Novel System for Potential Non-destructive Material Inspection Using Positron Annihilation Spectroscopy on Shot Peened parts

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Abstract

Shot peening is widely used for surface-treating of automotive and aerospace parts as a powerful method to enhance the fatigue durability. The efficacy of shot peening is usually evaluated by the X-ray diffraction, but this method is destructive. In order to increase the reliability of the treatment in various fields, a completely non-destructive method is strongly required. A new positron annihilation spectrometer, consisting of a radioactive-^{22}Na (^{22}NaCl) positron source sealed between two thin films, a Ge gamma ray detector and an accompanying digital spectrometer, was developed for measurement system of shot peening effects. By using this system, positron annihilation gamma ray spectra for several shot peened materials including the inner surface of pipes were measured and the shape of the gamma ray spectra was analyzed as the line-shape (S) parameter. A good relationship between the S parameter and residual compressive stress profile was obtained.

Keywords: Positron Annihilation, Non-destructive inspection, Residual compressive stress.

Introduction

Shot peening is widely used for surface-treating of automotive and aerospace parts as a powerful method to enhance the fatigue durability. The condition of shot peening could be strictly controlled by monitoring such parameters as shot flow rate, air pressure, etc. during the treatment with several monitoring systems. The efficacy of shot peening is usually evaluated by the X-ray diffraction, but this method is sometimes destructive. In order to increase the reliability of the treatment in various fields, a completely non-destructive method is required strongly.

In the present work, a positron annihilation spectrometer, consisting of a radioactive-^{22}Na positron source sealed between two thin films, a Ge gamma ray detector and an accompanying digital spectrometer, was constructed as a non-destructive inspection system. By using this system, positron annihilation gamma ray spectra for several shot peened materials including the inner surface of pipes were measured and the shape of the gamma ray spectra was analyzed as the S parameter. The new system does not require cutting of the sample and is potentially applicable to non-destructive inspection of various shot peened materials [1]. This paper describes the principal mechanism of the new method and shows the results of positron annihilation obtained for non-peened and shot peened materials. The positron-annihilation system with a Ge gamma ray detector is highly promising for the completely non-destructive inspection of various peened parts.

Experimental Methods

Positron annihilation spectroscopic system and principle

Figure 1 shows the schematic illustration of the constructed positron annihilation spectrometer for Doppler broadening measurements. As shown in this figure, the main constituent is a Ge gamma ray detector and a ^{22}Na radioisotope positron source with an activity of 1 MBq. In our system the Ge detector is electrically cooled with an uninterruptible power supply, so that no liquid nitrogen is required to cool the Ge crystal. High energy positrons are emitted (E_{max} = 545 keV) from ^{22}Na and are implanted into the material with several tens micrometers in depth (< 200 μm in case of steel) [2]. The positrons are thermalized and annihilate with surrounding electrons, followed by the emission of annihilation gamma rays of around 511 keV.

Figure 2 shows the principle of the Doppler broadening method. Positron annihilation is sensitive to the variation of open spaces in materials at the atomic scale. Positrons thermalized in a material are easily trapped by defects such as vacancies, dislocations, microvoids etc. Positrons in the defect-free region have a higher possibility of annihilation with core electrons with higher velocities, leading to the considerable Doppler broadening of the energy distribution due to the annihilation gamma rays centered at 511 keV. On the other hand positrons trapped in defects have a lower probability of annihilation with core electrons, which causes “narrowing” of the 511-keV annihilation photo peak. The extent of this “narrowing” is usually quantified by using the S parameter.

