Evaluation of Peened Aluminum by Positron Annihilation and Residual Stress

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Introduction

Improvement of fatigue property, i.e. fatigue strength and fatigue life, is a key technology for various structural members of transportation equipment especially in aircraft industries. The weight of fatigue critical parts can be saved by improvement of fatigue property and resulted in better performance of aircraft. Shot peening is the most common conventional technology to improve fatigue property, however, the technology is continuously highly developing today. Recently, for example, novel peening methods such as fine particle shot peening [1], cavitation peening [2], laser peening [3] and ultrasonic peening [4] are being developed and investigated.

As the evaluation methods for shot peened materials, intensity measurement by Almen strip, residual stress measurement by X-ray diffraction (XRD) including its depth profile by chemical etching, are applied as standard evaluation methods. Recently, positron annihilation phenomena have been applied to investigate metal surface disorders. And it is revealed that positron annihilation technique is a useful tool to analyze disordered metal crystals, including vacancy interstitial and dislocation etc[5]. K. Ono et al. reported that Doppler broadening of positron annihilation radiation (DBAR) technique, which is one of positron annihilation technique, effectively evaluated the property of conventional shot peening (SP) and fine particle shot peening (FPSP) [6].

Objectives

In this study, SP, FPSP and cavitation peening in water (CPW) have been evaluated by X-ray residual stress measurement and two kinds of positron annihilation technique, DBAR and positron lifetime (PL) measurement method. And effectiveness of positron annihilation technique for peened material has been evaluated in comparison with X-ray residual stress measurement.

Evaluation of CPW aluminum by positron annihilation technique seems to be not published previously so far. It is interesting that how the lattice defects created by CPW are evaluated by two kinds of positron annihilation technique, DBAR and PL measurement method.

Methodology

Specimens

Almen strip Y made of 7075-T6 were used as the specimens for all treatment and measurement.

Table 1 Each peening conditions

SP (Shot Peening)			
Condition number	SP1	SP2	
Media type	Conditioned Cut Wire (CW28)		
Diameter [μm]	710		
Projecting method	Suction		
Intensity [mmA]	0.134	0.284	
Coverage [%]	more than 100		
FPSP (Fine Particle Shot Peening)			
Condition number	FPSP1	FPSP2	
Media type	Gas atomized particle (FeCrB)		
Diameter [μm]	44-125		
Air pressure [MPa]	0.1	0.2	
Processing time [s]	80		
Nozzle distance [mm]	50		
Arc height [mmN]	0.106	0.158	
Coverage [%]	more than 100		
CPW (Cavitation Peening in Water)			
Condition number	CPW1	CPW2	CPW3
Processing time [s]	180	240	300
Injection pressure [MPa]	9.5		
Nozzle distance [mm]	50		

Peening

Table 1 shows the each peening conditions of SP, FPSP, and CPW. Cavitating jet was blown on fixed place of specimen and blowing period was changed by CPW while specimens or nozzles were moved in case of SP and FPSP.

Residual stress measurement

The surface compressive residual stress of the specimens was measured by μ-x360 device made by PULSTEC INDUSTRIAL CO., LTD. The measurement principle of μ-x360 is based on single incident angle method (cos α method) [7].

The penetration depth of the X-ray into aluminum will be a few tens micro meters. The depth profiles of residual stress were obtained by removing of surface layer with chemical etching. In addition, integrated values of compressive residual stress depth profile were calculated by an arithmetic method for each peened specimens [8].

Positron annihilation measurement

DBAR measurement

The energy extension of annihilation γ-rays was expressed in terms of S-parameter. As shown in Figure 1, the S-parameter was defined by the ratio of the number of counts as the center region (dS region) of the energy peak of annihilation γ-rays to the number of counts for the total range (dA region). When the density of lattice defect increases, the S-parameter increases [6].

Figure 2 shows the schematic diagram of DBAR instrument used for this study.

