Influence of Residual Stresses on the Hardness Number in the Affected Layer Produced by Shot Peening

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ABSTRACT

The hardness is a resistance for the local plastic deformation producing the stress field itself. The hardness number, therefore, is affected by applied or residual stresses. In order to clarify the influences of residual stresses on the hardness numbers quantitatively, shot peening and sheet bending were performed for a medium carbon steel (C: 0.45 %). Hardness and residual stress measurements were made using a micro-Vickers hardness tester and a X-ray diffractometer respectively. The following results are obtained; (1) Hardness numbers increase in the compressive stress field induced by shot peening. (2) The maximum hardness increment was 13 HV in the compressive stress field. (3) The influences of compressive residual stresses induced by shot peening on the hardness number are similar to the case of sheet bending.

1 INTRODUCTION

In shot peening process, various peening effects for fatigue, wear and stress corrosion cracking are influenced by residual stress, hardness and surface roughness [1], [2], [3]. The hardness number is a resistance for the local plastic deformation [4], and the hardness is closely related to residual stresses. The hardness in the affected zone produced by shot peening, therefore, must be also influenced by residual stresses induced by shot peening. In order to clarify the influences of residual stresses on the hardness numbers quantitatively, shot peening and sheet bending were performed for a medium carbon steel (C: 0.45 %).

2 EXPERIMENTAL CONDITIONS AND PROCEDURE

Experimental conditions such as shot peening, sheet bending, chemical etching and residual stress measurement are given in Table 1.

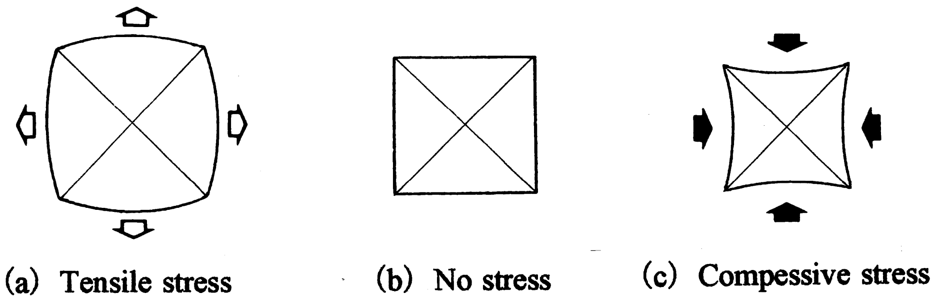
Hardness and residual stress measurements were made using a micro-Vickers hardness tester and a X-ray diffractometer respectively. Hardness distributions were obtained from averaging data measured on the three positions in the cross section perpendicular to the peened surface. At the first, the influences of the residual stresses induced by shot peening on the hardness distributions were examined, and then the influences of stresses induced by sheet bending on the hardness numbers were examined.

Table 1 Experimental conditions

Peening machine	Centrifugal type	
Shot peening	Shot size: 2.2 mm Shot velocity: 35 m/s Peening time: Full coverage	
Sheet bending	Surface strain (tension, compression): 0 - 5 %	
Specimen	Material	Medium carbon steel (0.45 %C, 180HV)
	Size	25L, 25W, 2-11.5t (shot peening) 78L, 20W, 3t (sheet bending)
Chemical etching	HNO_3 30% solution	
Residual stress measurement	X-ray diffraction, (211) plane $\mathrm{Sin}^2\ \phi$ method, ϕ : 0 - 60 deg.	

3 EXPERIMENTAL RESULTS AND DISCUSSION

The hardness number is influenced by the practical stress. For example, hardness number decreases in the tensile stress field and increases in the compressive stress field as shown in Fig.1.



(a) Tensile stress (b) No stress (c) Compessive stress

Fig. 1 Influence of two dimensional stress field on the shape of the indentation

3.1 Hardness in the affected layer produced by shot peening

As reported previous paper [5], residual stresses on the peened surface are induced by the resistance of the non-affected layer for the deformation and are influenced by the thickness of material.

