# Army Research Lab Uses XRD to Evaluate Shot-Peened Aerospace Materials

**THE U.S. MILITARY** is in fat-trimming mode and is cutting aerospace budgets through aircraft sustainment and the implementation of lighter, stronger aerospace materials that will reduce aircraft weight without sacrificing strength. Since shot peening is a useful tool for accomplishing both of these goals, the ability to evaluate shot peening's results is just as important.

The Army Research Lab (ARL) in the Aberdeen Proving Ground in Maryland was commissioned by the U.S. Army Aviation and Missile Research Development and Engineering Command to evaluate variations of shot peening intensity on several aerospace materials with x-ray diffraction (XRD).

The results were published in a paper titled, "Using XRD Elastic and Plastic Strain Data to Evaluate the Effectiveness of Different Cold-Working Techniques in Aerospace Materials." The paper was written by Beth S. Matlock with TEC, and Daniel Snoha and Scott Grendahl, both with the U.S. Army Research Laboratory. The following is a synopsis of the paper; the paper in its entirety is available at www.shotpeener.com/library. (The paper also reviews a cold-worked hole study from the U.S. Air Force.)

Shot peening is a widely used surface treatment in OEM and MRO facilities because it imparts compressive residual stresses that enhance fatigue life. These residual stresses are elastic and develop or change as a result of the plastic flow of a material. XRD is an excellent tool for measuring elastic and plastic strains in shot-peened materials. It is a direct method for measuring elastic strains and plastic strain can be determined by measuring the diffraction peak width at half the maximum intensity (FWHM). See Figure 1.

> **Elastic Strain**
> A form of strain in which the distorted body returns to its original shape and size when the deforming force is removed.
>
> **Plastic Strain**
> Strain in which the distorted body does not return to its original size and shape after the deforming force has been removed.

## Procedure

Titanium 6Al-4V (Ti-6-4), 4340 and 9310 steels and 7075-T73 aluminum were chosen for this study. An Almen strip intensity study of variations in impingement angle, air pressure, media flow rate and stand off/nozzle distance was used to establish desired shot peening parameters for the disks and fatigue specimens used in this study. The ARL staff used TEC 1610 and 4000 systems for the x-ray diffraction work.

## Results

The residual stress (RS) and full width-half maximum (FWHM) data are shown in Figures 2-6. This data represents the average of six separate measurements. V1 and V2 are different vendors while 4A - 12A and 3N - 14N represent A- and N-scale shot peening intensities, respectively.

The 4340 steel surface residual stresses ranged from 488.2 MPa (-70.8 ksi) for V2-12A to -593.0 MPa (-86.0 ksi) for V1-4A. For these samples, the maximum compressive stress occurred at the 0.025 mm (0.001″) and 0.051 mm (0.002″) depths and ranged from -576.4 MPa (-84.6 ksi) to -610.2 MPa (-88.5 ksi) for the V2-12A and V2-8A intensities.

**Peak Width-Full Width at Half Maximum (FWHM)**

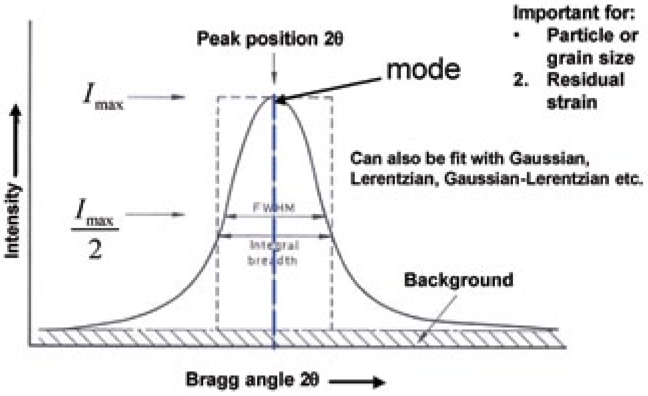


*Figure 1. FWHM is the width of the diffraction peak, in radians, at a height half-way between background and the peak maximum.*

The depth of compression from maximum to minimum for the different shot peening conditions was V2-12A, V1-8A, V2-8A, V2-4A, and V1-4A.

The diffraction peak widths (FWHM) ranged from 2.84° to 3.17°. For all cases, the maximum FWHM was at the surface. The largest to smallest FWHM values for the different shot peening intensities were V2-12A, V1 and V2-8A, V2-4A, and V1-4A. See Figure 2.

