RESIDUAL STRESS AND HARDNESS DISTRIBUTIONS INDUCED BY SHOT PEENING

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ABSTRACT

Hardness number is a resistance stress for micro-plastic deformation. It may be affected by the residual stress or distributed stress. This paper describes the relation between the hardness and the stress in the affected layer produced by shot peening. The material of the specimen is carbon steel (0.45%C) and the elastic stress field was induced by bending and tension of the specimen, and residual stress was induced by shot peening. The hardness was measured by micro-vickers hardness tester and the stress was measured by X-ray diffraction. Shot peening was performed under the following conditions; diameter of shot D mm: 2.2, velocity of shot V m/s: 35, Peening time : full coverage time. The results are as follows; (1) Hardness increases in compressive stress and decrease in tensile stress. (2)The maximum change in hardness number is -20 (HV) and the ratio of decrease is -9.8 %, wherein tensile stress increment is 460 MPa. (3)The influence on the hardness of the residual compressive stress induced by shot peening is the same to the elastic compressive stress of bending. (4)The residual stress distribution and hardness distribution produced by shot peening are changed by the thickness of specimen under the same shot peening condition.

KEYWORD

Shot peening, stress field hardness, hardness distribution, residual stress, size effect, affected layer.

INTRODUCTION

In shot peening process, the factors of peening effect on fatigue, wear and corrosion for metals are residual stress, hardness, surface roughness and etc.[1],[2],[3]. Hardness number is a resistance stress for micro-plastic deformation[4]. The hardness is deeply related with the stress distribution as residual stress. Therefore, hardness in the affected zone produced by shot peening must be also influenced by the residual stress.

In order to clarify the relation between the hardness and the residual stress, shot peening was performed for a carbon steel (0.45 %C). Hardness was measured on the stress fields; compressive or tensile, by bending or tension. At the first, the influences of elastic stress on the hardness and then the influence of the residual stresses induced by shot peening on the hardness distribution are examined.

EXPERIMENTAL CONDITIONS AND PROCEDURE

Experimental conditions: shot peening, strain of specimen, chemical etching and residual stress measurements are shown in Table 1.

Table 1 Experimental conditions

Blasting machine	Centrifugal type		
Shot peening	Shot size D:2.2 mm, Shot velocity V:35 m/s, Blasting time T:Tf (full coverage time)		
Strain	Bending	Tensile Compressive	0 - 5 %
	Tension	Tensile	
Specimen	Material	Annealed carbon steel 0.45 %C (HV 180)	
	Dimension	Bending 78 × 20 × 3 mm Tension 40 × 12 × 3 mm Peening 25 × 25 × 6 mm	
Chemical etching	HNO_3 30% solution		
Residual stress measurement	X-ray diffraction (211) plane 2θ-$\sin^2\psi$ method, ψ: 0, 30, 45, 60 deg		

Stress fields was produced as shown in Fig.1(a),(b),(c). Strain in the stress field were measured at on load and at off load with strain gauge, and hardness and stress were measured with vickers hardness tester and X-ray diffractmeter respectively. Strain gauge was used on the peened or the opposite surfaces after shot peening, and specimen was etched from the opposite surface or the peened surface owing to measure hardness and residual stress. Vickers hardness distribution was obtained on the perpendicular section of peened surface from average at the same depth data on the three positions.

Surface residual stress was calculated from the following formula:

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

where E: 206 GPa, ν : 0.28, θ_0 : standard Bragg's angle, 2θ : diffract angle, ψ : incident angle of X-ray.

EXPERIMENTAL RESULTS AND DISCUSSION

Hardness in Stress Fields

Tensile Stress and Hardness in Bending Test. Tensile stress induce on the outer surface in bending as shown Fig.1(a). The relation between the tensile strain and the stress is shown in Fig.2(a). At on load, tensile stress increases rapidly in small strain of bending and approaches a saturated value 200 MPa after 0.1 % tensile strain. The stress after off load become compressive residual stress and also approaches a saturated value. The difference of off load stress and on load is 150 MPa in elastic deformation and from 150 to 460 MPa in plastic deformation. The behaviour of on load hardness shows 3 different stage as shown in Fig.2(b). Namely, the first is rapidly decrease, the second is saturation and the third is the increase with increase of tensile strain.

