IMPROVEMENT OF FATIGUE STRENGTH AND FRACTURE SURFACE MORPHOLOGY OF HARD SHOT-PEENED TYPE 316L STEEL

Yasuo OCHI* and Kiyotaka MASAKI†

In order to investigate effects of hard shot-peening (HSP) on the fatigue properties of Type 316L austenitic stainless steel with attention to change the hardness and the residual compressive stress distributions and also the fractographical examination, rotating bending fatigue tests under water cooling condition were carried out. As results, the fatigue strength was improved markedly on the HSP mateials and crack origins were transfered from the surface to the sub-surface near borders of the hardening layer and the matrix.

INTRODUCTION

Surface hardening treatments are very useful for the improvement of the fatigue strength of steels. The shot-peening is the one of effective methods which have been studied by some researches (1-7) with respect to the treatments of spring steels, gear steels and othe machine element steels. In recent years, the shot-peened treatments have been applied to aluminum alloys (7,8), titanium alloys (9,10) and ductile cast irons (11,12). However, there have been few reported studied about the fatigue properties of shot-peened stainless teels (6) and the high cycle fatigue properties have not been clarified yet.

The purposes of this study reported here, are to investigate effects of shot-peened treatments on the high cycle fatigue properties of austenitic stainles steel with regarding the changes of the hardness and the residual stress distributions during fatigue process and the fractographical examinations of fracture surfaces.

* Deparment of Mechanical and Control Engineering, University of Electro-Communications, Chofu, Tokyo 182-8585, Japan.
† Graduate School of University of Electro-Communications.

EXPERIMENTAL PROCEDURES

The materials used in this study was SUS316L stainless steels, having the chemical compositions (weight %) of : 0.017 C, 0.39 Si, 0.80 Mn, 0.029 P, 0.014 S, 12.17 Ni, 16.31 Cr, and 2.06 Mo. SUS316L stainless steel is a low carbon type of SUS316 that is used for fast breeder reactors. The mechanical propereties of the material is given in Table 1. The average grain size of the austenitic structure was about 87.5 μ m.

The shape and the dimensions of specimens are shown in Fig. 1. The specimens have a circumferential shallow notch at the center (stress concentration factor Kt is about 1.06). After the machining , the specimens were polished by emery papers #400-1500 and were annealed at 1100℃ for 1 hr. in a vacuum furnace. Then, the center part of the specimens were finished with aluminum paste, and the specimens were shot-peened by two different conditions as shown in Table 2 ; one is the normal shot-peend (SP) and the other is the hard shot-peened (HSP) treatments.

Rotating bending fatigue tests were conducted on at 50Hz under water cooling condition by using deionized water. The high cycle fatigue tests to about 10^8 cycles on the SP, the HSP and also a non shot-peened (n.p.) materials were carried out.

RESULTS AND DISCUSSIONS

Results of Fatigue Tests

The results of fatigue tests are shown in Fig.2. Both fatigue strength and fatigue limit of the SP and HSP materials were remarkably improved in comparison with the n.p. materials. And the fatigue limit of 10^8 of the SP and the HSP materials were about 1.7 and 1.85 times of the n.p. materials, respectively. The reasons for the improvement in the fatigue strength were assumed to be the mean stress effect of compressive residual stresses, and also due to the shift in the crack origin from the surface to subsurface by surface hardening caused the plastic deformation

Changes of the Hardness and Residual Stress Distributions

The hardness tests and the X-ray diffraction measurements were also carried out on the direction of depth of the specimens, before, during and after the fatigue tests. Figure 3 shows the changes of the ratio of Vickers hardness (Hv/Hv_B) distributions : (a) the n.p., (b) the SP and (c) the HSP materials, where the Hv_B is the each minimum value of Hv in the three cases. The hardness of the inside of the n.p. material increased by cyclic stressing, but the surface layer was not hardening. For the SP and the HSP materials, the hardness of the surface layer decreased by cyclic softening, but the internal matrix hardness increased by cyclic strain hardening. Therefore, in the

SP and the HSP materials, the cyclic softening and the cyclic strain hardening occured at the same time by fatigue stressing.

The results of the residual stress measurements are shown in Fig.4: (a) the n.p., (b) the SP and (c) the HSP materilas. In the n.p materials, the residual stress was almost zero and also unchanged by fatigue stressing. In the SP materials, the surface compressive residual stresses were reduced by faigue. In the HSP materials, the maximum residual compressive stress inside the specimens (distance from the surface is about 100 μ m) were reduced, however, the residual compressive stresses were not fully released. So, these stresses were the factors which caused the preveting the crack growth and then, the improvement in the fatigue strength.