3.1.1 Hardness distribution in the cross section

As mentioned above, when shot peening variables are the same but the thickness of specimen are not the same each other, residual stresses induced by shot peening and their hardness distributions are not the same. Figure 2 shows the hardness distributions produced by shot peening under the same conditions for two specimens with the different thickness. The hardness near the surface in the thinner specimen is lower than that in the thicker specimen, but hardness in the deeper layer is higher on the contrary. This difference is owing to the change of residual stresses.

In order to discuss this phenomenon, two specimens with the same thickness were shot peened under the same conditions, and then one of them was chemically etched by 0.33 mm from the peened surface to release compressive stresses near the surface. Figure 3 shows that the hardness distributions are changed by releasing residual stresses.

Further experiment was run that two specimens were peened under the same conditions and one of them was chemically etched from the non-peened surface or the reverse side to remove all the non-affected layer. Figure 4 shows that the hardness distribution is influenced by the change of the residual stress distribution owing to the change of the thickness of specimen. As the result, these hardness distributions are similar to the result as shown in Fig. 2.

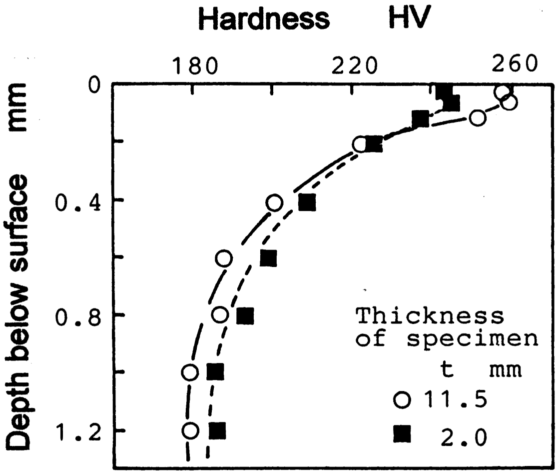


Fig. 2 Influence of the thickness of specimen on the hardness distribution

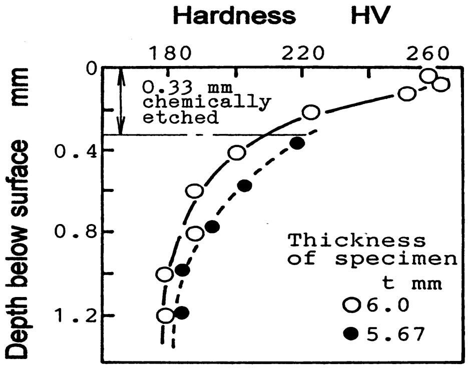


Fig. 3 Change of the hardness distribution

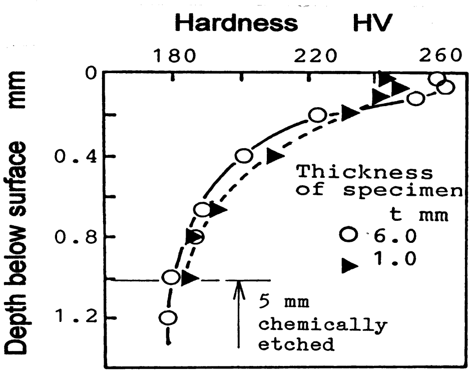


Fig. 4 Change of the hardness distribution

by etching the surface layer **by etching the non-affected layer**

3.1.2 Influence of residual stresses on the hardness near the peened surface

Figure 5 shows surface residual stresses and the hardness after etching layer by layer, in which "A" and "B" are the results on the peened surface and on the reverse side respectively. Changing the ratio of the depth of affected layer to the remaining thickness of specimen, the curvature of specimen increases once and then decreases gradually. Residual stresses on the peened and the non-peened surfaces, therefore, turn from compressive to tensile with the progress of the etching. Surface residual stresses fall to zero wherever the thickness of specimen and the depth of the work-hardened layer are overlapped.