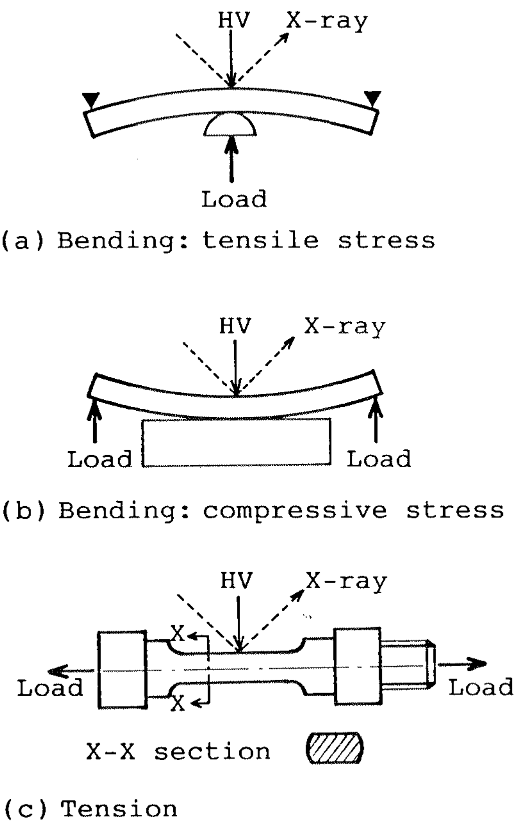

Fig.1 Various Loading and measurement.

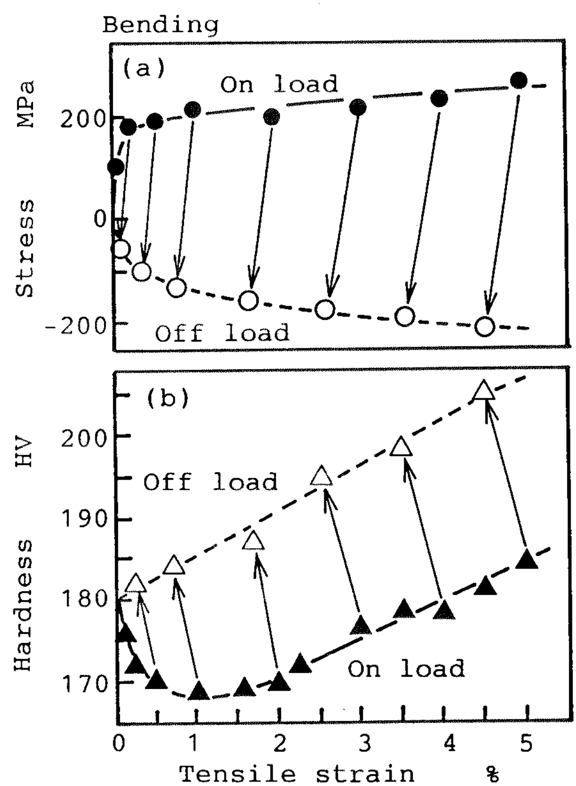

Fig.2 Influence of tensile strain on hardness and stress

In the first stage, in which the tensile strain is under 0.2 % or under yield point, off load hardness become the same value before bending. In the second stage, the tensile strain is from 0.2 to 1.0 %. When the load is released, off load hardness shows work-hardening in proportion to the residual strain. In the third stage, the tensile strain is over 1 %. In this stage, as the value of hardness increment with work-hardening is larger than that of hardness decrement with elastic tensile stress, the on load hardness begin to increase after 1 % tensile strain. After all, when tensile strain is about 1 % , the hardness number is the lowest in this tension test and the maximum softening ratio is 7 %. When the tensile strain is 4 %, the hardness number is offsetted by the influences of the tensile strain and work-hardening. The work-hardening after off load is proportion to the residual strain. The difference between off load hardness and on load is under 5 HV within the elastic limit, and 20 HV over the elastic limit.

The relation between tensile stress and hardness is shown in Fig.3. Fig.3 shows that the decrement of hardness by tensile stress is linear in low stress from 0 to 150 MPa, and the work-softening ratio is up to 3 % in the elastic limit. Over this stress, the influence of stress on the hardness increases. The influence of tensile stress on the hardness by off loading is shown in Fig.4. The relation between the tensile stress decrement and the hardness increment is linear.

