Improvement of Corrosion Resistance of High-Strength Aluminum Alloy by Fine-Particle Bombarding Treatment

T. Morita 1, A. Sakamoto 1, C. Kagaya 2, H. Nakaguchi 1,

1 Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan
2 Chubu University, Matusmoto 1200, Kasugai 487-8501, Aichi Prefecture, Japan

ABSTRACT
This study was conducted to investigate the effect of fine-particle bombarding (FPB) treatment on corrosion resistance of high-strength aluminum alloy. When the FPB treatment was carried out with fine particles of titanium, zinc or tin, the elements composing those particles were diffused over the surface and residual stress was introduced. In corrosion test, FPBed bolt-type specimens were immersed into 3 % salt water maintained at 373 K. During this test, the specimens were fixed by special fixtures to apply high tensile stress. After immersing the specimens in the salt water until 345.6 ks (4 days), 604.8 ks (7 days) and 864 ks (10 days), their corrosion features were observed on the cross-section in detail. The results showed that the corrosion resistance of the aluminum alloy was greatly improved by the FPB treatment and there was almost no corrosion on each FPBed specimens until 345.6 ks.

KEY WORDS
Fine-Particle Bombarding, Aluminum Alloy, Corrosion Resistance, Salt Water, Residual Stress

INTRODUCTION

In recent years, the global warming has become a significant world-scale problem to which we should immediately correspond. One of the methods to solve this problem is to cut emissions of CO_2 from automobiles. Application of high-strength aluminum alloys to automobile parts such as bolts is effective to reduce automobile's weight and to improve their milage. However, high-strength aluminum alloys have an inherent problem about stress-corrosion cracking. If the alloys are used for bolts where tensile stress always acts, such cracking must be perfectly prevented to assure the safety and reliability of products during a long period. Although attempts have been made to suppress stress-corrosion cracking through controlling microstructure by heat treatments, a fundamental solution has been unfound without reduction in the tensile strength (K. Matsumoto, 1993).

In order to prevent stress-corrosion cracking in high-strength aluminum alloys, their corrosion resistance has to be improved. As a useful method for this purpose, we focused on fine-particle bombarding (FPB) treatment (Maeda, 2001, M. Umemoto, 2003, S. Takagi, 2007). In this surface-modification method, after fine-particles are accelerated to a high speed by compressed air, they collide to the surface of materials. Energy of movement that the particles have is converted to heat through plastic deformation which occurs in the vicinity of the surface. Since the particles are very fine, only the surface temperature is greatly increased and elements composing the fine particles can be diffused. If selecting Ti, Zn or Sn as shot-particle elements, we will be able to form surface layers good for improving the corrosion resistance.

Based upon the above background, we conducted this study to investigate the effect of FPB treatment by Ti, Sn or Zn particles on the corrosion resistance of high-strength aluminum alloy 7075-T6. On the surface of the FPBed materials, distributions of the diffused elements were analyzed by electron probe micro-analysis (EPMA) and then residual stress was measured using X-ray technique. To confirm the influence of the FPB treatment on fatigue life, plane-bending fatigue test was carried out for the material FPBed by Ti particles (coverage: 100 %) and the obtained S-N curve was compared to that of the untreated material. For all the materials, corrosion test was conducted in 3 % salt water maintained at 373 K under the condition of high tensile stress applied by special fixtures. After this test, we investigated the change in their corrosion features and tensile strength.

EXPERIMENTAL METHODS

The starting material was round bars with 10 mm diameter of high-strength aluminum alloy A7075-T6511 (JIS). Its yield stress and tensile strength were 598 MPa and 630 MPa, respectively. The alloy was machined to the three configurations shown in Fig.1. The test section of the button-type specimens and fatigue specimens was polished to a mirror surface using emery papers (#320～#2,000) and alumina powders (#3,000, #30,000). We made no surface finish for the bolt-type specimens not to change the shape of threaded portions. For the button-type specimens and bolt-type ones, the FPB treatment was conducted under all the conditions shown in Table 1. The fatigue

