Evaluation of Shot Peened Aluminum by Doppler Broadening of Positron Annihilation Radiation Technique

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ABSTRACT

Shot peening has been applied to fatigue improvement of aircraft parts. Recently, fine particle shot peening (FPSP) technology has been developing to obtain superior fatigue property compared with conventional shot peening (CSP). Process of shot peening is controlled by intensity measurement using almen strip. X-ray diffraction (XRD) residual stress measurement, including its depth profile by chemical etching, is supplementary applied for more detailed understanding of the shot peened material. The Doppler broadening of positron annihilation radiation (DBAR) technique is a powerful tool to analyze disordered metal crystals, including vacancy, interstitial and dislocation, while it has been already applied to the investigation of polymer materials. Aluminum specimens were prepared and treated by FPSP and CSP with various conditions, i.e. media material, size and intensity. Evaluation of the aluminum specimens has been made with residual stress measurement by XRD and S-parameter by DBAR. The DBAR measurement system consists of a γ-ray Ge detector and a multi-channel analyzer. A sealed positron source of ^{22}Na was placed on the shot peened specimens, and the energy spread of annihilation γ-ray photo peak (S-parameter) was measured to evaluate the density of lattice defects introduced through the shot peening process. Surface compressive residual stress by XRD method properly represents the surface sensitive property of FPSP. While DBAR results suggest that S-parameter corresponds to integrated value of compressive residual stress of both FPSP and CSP.

KEYWORDS: Shot Peening, Fine Particle, Positron Annihilation, Residual Stress, Non-destructive measurement

INTRODUCTION

Shot peening is industrially applied including aerospace to improve fatigue properties of structural parts. Recently, some of novel peening methods such as cavitation peening [1] ,dry ice shot peening [2] , laser peening [3] are developing because of increasing requirements of weight reduction and advanced fatigue improvement. Fine particle shot peening (FPSP) is one of the new peening technologies which can induce higher compressive residual stress at surface layer. The technology has been developed in Japan mainly for automotive industries. Recently, it was reported that the fatigue property of aluminum 7075 with FPSP is much superior than that with conventional shot peening (CSP) [4,5]. Process of shot peening is commonly controlled by the Almen intensity with the strip, and X-ray diffraction is used additionally. However, the Almen intensity is not a suitable parameter to evaluate FPSP condition because the deformation by peening (arc height) is much less than that of CSP.

Doppler broadening of positron annihilation radiation technique (DBAR) is a measurement method which commonly used for evaluation of polymer material. The technique measure energy broadening of annihilation γ-rays peak [6,7]. There are a few reports on the relationship between peening intensity and S-parameter by DBAR [8]. In this study, evaluations by DBAR and XRD, including the residual stress depth profile, are compared for aluminum, 5052-H34 and 7075-T6, with FPSP and CSP, respectively.

EXPERIMENTAL METHODS

Specimens

Two types of aluminum specimens were prepared and used for the measurement of DBAR and XRD. 5052-H34 machined specimens which dimension of 30mm square and 5mm thickness were used for FPSP while Almen strip Y specimens made of 7075-T6 were used for CSP.

Shot peening

Table 1 shows the shot peening conditions. For FPSP process, fine particles with 50μm average diameter were projected by a suction type shot peening machine. The minimum peening coverage was more than 100%. For CSP process, Almen strips were peened by conditioned cut wire, and zirconia by suction or pressure type peening machine. The Almen intensity and coverage by CSP were 3.2–15.2mm inch A and above 100% respectively.

Table 1: Shot peening conditions

FPSP conditions						
Code	FHB	SUS	Ti	FHS	Sn	Zn
Media type	Hardened glass	Stainless steel	Titanium	High speed steel	Tin	Zinc
Average diameter [μm]	53	53	45	53	53	45
Air pressure [MPa]	0.2					
Processing time [s]	20					
Nozzle distance [mm]	100					
CSP conditions						
Media type	Conditioned Cut wire (CW28)				Zirconia (B40)	
Diameter [μm]	710				250 - 425	
Projecting method	Suction		Pressure		Suction	
Intensity [mm inch A]	3.4	7.2	11.2	15.2	3.2	5.7

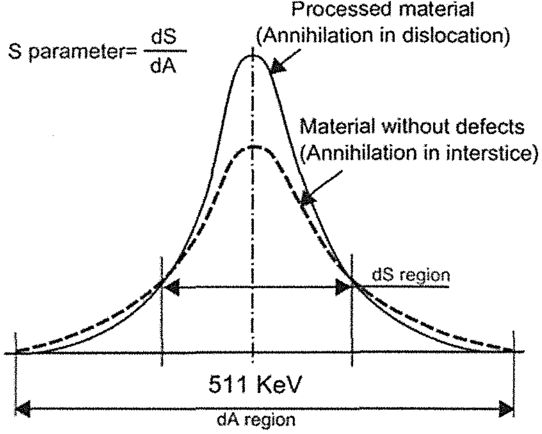
DBAR measurement

DBAR technique is an evaluation method, which can detect the density of lattice defect in materials by impressing γ-ray energy generated by positron annihilation with electron.