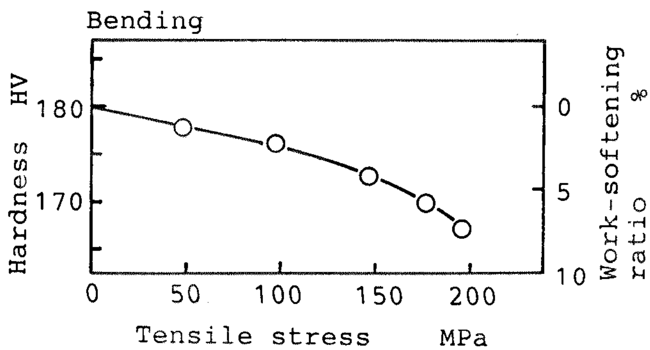

Fig.3 Decrement of hardness by tensile stress

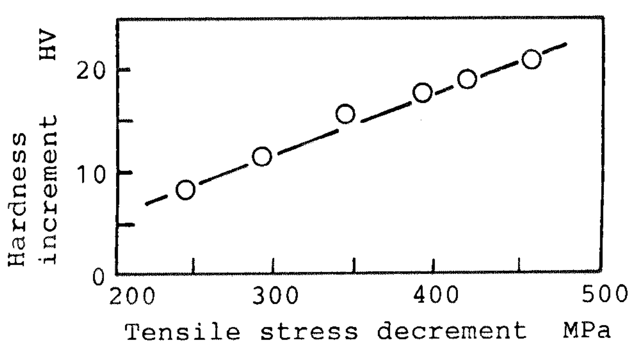

Fig.4 Relation between tensile stress decrement and hardness increment

Compressive Stress and Hardness in Bending Test. The influence of the compressive strain produced by bending and the hardness is shown in Fig.5. The on load compressive stress increases rapidly with increase of compressive strain and approaches a saturated value -260 MPa over 2 % compressive strain. The stress after off load is tensile and the approached value is about 200 MPa. The difference of stress of off load and on load increases with compressive strain, and when the strain is over from 3 to 4 %, the difference saturate 460 MPa. These relations are similar to tensile strain and stress.

In on load, the hardness increases with the increase of compressive strain as shown in Fig.5(b). The hardness after off load decreases but work-hardening appears in proportion to the compressive strain. The difference between hardness of off load and on load increase with compressive strain and approaches a saturated value 13 HV.

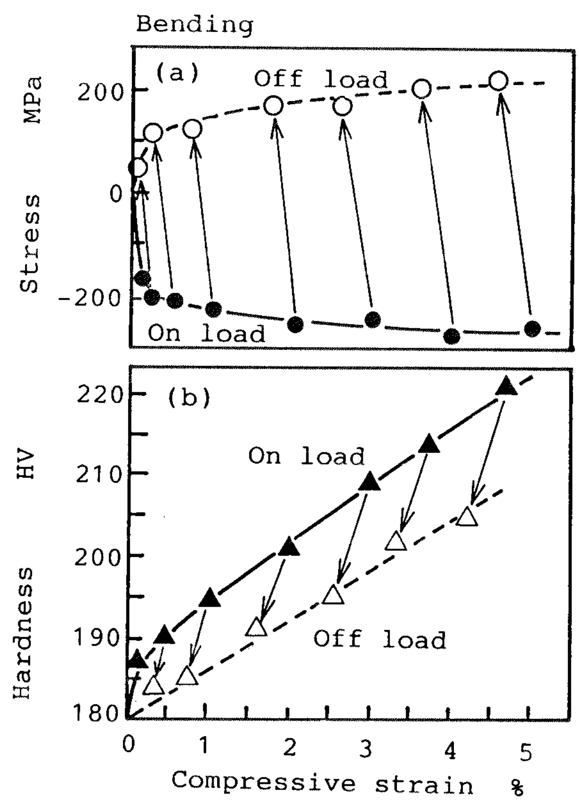

Fig.5 Influence of compressive strain on hardness and stress.

The relation between compressive stress and hardness is shown in Fig.6. Hardness increases with compressive stress under elastic strain and after compressive stress is over 150 MPa, increases rapidly. The influence of compressive stress on hardness is 2 % in elastic stress. The relation between compressive stress decrement and hardness decrement is shown in Fig.7. The change of hardness increases with increase of stress over yield point, and the difference of hardness by the change of compressive stress is 3/5 in the case of tensile stress. When the difference of stress is 460 MPa, the difference of hardness is 13 HV.

Tensile Stress and Hardness in Tension Test. The difference between tension and bending is stress gradient in the perpendicular section of the bent material. The influence of tensile strain on the stress and hardness is shown in Fig.8 and the result is similar to the bending.