Fractographical Examinations of Fracture Surface

Figure 5 shows an example of the crack origins in the fracture surface. The crack origin was assumed to be the A - A part in the figure, and the depth of the origin decreased with increasing the stress amplitude. Figure 6 shows the cross sectional observation near the crack origin. From these observations, it was assumed that the crack initiated near at the border between the surface hardening layer and the base metal. Figure 7(a)-(g) shows an example of the fracture surface of crack propagation in the HSP material. From these observations, it was assumed that the crack propagated as the following processes, (1) the crack initiated near at the borders as shown in Fig. 5, 6 and (b) in the Fig.7, (2) the crack propagated into the direction of depth as shown in (c) and (d) . (3) the crack propagated on the surface layer as shown in (e), (4) the final fracture as shown in (f) and (g).

CONCLUSIONS

High cycle fatigue tests of the non-peened (n.p.), the normal shot peened (SP) and the hard shot-peened (HSP) SUS316L stainless steel were carried out and the effects of the shot-peening treatments on the fatigue properties were investigated. The conclusions obtained are as the following in this study.

(1) The rotating bending fatigue strength was improved by the SP and the HSP treatments and the improvement trend was more remarkable in the HSP materials.

(2) The internal matrix hardness of the n.p., the SP and the HSP materials increased by cyclic strainhardening, however, the hardness of the surface hardened layer of the SP and the HSP materials decreased by cyclic strain softening.

(3) The residual compressive stresses caused by the SP and the HSP treatments were released partly by the fatigue stressing, and the maximum resisual sresses were reduced in the SP and the HSP materials.

(4) The fatigue crack origins were near at the borders of the hardening layer and the base metal, and after the crack initiation the crack propagated to the internal direction for a certai depth, and then, the crack appeared to the surface and propagated quickly on the surface to final fracture.

REFERENCES

(1) Hmma,T., J. Japan Inst. Metals, Vol.6, 1967; pp.770-782.
(2) Lyu, S., Inoue,K., Kato, M., Ohashi, M., and Shimoda, K., JSME Int. Jour. Ser. C, Vol.39, 1995, pp.108-114.
(3) Ogawa, K., Asano, T., Suzuki, K., Aihara, H., and Shimoda, K., Trans. Jap. Soc. Mech. Eng., Ser.A, Vol.61, 1995, pp.233-238.
(4) Inoue, K., Lyu, S., Deng, G., and Kato, M., Trans. Jap. Soc. Mech. Eng., Ser.C, Vol.62, 1996, pp.306311.
(5) Kocanda, D.N., Kocanda, S., and Miller, K.J., Fatigue Frac. Eng. Mater. Struc., Vol.19, 1996, pp.911-917.
(6) Iida, K, and Tanigchi, K., Trans. Jap. Soc. Shot Peening, Vol.8, 1996, pp.9-16.
(7) Hammond, D.W., and Meguid, S.A., Eng. Frac. mech.,Vol.37, 1990, pp.373-387.
(8) Ito, K., Suzuki,H., Nishino, S., and Teranishi, A., Trans. Jap. Soc. Mech. Eng., Ser.A, Vol.62, 1996, pp.1316-1320.
(9) Asami, K., and Hironaga, M., J. Soc. Mater. Sci., Japan, Vol.43,1994, pp.12-17.
(10) Kato, K., Takafuji,S., and Kiriyama, M., I. Soc.Mater. Sci.Japan, Vol.45, 1996, pp.43-47.
(11) Hashimoto, M., Shiratori, M., Ito, M., and Hirai, K., Trans. Japan Soc. Mech. Eng., Ser.A, Vol.61, 1995, pp.889-893.
(12) Suzuki,H., Magata,A., Gong,W.M., and Ito,M., TransJapan Soc. Mech. Eng., Ser.A, Vol.61,1995,pp.2349-2354.

Table 1 Mechanical Properties of SUS316L steel

Material	Tensile strength σ_B[MPa]	0.2% proof strength $\sigma_{0.2\%}$[MPa]	Reduction of area ϕ_n[%]	Vickers hardness [Hv]
SUS316L	548.8	178.25	82.9	135

Table 2 Conditions of shot-peening treatment

	SP	HSP
shot treatment	normal shot	hard shot
shot size	0.3mm Dia.	0.6mm Dia.
Almen intensity	0.2mmA	0.6mmA

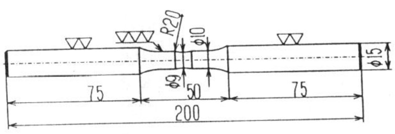


Fig. 1 Shapes and dimensions of test specimen (mm)