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.

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 multichannel analyzer. In this study, a sealed positron source was positioned above or 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 rays were detected by Ge detector located below the specimen and the positron

Fig. 1: Concept of DBAR measurement



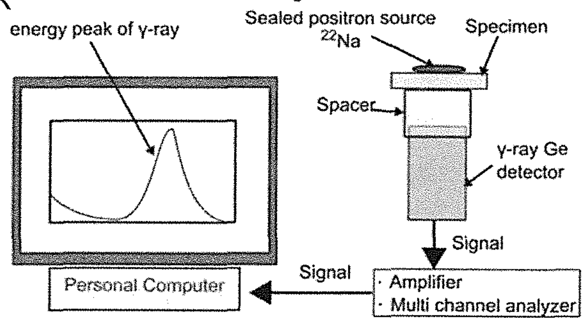


Fig. 2: Schematic diagram of DBAR device

source. The DBAR measurements were continued to obtain 50,000 counts of γ-ray counts at center region of spectrum for about 50 min. The measurements were executed at least 4 times for each position of the specimen to exclude outliers.

Residual stress measurement

For comparison, the surface compressive residual stress of the specimens was measured by two types of XRD devices, cosα [9] and sin$^2\psi$ methods both with a chromium Kα tube. The penetration depth of the X-ray into aluminum will be a few tens micron meters. Also, the depth profiles of residual stress were obtained by stepwise electrolytic etching method. In addition, an integrated value of compressive residual stress depth profile was calculated by an arithmetic method [10].

RESULTS AND DISCUSSIONS

FPSP specimens

Figure 3 shows the relationship between the S-parameter and surface residual stress. Each date shows the average of four or five measured S-parameters without outliers. There is no tendency between the two parameters.

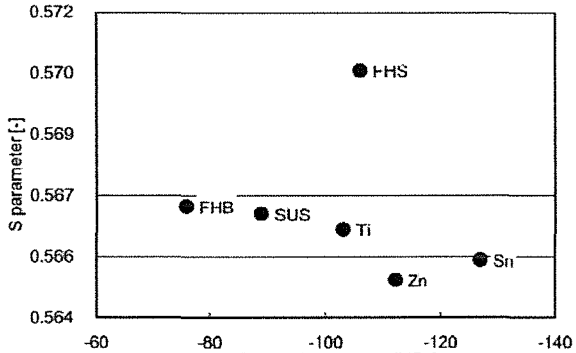


Fig. 3: S-parameter vs surface residual stress layer

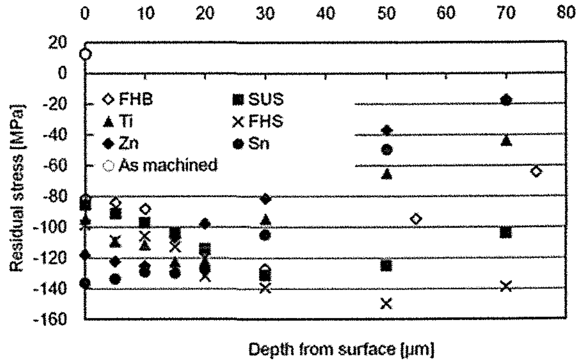


Fig. 4: Distribution of residual stress

Figure 4 shows the depth profile of residual stress. The horizontal axis shows the depth of etched surface from the original aluminum surface. Therefore, the measured residual stress values are the mean value from the measured surface into the specimen by penetrating X-ray.

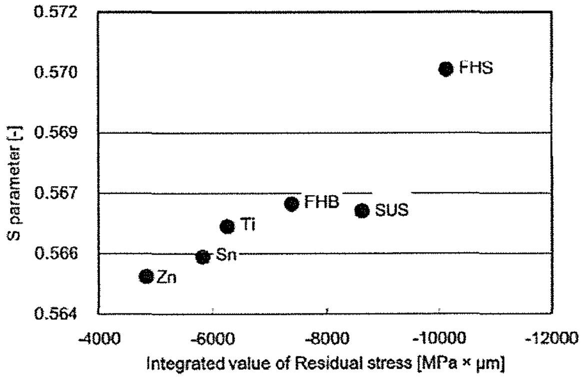


Fig. 5: S-parameter vs integrated value of residual stress

The as machined surface layer has tensile residual stress up to 13 MPa due to the surface machining. The specimens peened by tin and zinc show high surface compressive residual stress, however, the compressive residual stress decreased with increasing the depth. On the other hand, the other specimens show the maximum compressive residual stress inside the specimen between 15 and 50 μm. The different hardness of the FPSP medias probably influences the depth profile of residual stress in conjunction with the hardness of the specimen.