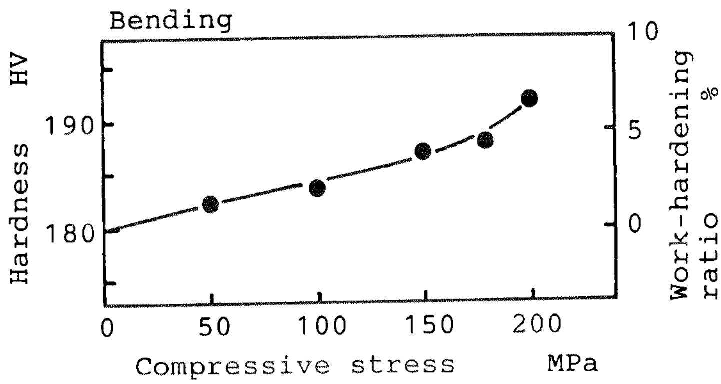

Fig.6 Increment of hardness by compressive stress.

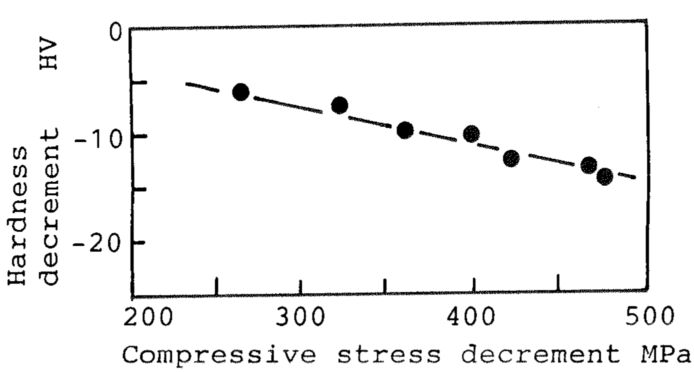

Fig.7 Relation between compressive stress decrement and hardness decrement.

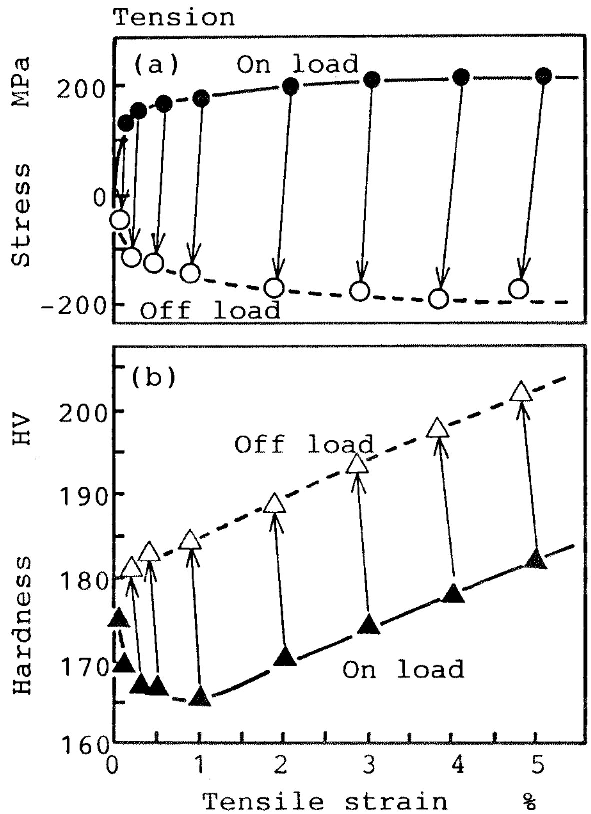

Fig.8 Influence of tensile strain on hardness and stress.

Residual Stress and Hardness on the Affected Layer Produced by Shot Peening

As reported previous paper[5], residual stress on the peened surface is induced from non-affected layer and are influenced by the thickness of material.

Hardness Distribution on the Perpendicular Section. As mentioned above, when shot peening variables are the same and the thicknesses of specimen are not the same each other, residual stresses induced by shot peening are not the same and then, their hardness distribution must be also not the same each other. Fig.9 shows the hardness distributions produced by shot peening with two different thickness specimens under the same conditions. The surface hardness of thinner specimen is lower than that of thicker specimen but higher in the core. This difference come from the influence of the residual stress.

In order to consider this phenomena, shot peening was performed with the same thickness specimen under the same peening variables, then the specimen was chemically etched by 0.33 mm from the peened surface owing to change the thickness of specimen. Fig.10 shows the comparison between the hardness distribution of etched specimen and of peened. Residual stress was released by etching and as a result of change of residual stress distribution, the hardness distribution also changed.