Figure 6 shows the relation between the decrement of compressive residual stress and the hardness decrement on the peened surface, which is obtained from the results shown in Fig. 5. Hardness decrement is in proportion to the decrement of compressive residual stress. Hardness numbers, therefore, depend upon not only shot peening variables but also the ratio of the depth of affected layer to the thickness of specimen.

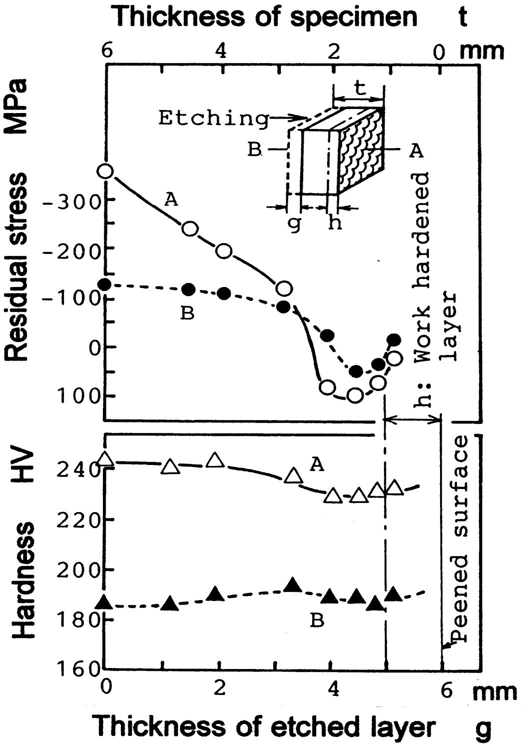


Fig. 5 Change of residual stresses and hardness on the peened surface by etching the reverse side

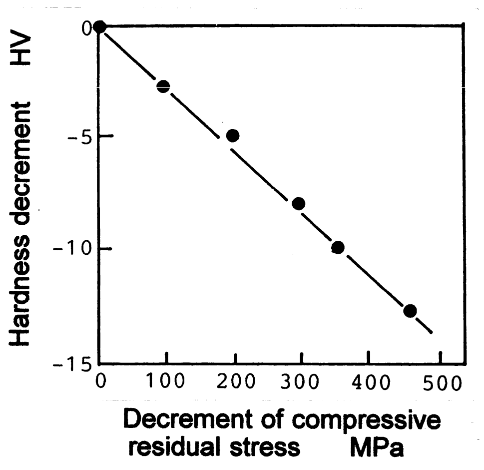


Fig. 6 Influence of residual stresses on the hardness numbers

3.2 Hardness in stress fields induced by sheet bending

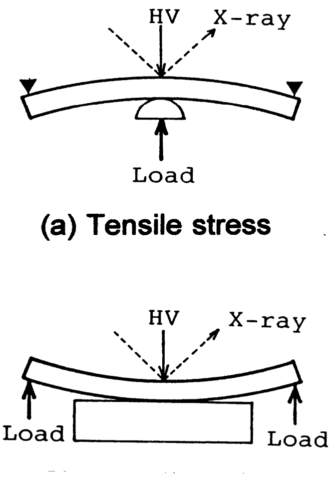
Further experiments were run to clarify the influence of stress on the hardness as shown in

Fig. 7. Strain measurements during on-load and after off-load were made using strain gauges.

3.2.1 Influence of tensile stress

Tensile stresses were induced on the convex surface by bending as shown in Fig. 7(a). The influence of the tensile strain on the stress is shown in Fig. 8(a). During on-load, the tensile stress increases remarkably in the low strain and approaches a saturated value about 200 MPa over about 0.5 % tensile strain. The stresses after off-load turn to the compressive residual stresses and also approach a saturated value about -200 MPa. The difference between off-load and on-load stresses is 150 MPa during the elastic deformation and is from 150 to 460 MPa during the plastic deformation. The hardness during on-load shows 3 different stages as shown in Fig. 8(b). Namely, the hardness decreases remarkably in the first stage, the decrement is saturated in the second stage, and then the hardness increases proportionally with the increase of tensile strain in the third stage.