Figure 5 shows the relationship between the S-parameters and the integrated value of compressive residual stress by calculation. The S-parameters increased with increasing the integrated value of compressive residual stress.

CSP specimens

Figure 6 shows the relationship between the surface residual stress and the measured almen intensity. The surface compressive residual stress linearly decreased with increasing Almen intensity apparently. While there was no tendency between the S-parameter and intensities as shown in Figure 7.

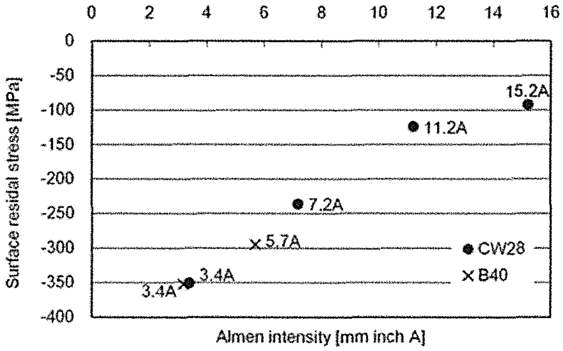


Fig. 6: Intensity vs surface residual stress

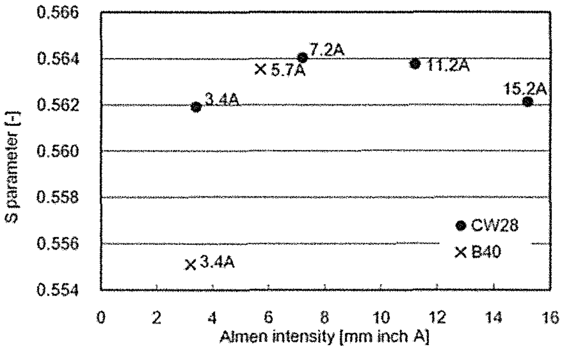


Fig. 7: S-parameter vs intensity

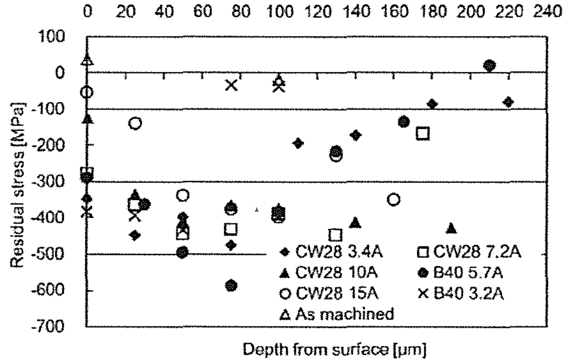


Fig. 8: Distribution of residual stress

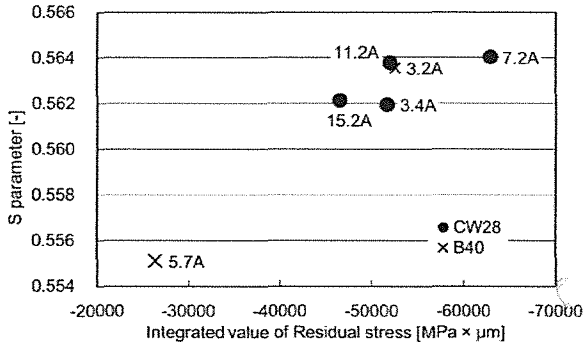


Fig. 9: S-parameter vs integrated value of residual stress

Figure 8 shows the depth profile of residual stress for CSP specimens. The CSP specimens showed much deeper distribution of compressive residual stress layer up to 200μm compared with FPSP in Figure 4. And all the specimens showed maximum compressive residual stress inside the specimen. The residual stress distribution is the reason of the apparent inverse relationship between the Almen intensity and the surface residual stress.

The integrated value of compressive residual stress was calculated and the relationship with the S-parameter is shown in Figure 9. The S-parameter increased with increasing the integrated value of compressive residual stresses.

CONCLUSIONS

FPSP and CSP aluminum specimens were evaluated by DBAR and XRD methods. The conclusions are summarized as follows:

(1) The depth profiles of compressive residual stress by XRD widely changed with the peening media and the condition.
(2) XRD stress measurements at peened original surface reflected the residual stress at surface layers. Therefore, XRD surface residual stress measurement is a suitable tool to evaluate FPSP.
(3) The S-parameters increased with increasing the integrated value of compressive residual

stress for both FPSP and CSP.

(4) DBAR properly evaluate total deformation at surface layer which was introduced by shot peening process.

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