FATIGUE PROPERTIES OF TITANIUM ALLOY, STAINLESS STEEL AND ALUMINUM ALLOY TREATED WITH FINE PARTICLE BOMBARDMENT

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ABSTRACT

Fine Particle Bombardment (FPB) treatment is commercially applied in various industries because of its beneficial effect to improve fatigue properties of metallic materials. The increase of fatigue strength of metals achieved by this process is due to a generation of compressive residual stress on their surfaces. In this study we investigated the effects of the FPB treatment on the fatigue properties of Ti-4.5Al-3V-2Fe-2Mo titanium alloy, Al6061 aluminum alloy and type304 austenitic stainless steel by carrying out rotational bending fatigue tests. In the FPB treated titanium alloy, fatigue strength was higher than that of the untreated one. This was due to the beneficial effects of surface hardening. In the case of the aluminum alloy, little increase of surface hardness and compressive residual stress was induced by the FPB treatment, which resulted in no improvement of the fatigue strength. Despite the higher hardness and compressive residual stress, the increase in fatigue strength of stainless steel was lower than that of the titanium alloy. This was because the surface hardness of the stainless steel was increased by a cyclic loading alone, due to a high work hardening factor. These results imply that the effects of the FPB treatment on the improvement of fatigue properties depend on the work hardening factor of treated materials.

1 INTRODUCTION

Fine Particle Bombardment (FPB) treatment, in which the surfaces of materials are bombarded with fine particles, is a newly developed surface modification process [1]. It has been reported that fatigue properties of structural steels were improved by this process due to generation of compressive residual stress and of surface hardened layers [2]. It also has been reported that the FPB treatment is more effective on carburized steels [3]. These results suggest that effects of the FPB treatment on fatigue properties depend on the microstructure of treated materials. However, most studies concerning the FPB treatment have focused on the steels as a substrate. Therefore, the effects of the FPB treatment on the fatigue properties of other materials have not been clarified.

The objective of the present study is to clarify the effects of the FPB treatment on three types of metals; titanium alloy, stainless steel and aluminum alloy, with special focus on the effect of work hardening factors.

2 EXPERIMENTAL PROCEDURE

The materials used were a Ti-4.5Al-3V-2Fe-2Mo alloy (T series), an Al6061 aluminum alloy (A series) and a type304 austenitic stainless steel (S series). Table 1 shows the work hardening factors of these metals. These materials were machined into hourglass specimens as shown in Fig.1. The surfaces of the specimens were ground with alumina powder and polished electrolytically (polished specimen). FPB treatments were performed on the polished specimen with an 80μm diameter high speed tool steel shot. Table 2 shows the conditions of the FPB treatment. To characterize the FPB treated specimens, measurements of Micro-Vickers hardness, residual stress and surface roughness of specimens were carried out.

Fatigue tests were carried out with a rotational bending machine at room temperature. Cyclic frequency was 50Hz. The maximum stress at which no fracture occurred after applying 10^7 cycles of stress, was defined as the *fatigue strength* in this study. After fatigue tests, fracture surfaces were observed by a Scanning Electron Microscope (SEM).