The instrument consists of a sealed ^{22}Na positron source, a high resolution γ-ray Ge detector, an amplifier, a multi-channel analyzer. In this study, a sealed positron source was positioned between the specimens. The diffusion depth of positron into aluminum will be around 300 micron meters. The γ-rays were generated as a result of annihilation of positron with electron in the specimen, and the γ-rays were detected by Ge detector located below the specimen and the positron source [6]. The DBAR measurements were continued to obtain 30,000 counts of γ-ray counts at center region of spectrum for about 25 min. The measurements were executed at least 5 times for each specimen.

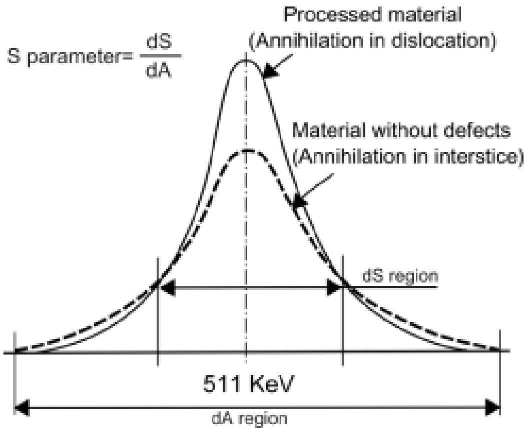

Figure 1 Concept of DBAR measurement

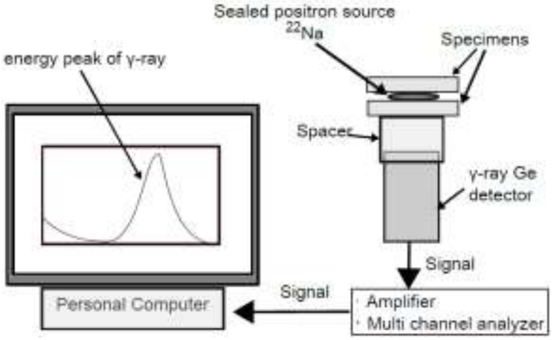

Figure 2 Schematic diagram of DBAR

PL measurement

PL technique is an evaluation method to detect positron lifetime. Figure 3 shows the schematic diagram of PL instrument used for this study. The instrument consists of a sealed ^{22}Na positron source (same as DBAR), two photoelectron multiplication tubes (PMT), a BaF_2 scintillator, a digital oscilloscope. In this study, a sealed positron source was positioned between the specimens. The PL measurements were continued to obtain 1,000,000 counts of positron annihilation. The measurements were executed at one time for each specimen.

Results and analysis

Residual stress measurement

In case of SP and FPSP specimens, the surface residual stress of more intense condition is lower than that of less intense condition. The surface residual stress of CPW specimens is higher than that of SP and FPSP.