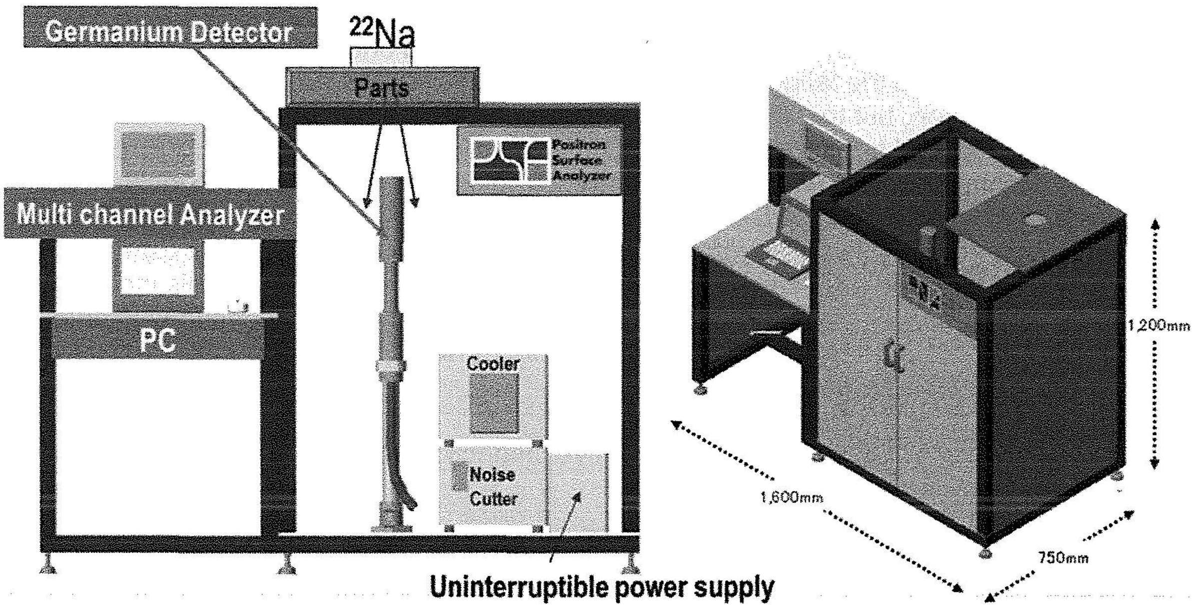


Fig. 1 Positron annihilation spectroscopic system with Doppler broadening method

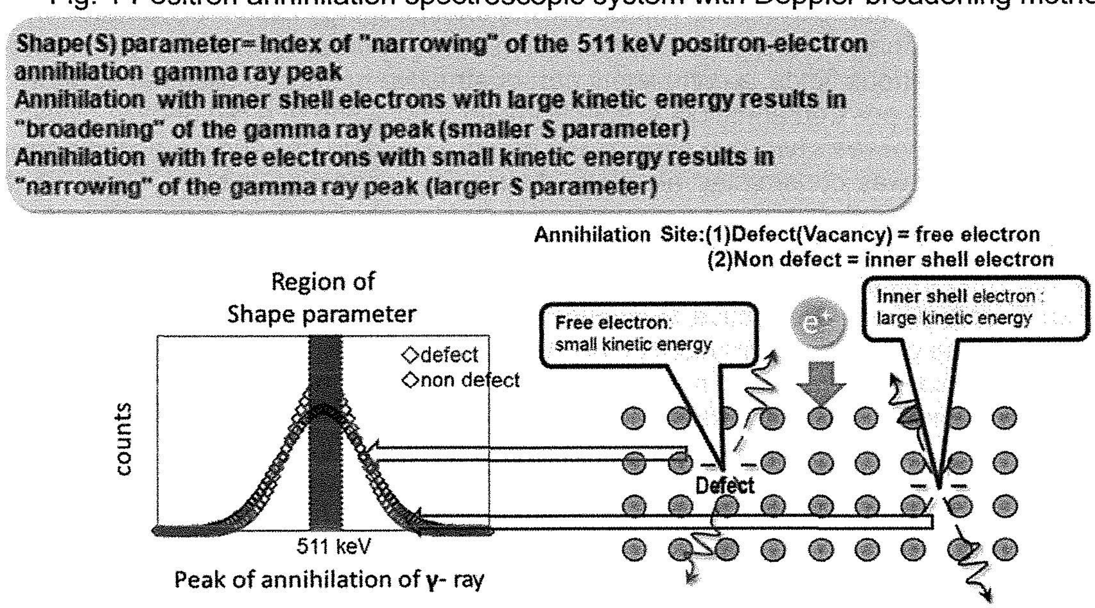
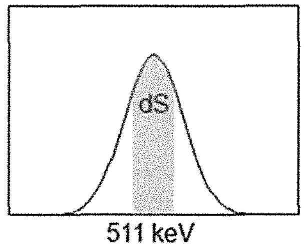


Fig. 2 Principle of the Doppler broadening method



$$S = \frac{dS}{\text{total counts (dA)}}$$

Peak annihilation of gamma ray

Fig. 3 Definition of the S parameter

The S parameter is defined as a fraction of gamma-ray counts in the central window (dS) to those in the whole 511 keV peak (dA) as shown in Fig 3.

S parameter = dS / dA (1)

The width of the central window is arbitrarily determined so that the S parameter is in the range from 0.4 to 0.6. For the peened materials with defects such as dislocations, the S parameters are larger than for the non-peened materials, due to the “narrowing” of the 511-keV photo peak as a result of the positron trapping by the defects.

Shot peening treatment and X-ray diffraction measurement

Shot peening treatments were conducted for two-kind parts of different materials. One is block shape test specimens made from a carburized gear steel and the other is tube samples made from a carbon steel, which is AISI 1050. Table 1 shows the shot peening conditions for the block shape test specimens. Shot peening for the tube samples was performed at the inner side of the tubes by using an air type peening device with a 0.6 mm conditioned cut wire. The residual stresses were determined by using an X-ray diffractometer with the $\sin^2\Psi$ - method. The residual stress distribution was obtained by repeated X-ray measurements and electro-chemical polishing. After the measurements, the integrals of the stress profiles were calculated over 0 - 30 micrometers and 0 - 50 micrometers in depth, in order to compare those with the corresponding S parameters.

