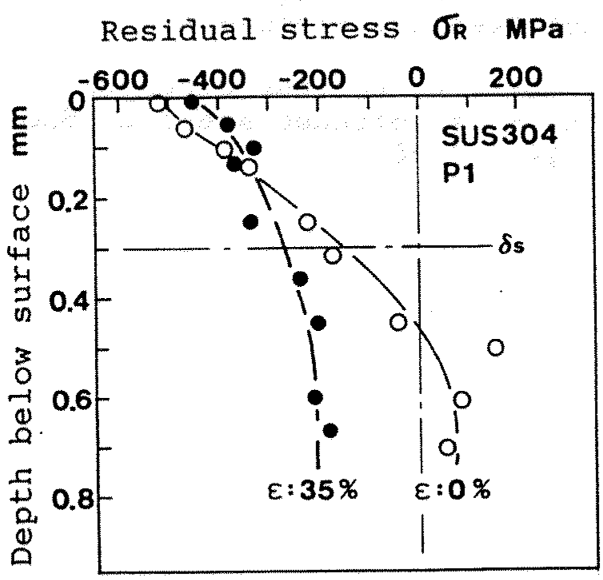

Fig. 11. Residual stress distributions.
(C type, P1)

4. CONCLUSIONS

The following conclusions have been drawn from this investigation:

(1) Martensitic transformation of austenitic stainless steel has not occurred by compression and the following shot peening but magnetic transformation has occurred by them.

(2) Hardness distributions are changed from work-hardening to work-softening by shot peening as similar to other metals.

(3) Half width in the work-softened zone is decreased and then this suggests the recover on the crystal structure from prestrained state by shot peening.

(4) Surface residual stresses induced by shot peening are not concerned with prestrain or work-softening.

(5) The maximum work-softening ratio was 7.1 % in this experiment.

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