MICROSTRUCTURE ASPECTS OF WORK-SOFTENING PHENOMENON FOR STEEL AND ALUMINUM

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ABSTRACT

Experiments were designed to reveal the nature of work softening aspect of shot peening. A steel specimen is compressed in different strains and then tensiled. The half width decreases to a minimum value and increases again, that agrees with the hardness distribution of a softened layer of peened specimen. Microstructure analysis of Al specimen shows the reverse loading makes the cell structure indistinct and forms dislocation networks, but in further loading, the well formed cells establish again thus the material becomes hardened. Below the strain threshold of softening, the material increases its half width under cyclic loading, but its residual stresses decay with the cycle number.

KEYWORDS:

Half width, Softening, Shot peening

INTRODUCTION

Softening was observed when a plastic deformed part had been experienced with shot peening. The softened layer lying beneath the surface appears only if the plastic deformation of a soft material reaches a minimum magnitude, and it will result in the drop of fatigue endurance [1]. In fact, experimental results were also reported for the solely peened or rolled specimens[2,3].

Softening as a decrease of hardness is thought to be associated with cyclic loading by repeated impact beads. However, it is not clear how the microstructure change to form a layer softer than the original one and how the other parameters, for instance, half width (Hw) or residual stress (σ_r) change during the process. This paper tries to study the dislocation configurations of the shot peened layers in different states with the change of micro– and macro– internal stresses.

EXPERIMENTS AND DISCUSSIONS

Material used are S15C and S45C steels and aluminum. A group of specimens were annealed and compressed with 0, −10%, −20% and −40% plastic deformations. Shot peening was processed with steel shots of 2.2mm in diameter and 35 m / sec. of velocity. Specimen preparations were detailed in reference[1].

X–ray profile analysis were performed on D / max–3A diffractometer and the residual stress measurement on MSF–2M X–ray stress analyzer. Microstructures were observed with JEM–200CX transmission electron microscope. In order to examine the near surface layer of the steel specimen, Ni was electro–plated on the shot peened surface. A slice cut from the specimen with a part of Ni was prepared for TEM analysis, for which microstructure observations were focused on the low hardness area about 0.4 mm from the vary surface.

Half Width of Steel Specimen

Half widths of S15C and S45C specimens with different compressions and shot peenings are shown in Fig.1 and 2.

All the half width curves consistent with the hardness curves reported in reference [1]. The decreases of the half widths of $K_{\alpha 1}$lines beneath the surface only appear at the compressions larger than −20%. We tried to separate the microstrain and subgrain size by the diffraction profile analysis, but no substantial difference occurs for the microstrain curves in comparison with the half width distributions.

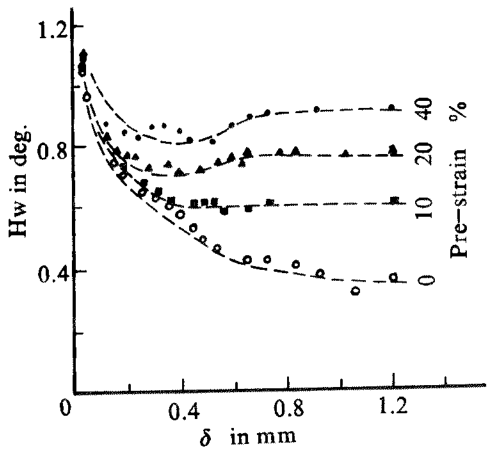

Fig.1 Half widths of S15C

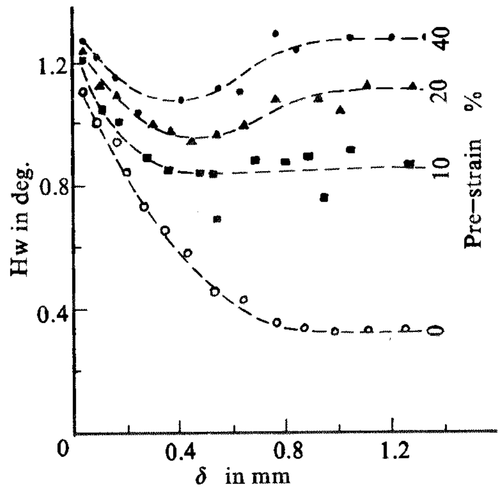

Fig.2 Half widths of S45C

In order to reveal the nature of the change of half width during plastic deformation, a medium carbon steel specimen was prepared for uniaxial tension and compression. The specimen was loaded with 3 steps in compression up to −2.5% of plastic strain and then reversed the loading direction to tension. Halfwidth of $K_{\alpha 1}$ X−ray diffraction profile was measured for each loading step as shown in Fig.3.