In the first stage where the tensile strain is under 0.2 %, the hardness after off-load return to the same value before the bending. In the second stage where the tensile strain is from 0.2 to 1.0 %, when the load is released, the hardness that shows work-hardening is in proportion to the residual strain. In the third stage where the tensile strain is over 1 %, as the value of hardness increment with work-hardening is larger than the hardness decrement by tensile stresses, the hardness during on-load increases. After all, when tensile strain is about 1 %, the hardness number reaches the lowest value and the maximum softening ratio is 7 %. When the tensile strain is 4 %, the hardness number is offset by the influences of the tensile strain and the work-hardening. The work-hardening after off-load is in proportion to the residual strain. The difference of hardness between off-load and on-load is under 5 HV within the elastic limit, and 20 HV over the elastic limit.



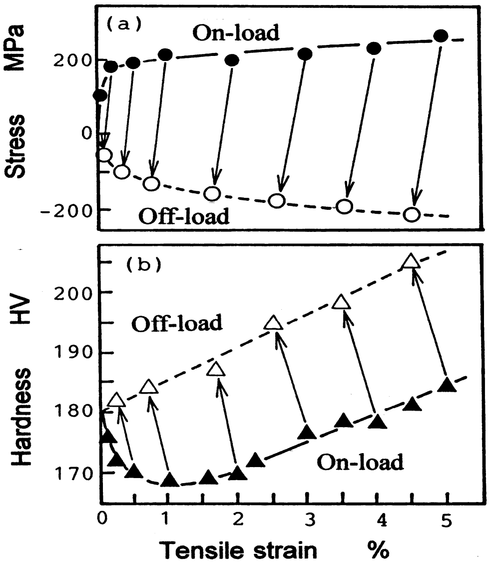


Fig. 7 Measurements of hardness and

Fig. 8 Influence of tensile strain on

residual stress in sheet bending **hardness and stress values**

The relation between the tensile stress and the hardness number is shown in Fig. 9. The hardness decrement by the tensile stress is linear in the low stress level by about 150 MPa, and the work-softening rato is up to 3 % in this stage. The influence of stress over about 150 MPa on the hardness number increases. The relation between the tensile stress decrement and the hardness increment is linear as shown in Fig. 10.

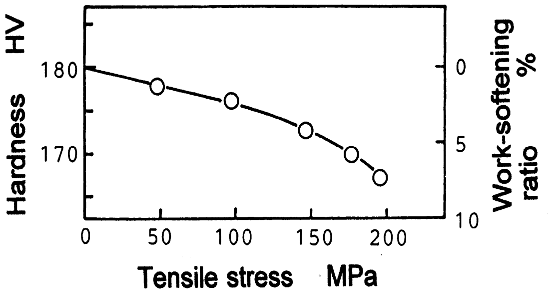


Fig. 9 Influence of tensile stress on the hardness number

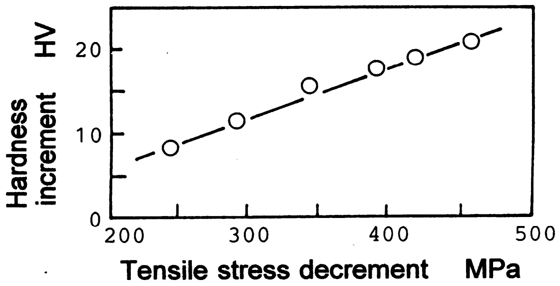


Fig. 10 Relation between tensile stress decrement and hardness increment

3.2.2 Influence of compressive stress

Compressive stresses were induced on the concave surface as shown in Fig. 7(b), and the influences of the compressive strain on the stress and on the hardness are shown in Fig. 11. Compressive stresses during on-load increase remarkably in the low compressive strain and approaches a saturated value -260 MPa over 2 % compressive strain. The stresses after off-load turn to the tensile and the saturated value is about 200 MPa. The difference of stresses during on-load and after off-load increases with the increase of the compressive strain, and when the strain is over about 3 %, the difference of their stresses reaches a saturated values about 460 MPa.