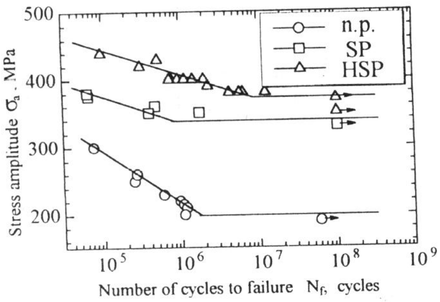


Fig. 2 S - N curves under water cooling condition

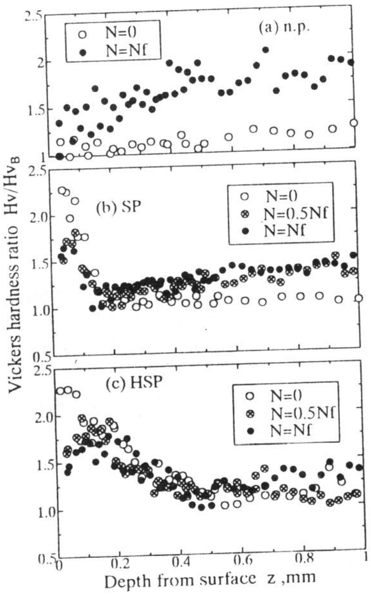


Fig. 3 Changes of Vickers hardness distribution in depth from surface

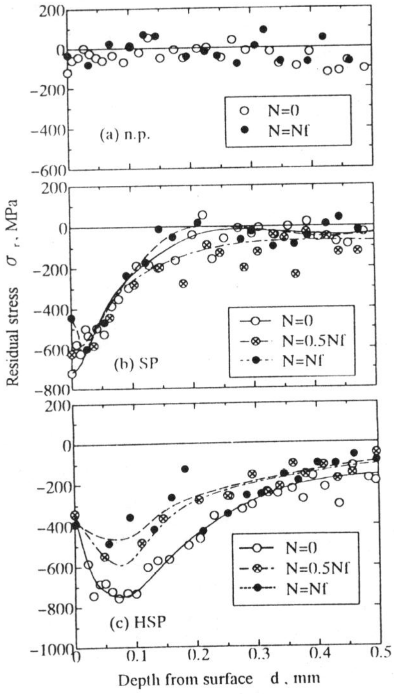


Fig. 4 Changes of residual stress distributions in depth from surface

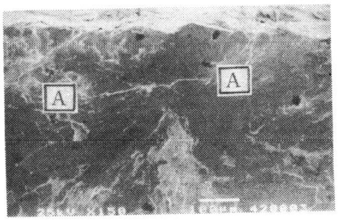


Fig. 5 Crack intiation area on fracture surface
(σ_a=420MPa, $N_f=3.1\times10^5$)

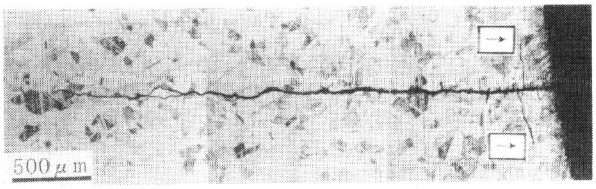
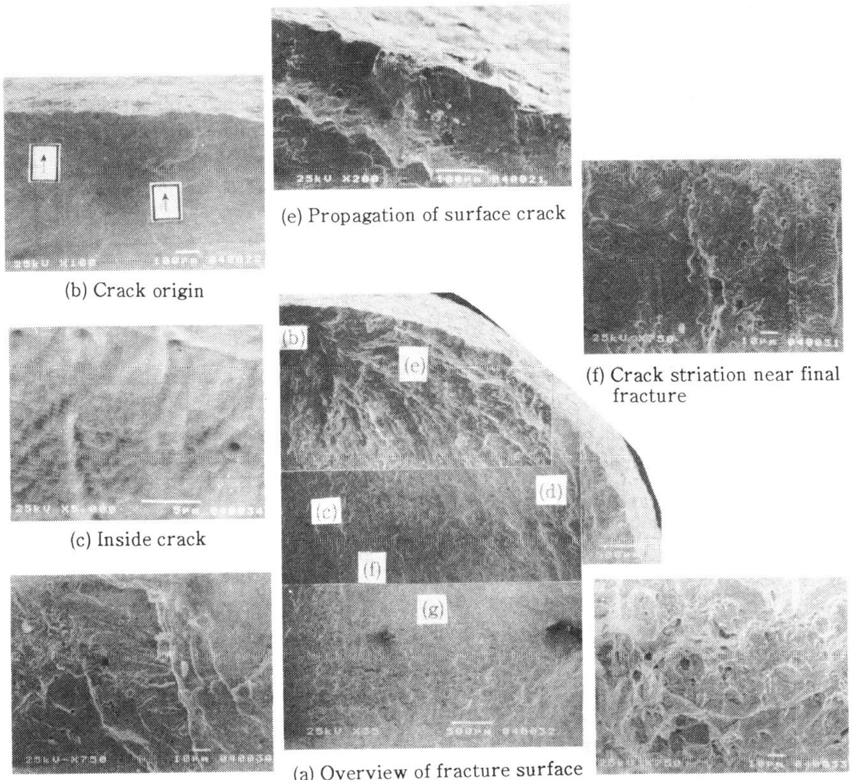


Fig. 6 Observation of crack at cross section



(e) Propagation of surface crack

(b) Crack origin

(f) Crack striation near final fracture

(c) Inside crack

(d) Edge of inside crack

(a) Overview of fracture surface

(g) Final fracture surface

Fig. 7 Observation of fracture surface (σ_a=400MPa, $N_f = 9.3 \times 10^5$)