Table 1 Work hardening factor of the metals

Titanium alloy	Stainless steel	Aluminum alloy
0.36	0.50	0.24

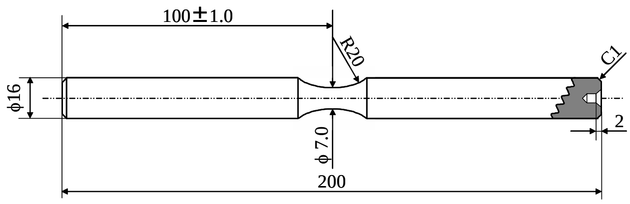


Fig.1 Shape of specimen

Table 2 Conditions of FPB treatment

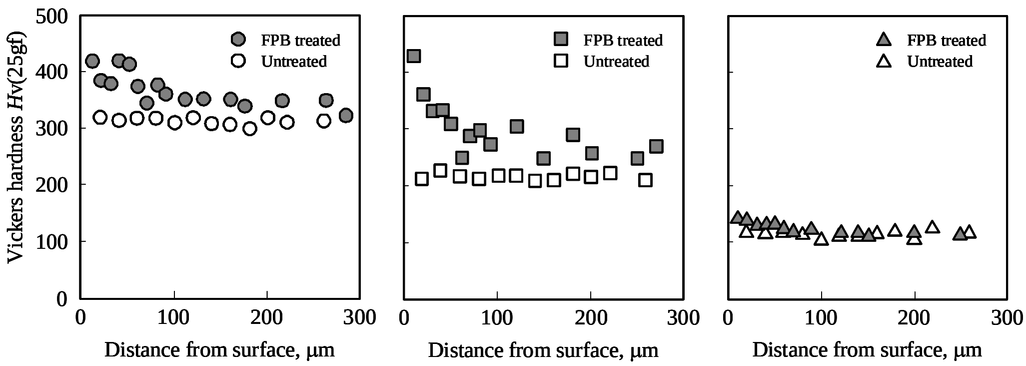
Peening pressure	Average particle diameter	Nozzle distance	Peening time	Shot material
0.6MPa	80μm	100mm	40sec	SKH59 (High speed tool steel)

3 EXPERELIMENTAL RESULTS

Fig.2 shows Micro-Vickers hardness distributions of the FPB treated and untreated specimens. In these figures, open marks represent the results of the untreated specimens, and solid marks represent the ones with the FPB treatment. In the case of the T series and the S series, significant increase of hardness was observed on the surface layer after the FPB treatment. However, the FPB treatment achieved no significant increase for aluminum alloy specimens (A series). This is due to the small value of work hardening factor of the alloy as shown in Table 1.

Fig.3 shows residual stress of the FPB treated surfaces. Higher residual stress was generated on the surface of the stainless steel (S series) than that of the aluminum alloy (A series). In the case of the titanium alloy, X-ray diffraction stress measurements failed because of its micro structure.

Table 3 shows surface roughness of the FPB treated specimens. The largest value of surface roughness *R*a was observed on the aluminum alloy specimens (A series).



(a) T series (b) S series (c) A series

Fig.2 Vickers hardness distribution

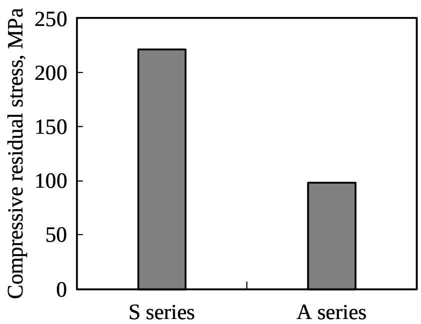


Fig.3 Residual stress on the surface

Table 3 Surface roughness *R*a of specimens

T series	S series	A series
0.24μm	0.26μm	0.52μm

Fig.4 shows the the results of fatigue tests on titanium alloy (T series). In this case, the *fatigue strength* of the FPB treated specimens was higher than that of the untreated one. This was because the higher hardness of the surface layer suppressed fatigue crack initiation and its propagation.

Fig.5 shows the results of fatigue tests on stainless steel (S series). Despite that higher hardness and compressive residual stress were observed on their surface layer (see ■marks in Fig.2), the increase of fatigue strength of the stainless steel was less than that of the titanium alloy. To clarify the reason for this, hardness distributions were measured after 10^7 cycles of loading and then compared to the results before fatigue tests (Fig.6). In these figures, lines represent the hardness distributions before cyclic loading. In S series (Fig.6 (b)), noticeable increase of hardness was observed on the surface layer even in the untreated specimens. This was because of the higher work hardening ability of stainless steel. As a result, surface hardness of the FPB treated specimens and untreated specimens showed almost similar value after cyclic loading; resulting in the similar *fatigue strength*.