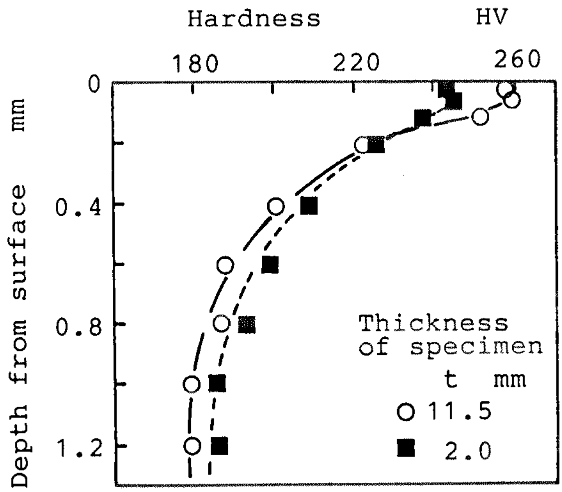

Fig.9 Hardness distributions in work-hardened layer produced by shot peening.

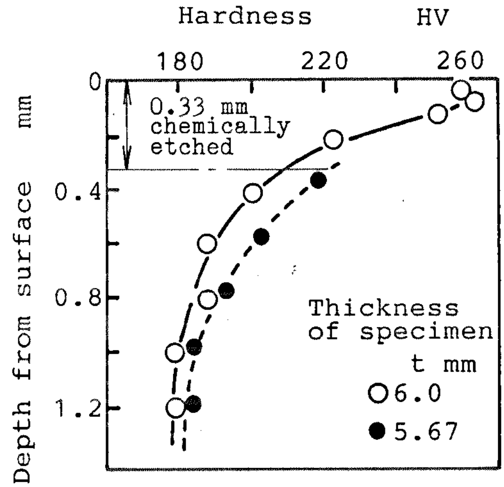

Fig.10 Influence of chemical etching from peened surface on hardness distribution.

Further experiments were run that the specimens peened under the same conditions chemically etched 5 mm from the non-peened surface. Fig.11 shows that the hardness distribution was influenced by the change of the residual stress distribution, namely the compressive residual stress near the peened surface decreases and the tensile residual stress in the core also decreases with etching from the non-peened surface. As the result, these hardness distributions are similar with them as shown in Fig.9.

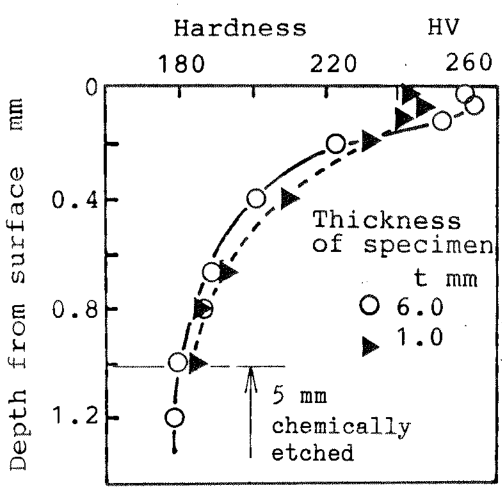

Fig.11 Influence of chemical etching from non-peened surface on hardness distribution.

Hardness on the Peened and the Non Peened Surfaces. As mentioned above, the distribution of hardness and residual stress are changed simultaneously by etching. Fig.12 shows the results on the residual stress and the hardness with etching from the peened surface. Etching the affected layer, the elastic deformation of specimen produced by shot peening decreases and then the residual stress on the opposite surface B decreases.

The results of etching from non-peened surface is shown in Fig.13. Changing the ratio of the depth of affected layer to the thickness of specimen with etching, the deformation or arc height increases once and then decreases gradually. Therefore, the residual stresses on the peened and non-peened surfaces turn from compressive to tensile with etching. The surface residual stress falls to zero wherever the thickness of specimen and work hardened layer are overlapped.