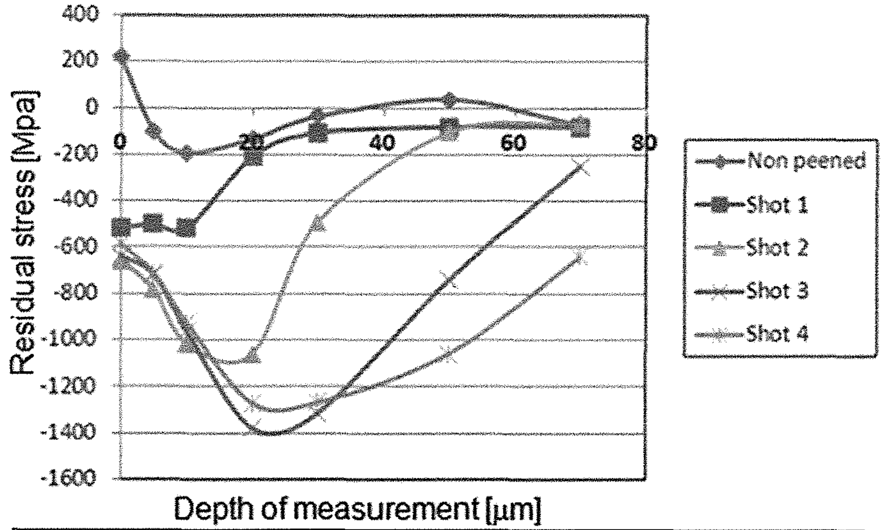
Table 1 Shot peening conditions for block test specimen

Shot conditions	1	2	3	4
Peening machine	Air type(Direct pressure)			
Shot media	Micro Bead 50 micron HV700	Micro Bead 100 micron HV700	CCW 0.177mm HV800	CCW 0.25mm HV800
Air pressure	0.15MPa	0.25MPa	0.30MPa	0.40MPa
Peening time	24sec (6pass)			
Nozzle distance	200mm			
Table rotating speed	15r.p.m.			
Coverage	300%			
Arc hight	0.066mmN	0.196mmN	0.382mmN	0.508mmN
	0.018mmA	0.084mmA	0.150mmA	0.182mmA

Experimental Results

Carburized block test specimens

Figure 4 shows the residual stress profiles of the block test specimens subjected to the different shot peening conditions. In this figure are also shown the integral values of the residual stress profiles, which are calculated down to 30 micrometers and 50 micrometers.



Integral Value (MPa X mm)	Down to 30 micron	Down to 50 micron
Shot 1 (Micro Bead 50 micron)	0.990	1.159
Shot 2 (Micro Bead 100 micron)	2.675	3.213
Shot 3 (CCW 0.177mm)	3.109	5.417
Shot 4 (CCW 0.250mm)	3.345	5.424

Fig. 4 Residual stress profiles and calculated integral values

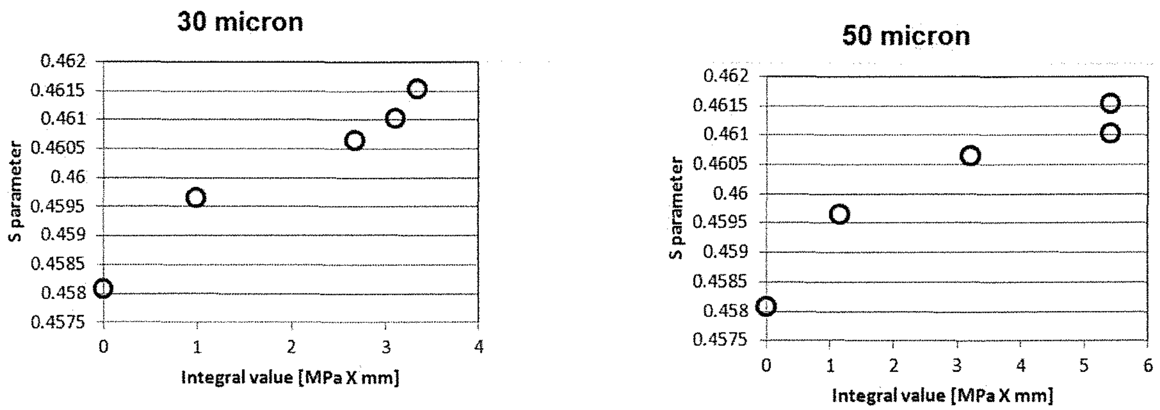


Fig. 5 Relation between the integral value of residual stress profiles

and the S parameters

As shown in Figure 5, the relation between the integrated residual stresses and the S parameters is almost linear and the S parameter for the non-peening sample is lower than that for all the specimens subjected to the shot peening. Here, the measurement time for the S parameter was only 7 minutes. In conclusion, the S parameter by the positron annihilation spectroscopy could non-destructively represent the surface residual stress profile at the sub-surface layer.

