Subsurface Residual Stress Nondestructively Quantified for Alloys

PIPA measures shot peening effects at the atomic level
Advances have been made in the design of metallic/intermetallic alloys and in the surface treatments which increase performance and decrease component weight. One such surface treatment is shot peening, which is used to improve durability and limit crack initiation in high performance/high stress components, such as turbine blades and engine parts in aircraft. However, material evaluation technologies have been limited in their ability to characterize the effect of these surface treatments on a component's structural integrity. Shot peening induces subsurface compressive stress that increases a component's resistance to cracking. It remains unclear how this compressive stress interacts with thermal and mechanical fatigue over time. Consequently, little credit can be taken for shot peening in design and maintenance activities.

Positron Systems, Inc. (PSI) has commercialized an advanced material evaluation process capable of quantifying the effects of subsurface compressive stress and measuring its release, or relaxation, over time due to varying thermal/mechanical conditions. Photon Induced Positron Annihilation (PIPA) is a patented technology that can assay the atomic micro-structure of a component to determine the effects of surface treatments. PIPA can be used to measure shot peening intensity levels, quantify the subsurface compressive stress, and monitor its long term effects on structural integrity.

In this case, the customer wanted to know if PIPA would quantify subsurface compressive stress in test Almen strips and engine propulsion components. By examining the lattice structure changes in the test specimens, PIPA was able to provide quantifiable measurement data that corresponded with the expected shot peening levels in the Almen strips. Figure 1 and Table 1 show this correlation. The evaluation was conducted at PSI's Test and Analysis Center in Pocatello, ID.

Challenges
There were several immediate challenges. First, a quick turnaround time was important to the customer. The "conventional" measurement of residual stress by x-ray diffraction was not applicable because the samples were a single crystal super alloy material. Second, the dislocation density depth profile of the samples was unknown; therefore, a bulk and surface analysis technique was required. And third, the turbine blade geometry was complex. These challenges for the PIPA technology were addressed in two phases: Phase I consisted of a feasibility study on test Almen strips that had been subjected to shot peening at known intensity levels (new to approximately 6A); Phase II was designed to determine the unknown shot peening intensities for new turbine blades which were sent to Positron Systems as blind samples. In both cases, the goal was to demonstrate that PIPA could provide quantifiable data on shot peening intensity levels. No other NDT technology is capable of providing similar data.

How the process works
PIPA uses a patented approach to create positrons within bulk materials. Positrons are trapped at lattice structure defects or dislocations. After losing momentum and annihilating with electrons, 511 keV gamma rays are produced and analyzed.

A second approach was used to rapidly create positrons at the surface of the material which limited the depth of penetration to approximately 1 mm. By incorporating both methods, it was possible to accurately measure the dislocation density at the surface and in the bulk material.

Figure 2 and Table 2 show the results of the comparison between the sample blades and the certified blade.

Collecting and understanding data
Gamma spectroscopy with Doppler broadening analysis is used to determine the momentum distribution of the positron annihilation gamma rays. Annihilations that take place at induced compressive stress or defected areas have energies at 511 keV. Other annihilations have higher or lower energies, which represent non induced stress or non defect areas. Data is reported as a "line shaping parameter," or "S" parameter. Calibrations are performed by obtaining "S" parameter data from as-manufactured materials, or at undamaged or non shot peened areas on the test sample itself. This provides a quantitative analysis of defect density and fatigue damage or induced compressive stress. The S parameter is highly sensitive to small changes in defect dislocation density. This can be seen in Tables 1 & 2, when comparing the S parameter results for each phase. This data is charted graphically in Figures 1 & 2.

Figure 1. Phase I - S Parameter Results

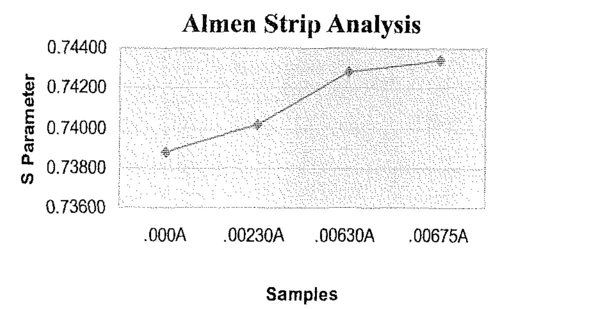

Table 1. Phase I - Almen Strip S Parameter Results

Sample	Results
.000A	.73882
.00230A	.74019
.00630A	.74284
.00675A	.74342

Phase I - Almen Strips
Phase I demonstrated that PIPA can quantify compressive stress levels in the Almen strips. Five samples were provided with shot peening intensities ranging from new to approximately 6A. PIPA measurements were performed to determine the shot peening intensity levels. Doppler broadening analysis was used to evaluate the results. As seen in Table 1 and Figure 1, the sensitivity of PIPA makes this possible.

Phase II - Turbine Blades
Phase II, PIPA was used to measure the shot peening intensity levels in three turbine blades. They were then compared to the results of a "certified"

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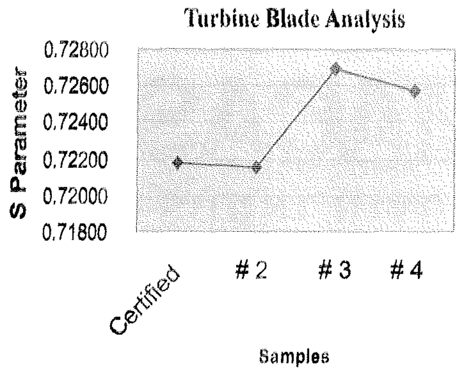
blade that had been subjected to an acceptable shot peening intensity level. The "certified" blade had passed the customer's qualification test prior to this analysis by Positron Systems.

The turbine blades were tested on multiple angular surfaces to discern differences in shot peened intensity levels. The objective was to determine if the shot peening intensity level of the three blades was equal to or greater than that of the "certified" sample. Table 2 lists the S parameter results of a specific surface on the three samples to the corresponding surface on the "certified" sample. Shot peening intensity levels were determined to be nearly equal to or higher than the certified blade for all samples.

Figure 2. Phase II - S Parameter Results



Substantial Benefits

Photon Induced Positron Annihilation (PIPA) provides early detection of fatigue or induced residual stress damage to metals. With the PIPA technology, it is now possible to quantify induced residual stress for critical components and to monitor stress relief throughout the life of the component. This empirical data can be used to establish the design and maintenance specifications for critical systems that must currently adhere to overly conservative design and operational replacement parameters. By improving design and maintenance guidelines, the enhanced safety and life extension of critical components can be accomplished.

Analysis can be conducted at Positron Systems' Test and Analysis Center (TAC) to identify lattice structure damage at less than 1% of fatigue life. In a field environment, mobile PIPA systems can be deployed for the onsite evaluation of operational components.

Table 2. Phase II - Turbine Blade S Parameter Results

Sample	Inner Groove—Concave Surface
Certified	.72176
# 2	.72147
# 3	.72695
# 4	.72565

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