During on-load, the hardness is increased by the compressive strain as shown in Fig. 11(b). The hardness after off-load decreases and the work-hardening appears in proportion to the compressive strain. The difference between the hardness during on-load and after off-load increases with the increase of the compressive strain and approaches a saturated value 13 HV.

The influence of compressive stress on the hardness is shown in Fig. 12. The hardness increases with the compressive stress in the elastic strain and increases rapidly after the compressive stress is over 150 MPa,. The influence of compressive stress on the hardness number is about 2 % in the elastic stress field. The relation between the compressive stress decrement and the hardness decrement is shown in Fig. 13. When the difference between compressive stresses and the tensile stresses 460 MPa, the difference of the hardness become 13 HV. These influence of compressive stresses on the hardness values in this bending are very similar to the case of shot peening.

4 CONCLUSIONS

(1) The hardness number increases in the compressive stress field induced by shot peening.

(2) The maximum hardness increment was 13 HV in the compressive stress field induced by shot peening

(3) The influences of residual stresses induced by shot peening on the hardness numbers are similar to the case of sheet bending.

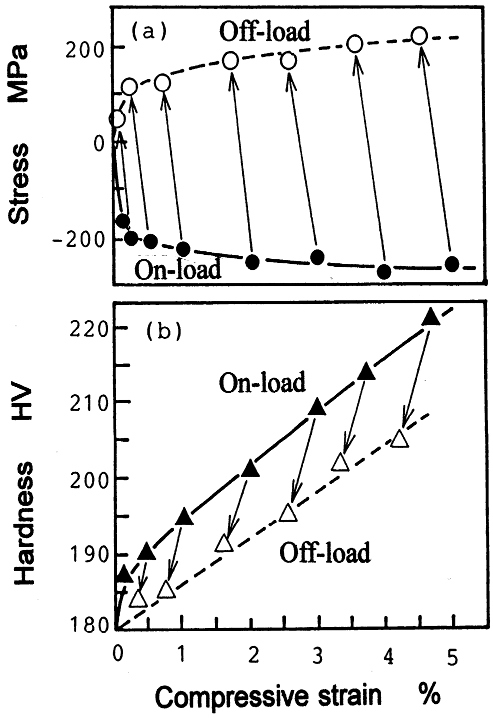


Fig. 11 Influence of compressive strain on the stress and hardness values

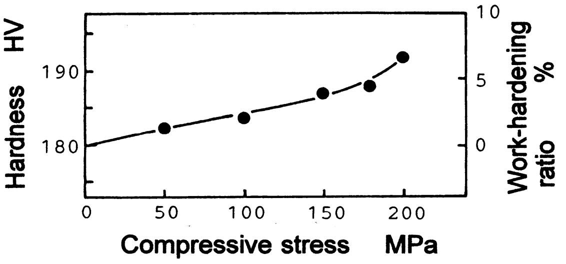


Fig. 12 Influence of compressive stress on the hardness values

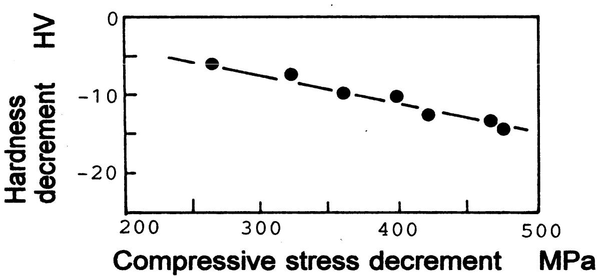


Fig. 13 Relation between compressive stress decrement and hardness decrement

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