Pipe measurement

In order to confirm the peening performance for the inner surface of the peened tubes, cutting the sample should be required in the case of the X-ray diffraction. So the positron annihilation analysis was evaluated for this application as a completely non-destructive method. A peened pipe sample as shown in Figure 6 was prepared and the ^{22}Na radioisotope source was placed on the inner surface of the pipe. Here, the shot peening was conducted using two sized shots with different hardness. Table 2 shows the shot peening conditions and the measured S parameters.

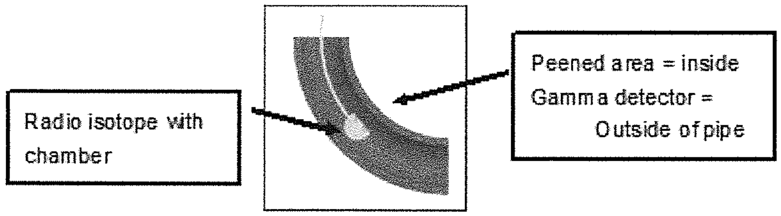


Fig. 6 Illustration of the peened pipe and the location of radioisotope

Table 2 Shot peening conditions and measured S parameter

Shot hardness and Coverage	1	2	3	4
HV600 Coverage 100%	0.46014	0.46107		
HV600 Coverage 50%	0.46136	0.46068		
HV700 Coverage 100%	0.46082	0.46109		
HV700 Coverage 50%	0.45982	0.45865		
Non peened part	0.45611	0.45620	0.45604	0.45587

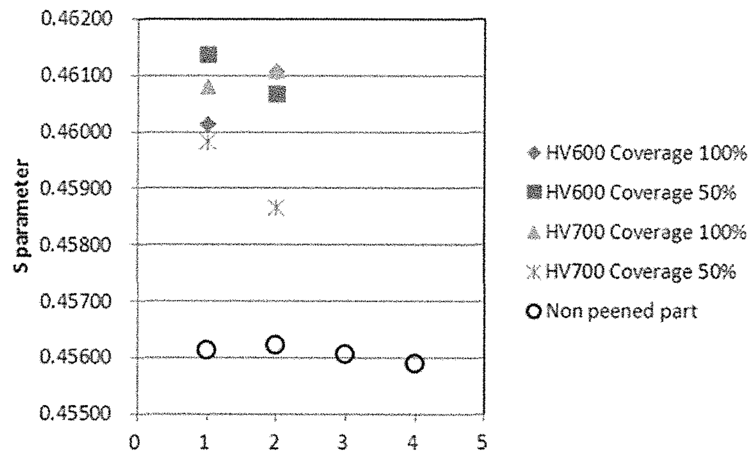


Fig. 7 Relationship between the S parameters and shot peening conditions

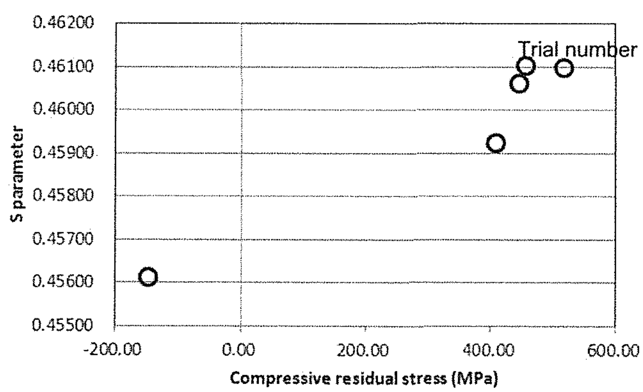


Fig.8 Relationship between the surface compressive residual stresses
and the S parameters

As shown in figure 7, the S parameter of the non–peened specimen was completely lower than those for the peened specimens. So, the non-destructive inspection could be applied for the pipe sample. Further the relation between the S parameter and the surface residual stress value at the inside of the pipe is shown in Figure 8. As one can recognize easily a good relation is observed; it means that the S parameter could represent the surface residual stress profile with the 50-μm sub-surface layer after the proper calibration.

Conclusion

In the present study, the positron annihilation analysis was confirmed to be a non-destructive inspection method. Following is a summary of the results obtained;

(1) It was confirmed that the S parameter by the positron annihilation spectroscopy could represent the surface residual stress profile at the sub-surface layer without any destruction of the sample materials.

(2) The positron analysis could work for peened pipe parts and represent the surface residual stress.

Reference

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