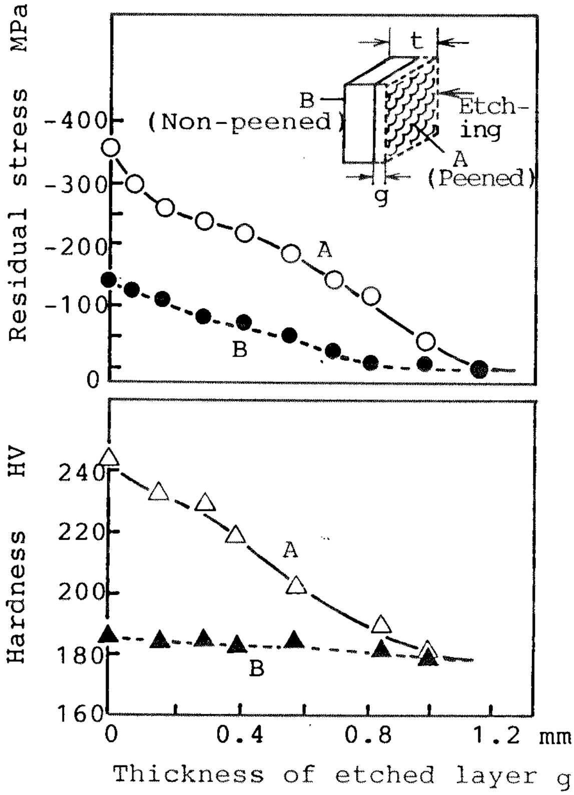

Fig.12 Influence of thickness of etched layer on hardness and residual stress. (etching from Peened surface)

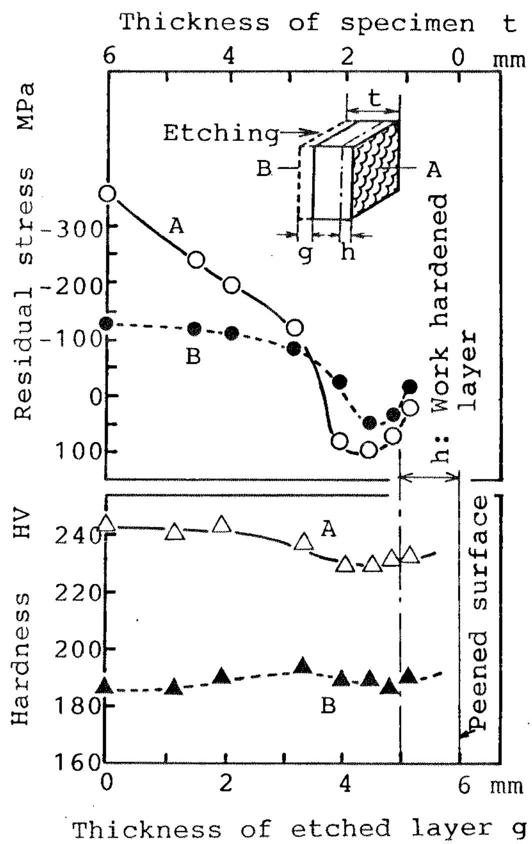

Fig.13 Influence of thickness of etched layer on hardness and residual stress. (etching from non-peened surface)

The relation between decrements of compressive residual stress and of hardness is obtained from the result of discussed above as shown in Fig.14. This relation is proportion to each other and similar to the result shown in Fig.7. Therefore, the hardness in the affected layer depends upon not only shot peening variables but also the ratio of the depth of affected layer to the thickness of specimen.

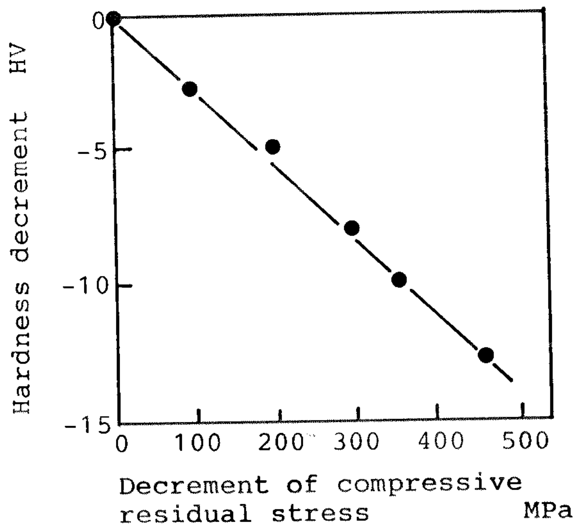

Fig.14 Relation between decrement of compressive residual stress and hardness decrement.

CONCLUSIONS

1)The ratio of influence by the applied stress to the hardness is 0.028 (HV/MPa) for compressive stress and -0.044 (HV/MPa) for tensile stress under yield point.
2)The maximum change of hardness was -20 HV under the release of 460 MPa tensile stress and the decreasing ratio is 9.8 % in this experiment.
3)The ratio of influence by the stress in the affected layer produced by shot peening to the hardness is 0.028 (HV/MPa) and the same in bending.
4)The hardness distribution produced by shot peening depends upon shot peening variables and the thickness of specimen.

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