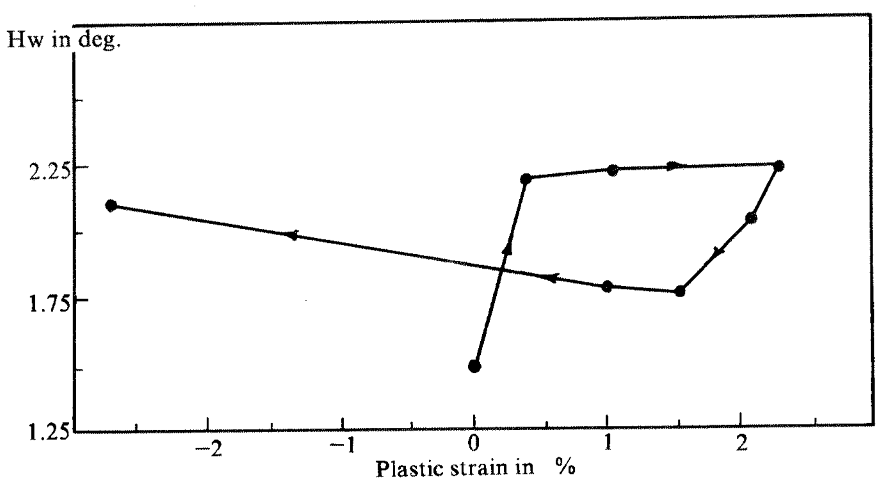

Fig.3 Half width vs. plastic strain with tension and compression

Half width increases rapidly for the virgin sample under compression at beginning and then turns to be saturated. The half width only increases slightly for the plastic strain larger than −0.5%. At reverse loading, the siope of the half width vs. plastic strain is smaller than that of rapid hardening stage. Hw may increase again when the specimen was tensiled to reach its original size, ie. the gross platic strain recovers to zero. Thus a minimum value of Hw appears in softening at about + 1% strain, close to the plastic strain of knee point in hardness curve. The reverse loading curve is close to the softening curve by shot peening. Either repeated loading or uniaxial loading on a piece of drastically plastic deformed specimen, softening is ought to occur. Further deform of the softened specimen, the half width increases again. According to the good agreement of the hardness and half width distributions in the hardening and softening processes. It is expected that the hardness follows the trace of the half width vs. strain in Fig.3, and it is not surprise that the hardness or half width is higher in the vary surface of the shot peened specimen. In other words, if we keep on pulling the specimen, the half width may be higher than the saturated value of 2.25 ° in Fig.3.

Microstructures of Steel and Al Specimens

The microstructure of S15C with −40% compression at the minimum half width in the softened layer is shown in Fig.4 and its original feature in the interior part of this specimen is in Fig.5.

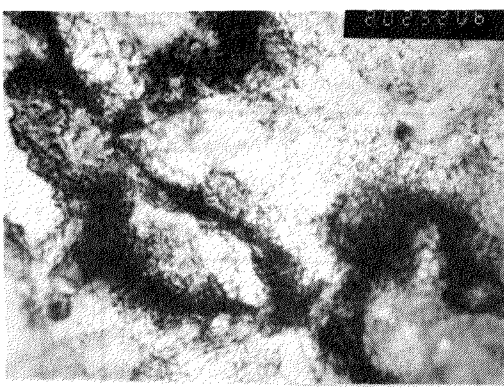

Fig.4 Microstructure of softened layer for S15C, −40% compression

Fig.5 Microstructure of interior part for S15C, −40% compression

After −40% 0f compression, subgrains are pressed band structure enclosing dislocations. Shot peening induced softening is seemed to be that an indistinct cell structure along with tangled dislocations is established and the cell walls increase their dislocation densities during shot peening, but the average cell size is larger than tne subgrain size before peening.

The same experiment as half width tests for the steel specimens were conducted on a pure aluminum specimen. Al sample was pressed to a plastic strain of −5.3% for several steps. In the compressive strain of −1.94%, a network of dislocation is appeared. For −5.3% compression, cell structure is formed, the dislocation density in the cell wall increases remarkedly, as shown in Fig.6. If the −1.94% compressed sample was tensiled to a strain of +3.42%, the cell structure is more distinct than the −1.94% one. However, if the −5.3% strain is pulled to a strain of +0.80%, the cell wall turns to be indistinct and close to a configuration of dislocation network as Fig.7. If the reverse loading increases further to +4.8%, the cell structure reforms again and to +7.1%, the cells are well established and enclosed with distinguished walls as shown in Fig.8.