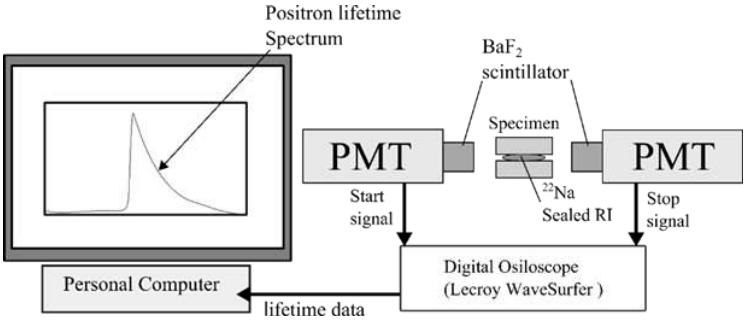

Figure 3 Schematic diagram of PL device

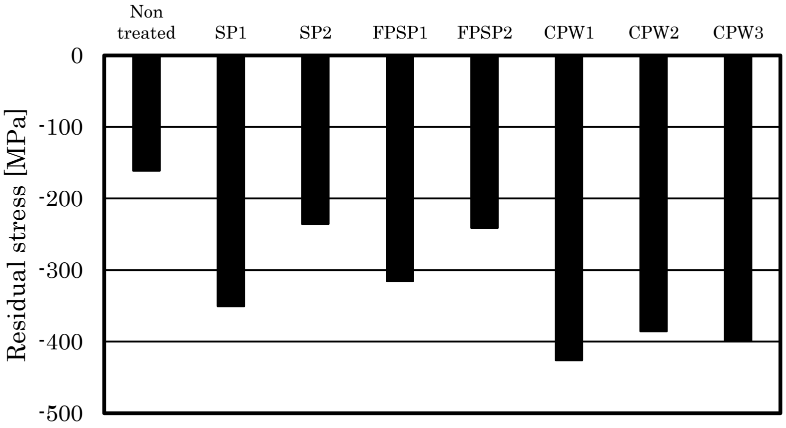

Figure 4 Surface residual stress

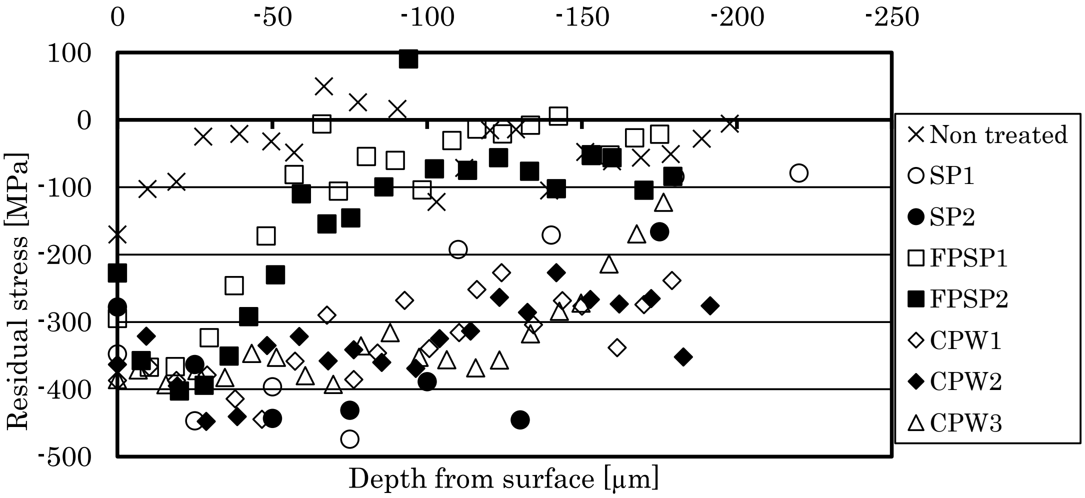

Figure 5 Depth profile of residual stress

Figure 5 shows the depth profile of residual stress. The horizontal axis shows the depth of etched surface from the original specimen surface. The high compressive residual stress of SP specimen is distributed to more than 200 μm depth.

On the other hand, the high compressive residual stress of FPSP specimens at the surface sharply decreases with increasing the depth and being almost constant at around 100 µm depth and more.

Positron annihilation measurement

Figure 6 shows the relationship between S-parameter and integrated value of residual stress. The integrated value of compressive residual stress was calculated from the data of figure 5. The integrated value of compressive residual stress has liner relationship with the S-parameter. The S-parameter increased with increasing the integrated value of compressive residual stress regardless of peening types.