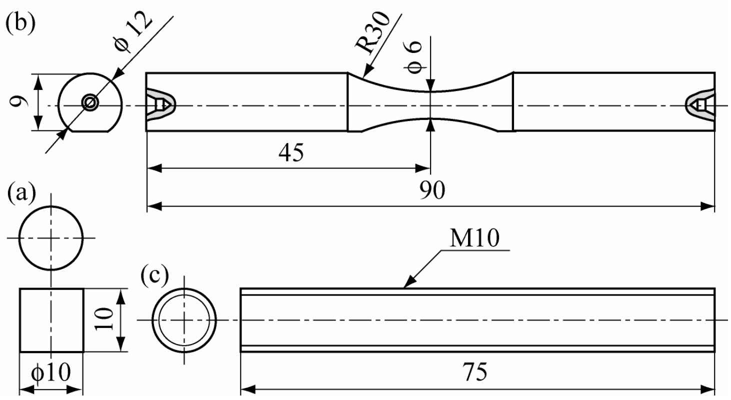

Fig. 1 Configurations of the specimens: (a) button-type specimen, (b) fatigue specimen, (c) bolt-type specimen (mm).

Fig. 2 Bolt-type specimen set in the special fixtures.

Table 1 Conditions of the FPB treatment.

Materials of fine particles	Maximum diameter (μm)	Coverage (%)	Pressure (kPa)	Treatment time (s)
Ti	250	100, 300	600	60
Sn	103	100	600	60
Zn	155	100	600	60

Table 2 Residual stress measured on the surface.

	Residual stress (MPa)
Untreated	-106±6
Ti-FPBed (100 %)	-166±6
Ti-FPBed (300 %)	-158±5
Sn-FPBed	-186±40
Zn-FPBed	-129±28

specimens were FPBed only with Ti particles (coverage 100 %). In addition, the untreated specimens with the three configurations were prepared for comparison.

The distributions of the diffused elements were investigated by EPMA (line analysis). X-ray residual stress measurements were conducted using Cr/Kα ray under the following conditions: diffracting plane (222), diffraction angle 2θ=156.7 deg. and stress constant K=-92.4 MPa/deg. For those experiments, the button-type specimens were used. Plane-bending fatigue test was conducted under a stress ratio R=-1 and frequency of 20 Hz in air at room temperature.

In corrosion test, the bolt-type specimens were fixed to the special fixtures to apply high axial tensile stress, as shown in Fig. 2. Clamping torque was determined for giving 90% (538 MPa) of the yield stress to the specimens. Then, the specimens with the