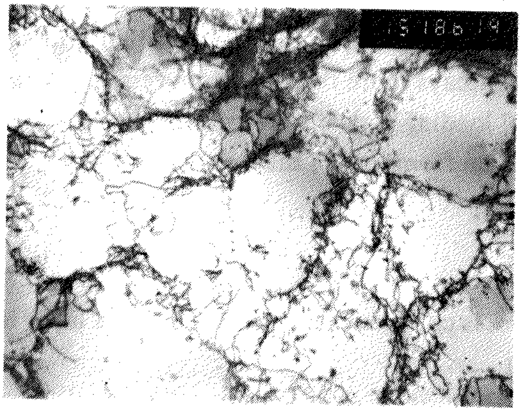

Fig.6 Al with −5.3% strain of compression

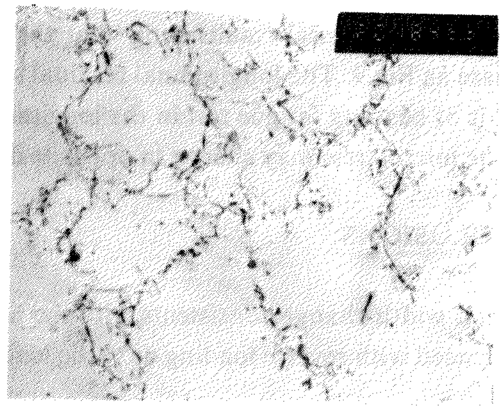

Fig.7 Al with +0.8% tension after −5.3% compression

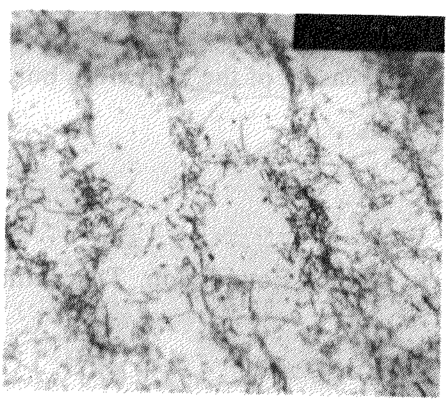

Fig.8 Al with 7.1% tension after −5.3% compression

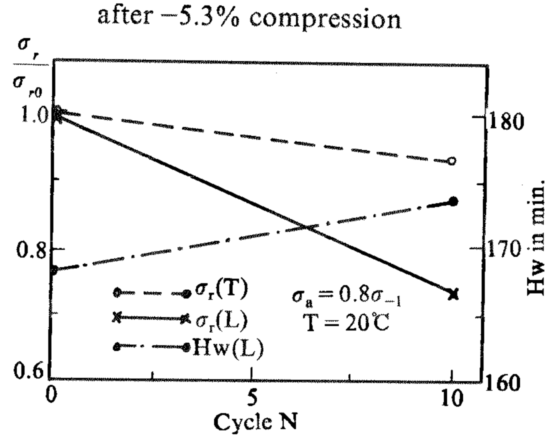

Fig.9 Half width and residual stress with cycles

In comparison with the hardness distribution of shot peening on the plastic deformed Al in [1], the cell structure becomes obscure and forms dislocation networks. It will result in the decrease of half width of X−ray diffraction profile and the hardness as well. Further increase of the reverse loading, the well formed cell is associated with the increase of half width similar to that of the very surface layer after shot peening.

Different Aspects of Micro and Macro Stresses

To reveal the softening aspect in hardness distribution, a minimum strain before reverse loading or cyclic loading is required. Below this strain threshold, the half width keeps on increasing under cyclic loading. A group of fatigue specimens of medimum carbon steel were shot peened with a fairly low peening intensity. The fatigue test was performed at 80% of the fatigue limit and was interrupted for the measurements of half width and residual stresses. Experimental results show that the half width increases but the residual stresses decrease as Fig.9. The longitudinal residual stress decays more than the transverse stress as a result of bending fatigue test in the longitudinal loading states. This experiment indicates that the microstress may change in opposite direction from that of macro stress.

CONCLUSIONS

The half width change consistents with the hardness change when the shot peened layer is experienced with reverse loading or cyclic loading.

The cell structure becomes indistinct when the reverse loading is applied, it results in a softening aspect. That is close to the cyclic softening of the shot peened layer.

Below the strain threshold, cyclic loading will keep on increasing of the half width but the residual stresses relax with the cycle number.

ACKNOWLEDGEMENTS

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REFERENCES

[1]. k.Iida, "Fitigue Strength of Work Softening Layer Produced by Shot Peening", ICSP−3,pp.611−618,(Oct. 1987)

[2]. Wang Renzhi, "Investigation on the Microstructure in Shot−peening Surface Straining Layer of Material", ICSP−1,pp.185−192,(Sep. 1981)

[3]. Hu Naisai "The Effect of Surface Plastic Deformation on Fatigue Strength and Its Mechanism", ICSP−1,pp.351−357,(Sep. 1981)