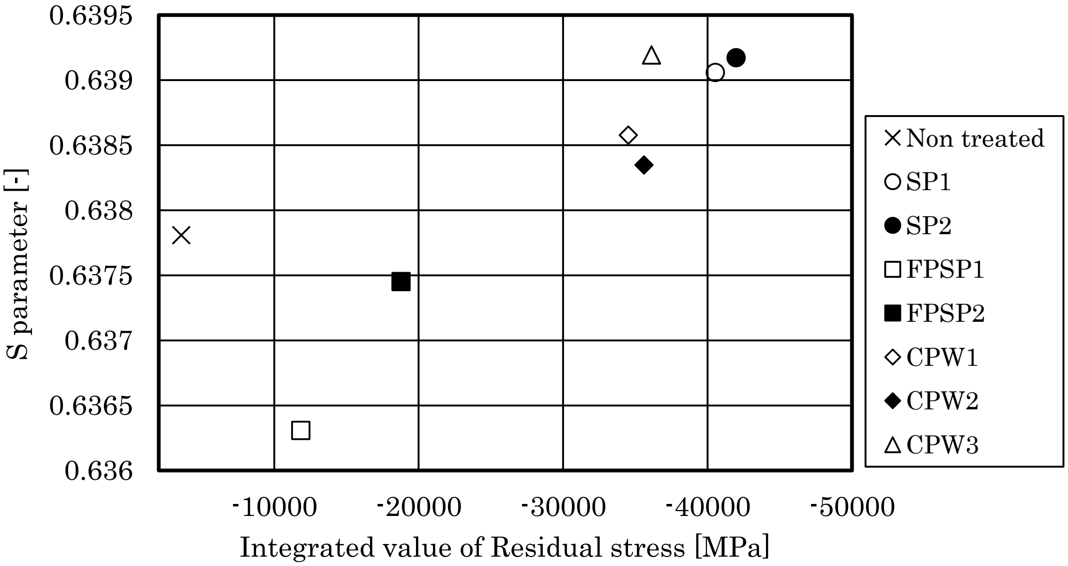

Figure 6 S-parameter vs integrated value of residual stress

Figure 7 shows the relationship between positron lifetime and integrated value of residual stress. The tendency is the same as that of figure 6, the positron lifetime increased with increasing the integrated value of compressive residual stress regardless of peening types. SP1 specimen shows somewhat higher positron lifetime.

These results suggest that the lattice defects, such as vacancy, interstitials and dislocation, induced by peening can be detected by both DBAR and PL.

According to the above-mentioned linear relationship between S-parameter/Positoron lifetime and integrated value of residual stress obtained in this study, the kinds lattice defects created by CPW seem to be the same as those created by SP and FPSP.

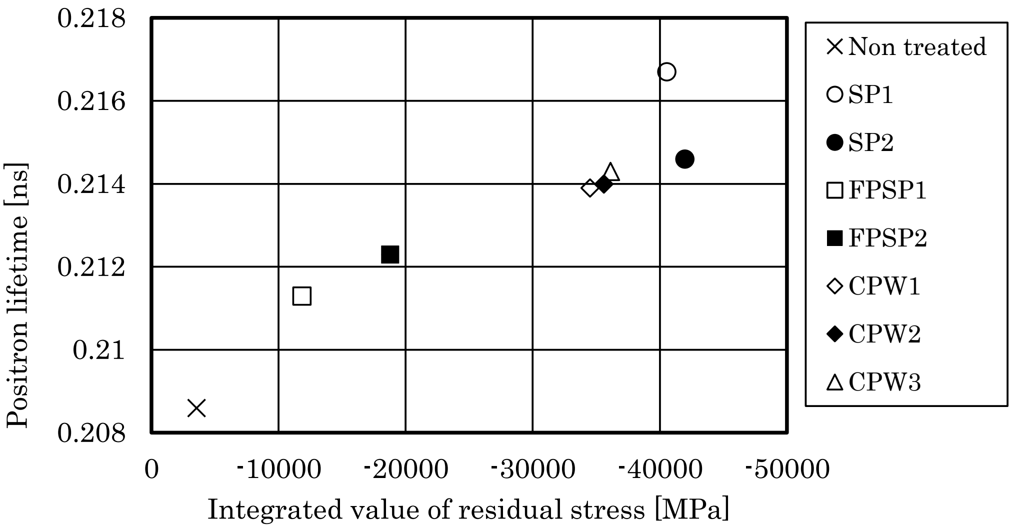

Figure 7 Positron lifetime vs integrated value of residual stress

Conclusions

SP, FPSP and CPW treated extra super duralumin specimens were evaluated by residual stress measurement and two kinds of positron annihilation methods. The conclusions are summarized as follows:

(1) In case of SP and FPSP, the surface compressive residual stress of more intense condition is lower than that of less intense condition. However the integrated value of the residual stress is higher in case of more intense condition.
(2) Both the S-parameters and the positron lifetime increased with increasing the integrated value of compressive residual stress regardless of peening methods.
(3) It is suggested that both DBAR and PL are candidate methods to evaluate peened aluminum.

References

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