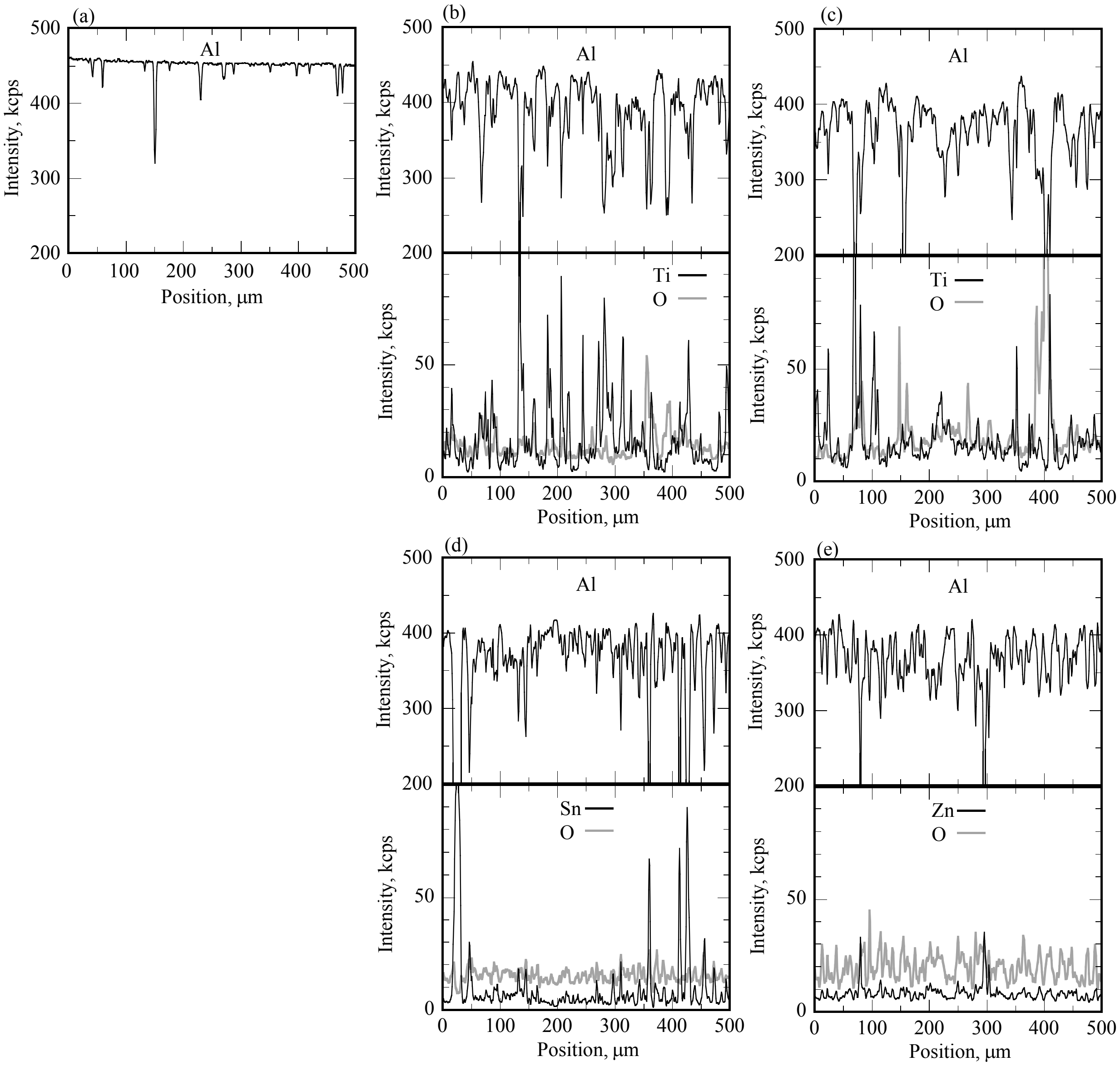

Fig. 3 Results of the EPMA (line analysis): (a) untreated, (b) Ti-FPBed (covertage: 100 %), (c) Ti-FPBed (covertage: 300 %), (d) Sn-FPBed (covertage: 100 %), (e) Zn-FPBed (covertage: 100 %).

fixtures were immersed into 3 % salt water maintained at 371 K until 345.6 ks (4 days), 604.8 ks (7 days) and 864 ks (10 days). After this test, their corrosion features were observed on the cross-section in detail, using an optical microscope. Further, the change in the tensile strength as time elapsed was investigated. For the tensile test, we used a pair of fixtures which had internal threads matching the external thread of the bolt-type specimens.

RESULTS AND DISCUSSIONS

Surface Characteristics and Fatigue Life

Figure 3 shows the results of EPMA carried out on the surface of all materials. Comparing the data about the untreated material (Fig.3 (a)) and the materials FPBed with Ti particles under coverage of 100 % and 300 % (Fig.3 (b), (c)), we can find that the diffusion of Ti occurred over the surface and the amount of diffused Ti was increased with increasing coverage. At the point that the elements composing fine particles were diffused over the surface, the other kinds of FPBed materials were the same (Fig.3 (d), (e)). In addition, since oxygen was detected on all FPBed materials, it was thought that a part of the diffused elements was oxidized during the treatment.

In Table 2, the residual stress of each material is shown. Figure 4 shows the S-N curves of the untreated material and the material FPBed by Ti particles (converage 100 %). As understood in Table 2, compressive residual stress was introduced by the FPB treatment on the surface of all FPBed materials. On the other hand, the fatigue life was improved by the FPB treatment, as shown in Fig. 4. This improvement in the fatigue life would result from the introduction of the residual stress. However, since the value of the residual stress was not so high, the fatigue strength was unchanged.

From the above results, it was clearly shown that we can form surface layers where the elements composing fine particles were diffused and compressive residual stress was introduced through the FPB treatment (Fig.5).

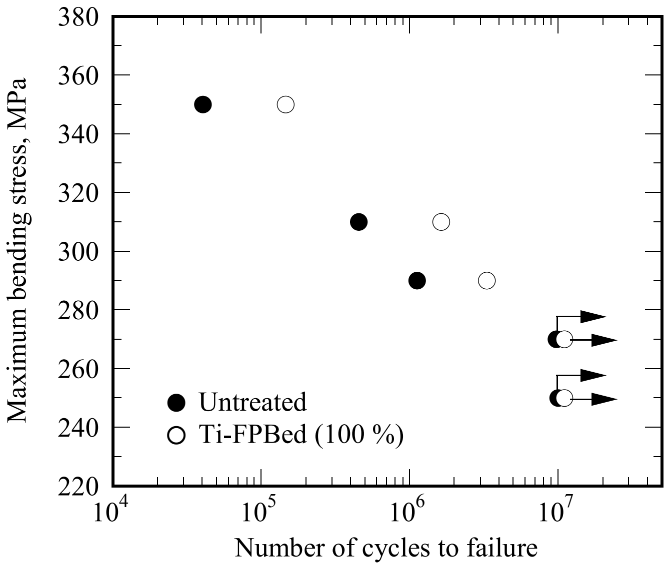

Fig. 4 S-N curves of the materials untreated and FPBed with Ti particles (coverage 100 %).