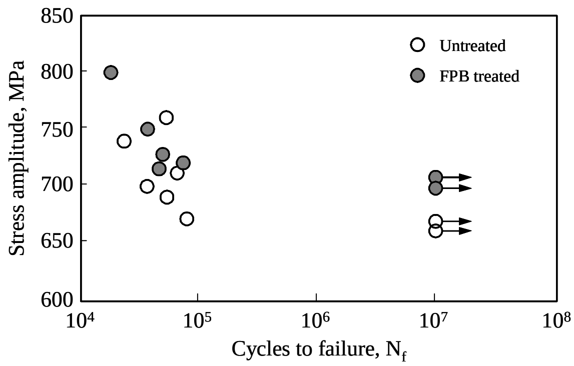


Fig.4 S-N curves of the T series

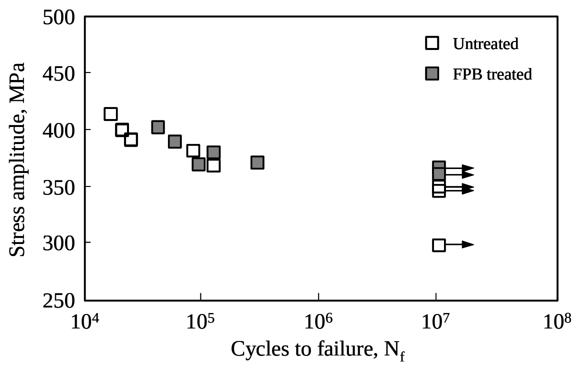


Fig.5 S-N curves of the S series

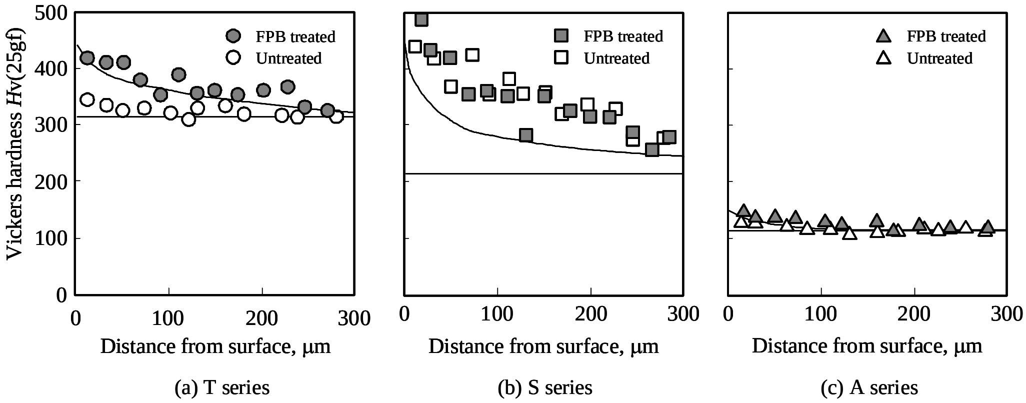


Fig.6 Vickers hardness distribution after 10^7 cycles of loading

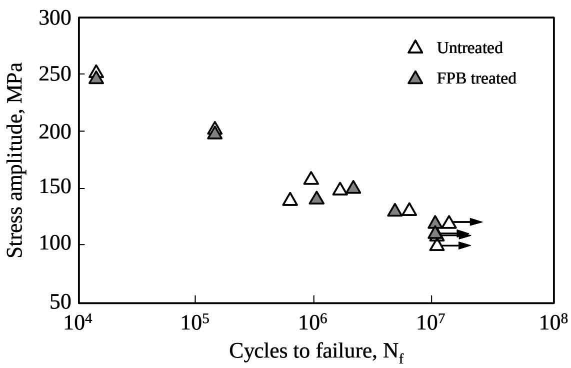


Fig.7 S-N curves of the A series

Fig.7 shows the results of fatigue tests on aluminum alloy (A series). The *fatigue strength* of the FPB treated specimens was slightly lower than that of the untreated specimens. This was because there was no increase of the surface hardness (Fig.2) and an increase in the surface roughness (Table3).

5 CONCLUSION

Depending on the material properties, the FPB treatment induces different effect on the fatigue properties. With titanium alloy, beneficial effects of surface hardening increases *fatigue strength* of the treated specimens. In the case of the stainless steel, since influence of work hardening during the fatigue tests is greatly noticeable, the effect of the FPB treatment on the fatigue strength is less than that of the titanium alloy. This suggests that the work hardening ability of the materials affects the improvement of fatigue properties induced by the FPB treatment.

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7 REFERENCES

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