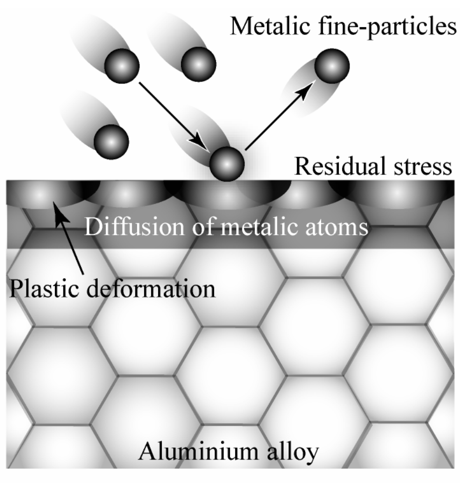

Fig. 5 Illustration of the FPB treatment.

Corrosion Resistance

Figure 6 shows the result of the observation conducted on the cross-section of each material after the corrosion test. Figure 7 shows the change in the tensile strength obtained in all materials with immersion time.

In case of the untreated material, considerable corrosion was observed near the grooves of the screw threads after the immersion for 4 days (Fig.6). This feature of corrosion suggested that cracks were firstly generated at the roots of the grooves under the tensile stress in the corrosion environment and then corrosion was progressed along the cracks. When the untreated material was immersed for longer time, the threaded portions were lost at many sites. As a result, the tensile strength was rapidly decreased by the immersion from 7 days (Fig.7).

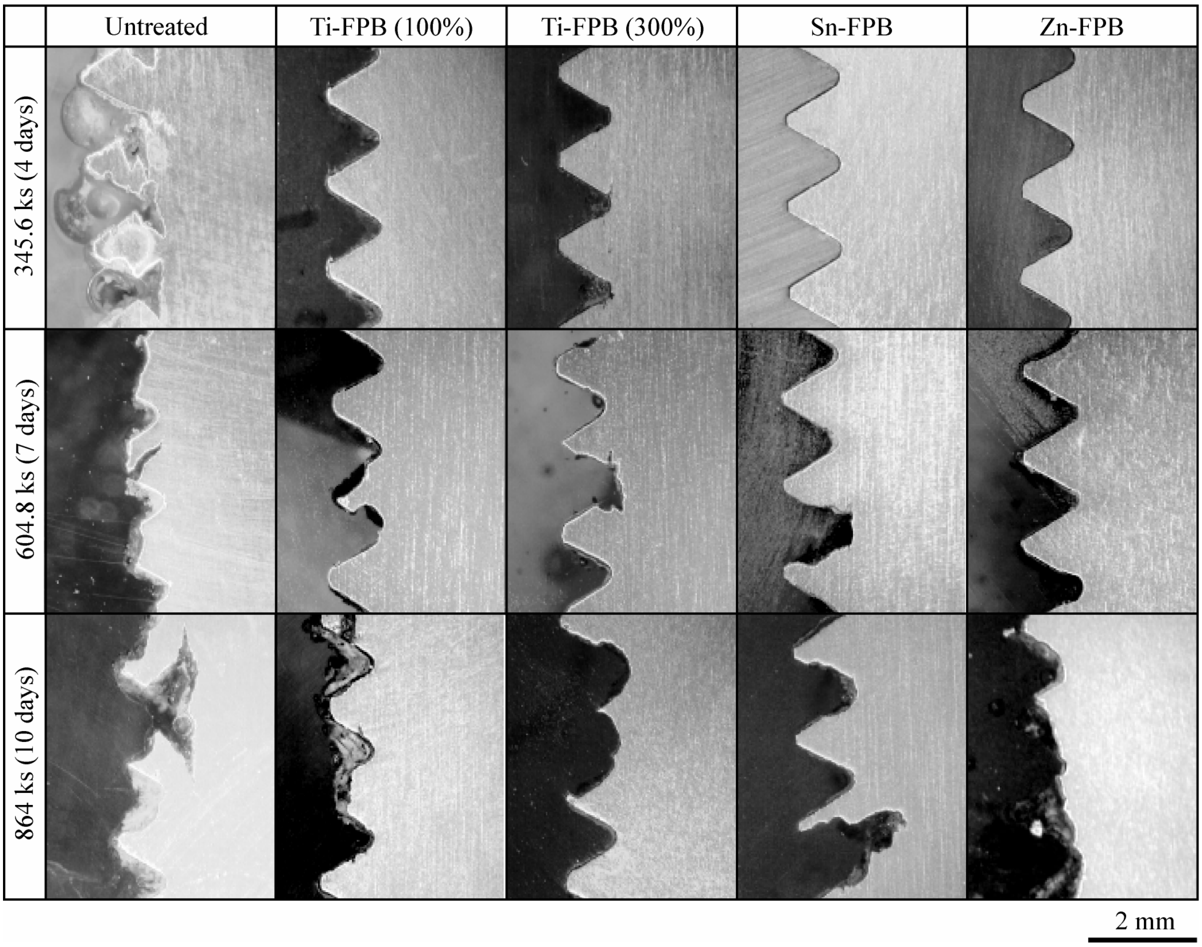

Fig. 6 Features observed on the cross-section of the specimens after the immersion in 3 % salt water (373 K) under high tensile stress..

On the other hand, the features of all FPBed materials revealed that there was no remarkable corrosion until 4 days. Accordingly, their tensile strengths were almost unchanged except the material FPBed by Ti particles (100 %). After immersing the specimens in salt water for 7 days, we can see that the corrosion started at the screw thread. However, comparing the case of untreated material, the corrosion degree observed on each FPBed material was mild and the decreasing rate of the tensile strength was lower. These results meant that the diffusion of the elements such as Ti, Sn and Zn by the FPB treatment can strikingly improve the corrosion resistance of the aluminum alloy.

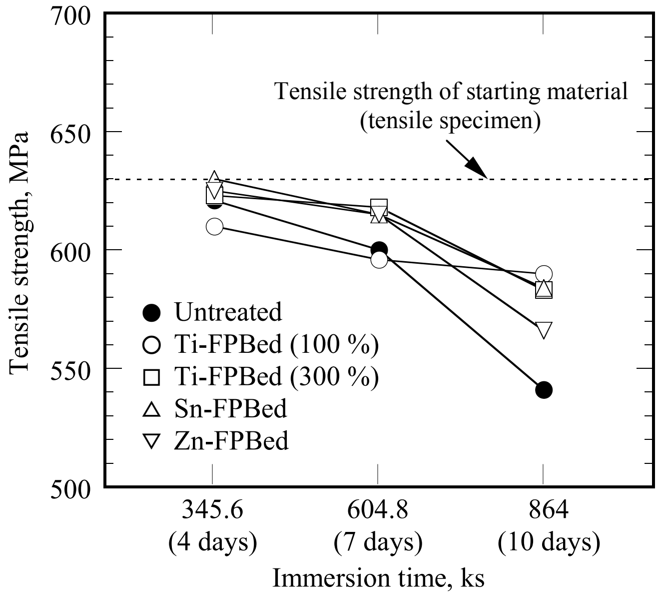

Fig .7 Change in the tensile strength of the bolt-type specimens with immersion time.

After the immersion for 10 days, more remarkable corrosion was observed even on the FPBed materials. Especially, the corrosion degree of the material FPBed with Zn particles was striking. In this FPBed material, diffused Zn would work as sacrificial anode. However, since it was almost completely consumed by the immersion for a long term, the surface condition became the same with the untreated material and the corrosion was rapidly progressed. Nevertheless, the tensile strengths of the FPBed materials were still higher than that of the untreated material because the corrosion was delayed.

CONCLUSIONS

1. The elements composing fine particles such as Ti, Sn and Zn were diffused and compressive residual stress was introduced through the FPB treatment.
2. The corrosion resistance of the high-strength aluminum alloy was greatly improved by the FPB treatment with the fine particles of Ti, Sn and Zn. This improvement resulted from the protection of the substrate from the aggressive environment due to the above surface layers. Furthermore, the tensile strength of the FPBed materials was higher than that of the untreated material because of the delay of the corrosion.

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