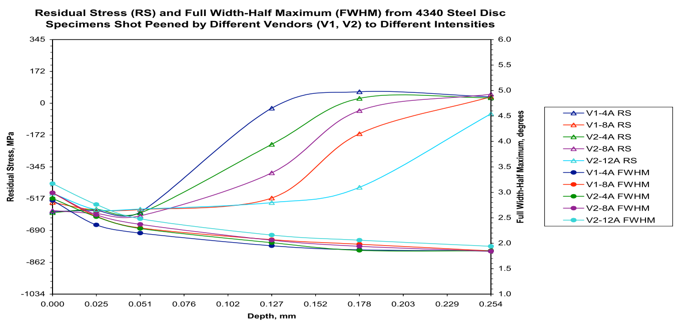


*Figure 2. Residual Stress and Peak Width Profile for 4340 Steel*

Trends for the 9310 steel followed the pattern for the 4340 steel; however, the compressive stresses were higher. The depth of compression from maximum to minimum was V2-12A, V1-8A, V2-8A, V2-4A and V1-8A. The maximum to minimum FWHM order was V2-12A, V2-8A, V1-8A, V2-4A, and V1-4A. Allowing for slight differences in vendor processing, the trend still followed the maximum to minimum shot peening intensities. See Figure 3.

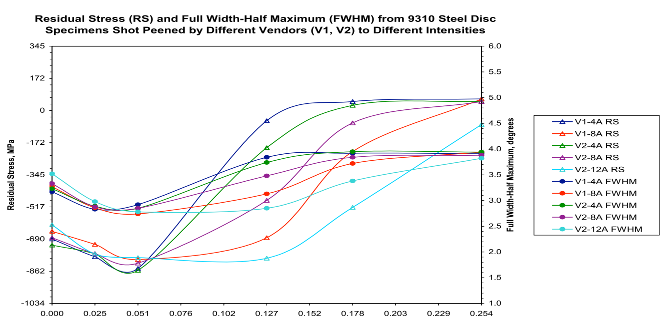


*Figure 3. Residual Stress and Peak Width Profile for 9310 Steel*

The Ti 6-4 samples were shot peened to both A- and N-scale intensities. The A-scale intensities resulted in deeper levels of compression with the maximum to minimum depth of compression order being V1-11.5A, V2-14A, V1-8A, and V1-4A. For these samples, the FWHM order was V2-14A, V1-11.5A and V1-8A, and V1-4A. There was a slight variation in depth of compression and FWHM trends that again can be attributed to vendor shot peen processing differences. See Figure 4.

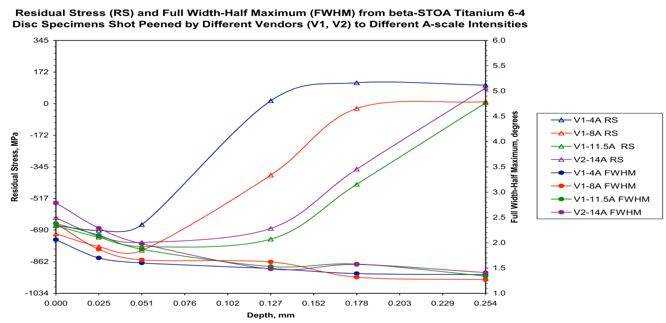


*Figure 4. Residual Stress and Peak Width Profile for Ti-6-4, A-Scale*

For the Ti 6-4 N-scale intensities data, the compressive stresses approached neutral between 0.025 mm (0.001″) and 0.051 mm (0.002″) for the lower intensity shot peening and prior to the 0.127 mm (0.005″) depth for the higher intensity. The maximum to minimum compression level was V1-14N, V1-11N, V1-5N, and V1-3N. The FWHM data exhibited the same trend as the stress data. See Figure 5.

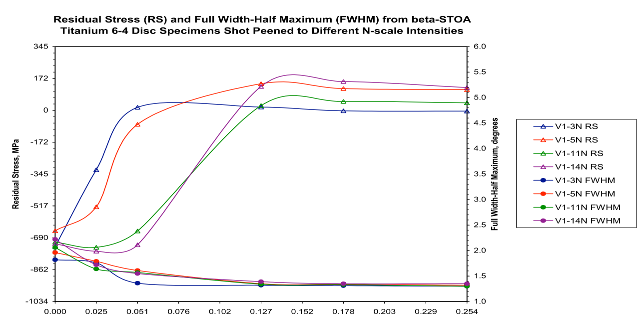


*Figure 5. Residual Stress and Peak Width Profile for Ti-6-4, N-Scale*

The 7075-T73 aluminum samples remained in compression to 0.254 mm (0.010″). At that depth, the residual stresses for the 10A, 12A, and 14A intensities ranged from -218.6 MPa (-31.7 ksi) to -295.8 (-42.9 ksi). The order of maximum to minimum compressive stresses was V1-14A, V1-12A, V2-10A, V2-12A, V1-10A, and V1-4A. Here the surface FWHM was V1-14A, V1-12A, V1-10A, V2-12A and V2-10A, and V1-4A. Since there was no significant difference in the subsurface stresses for V1-12A, V2-10A and V2-12A, the trend of larger surface FWHM for more compressive depth holds. See Figure 6 on page 40.

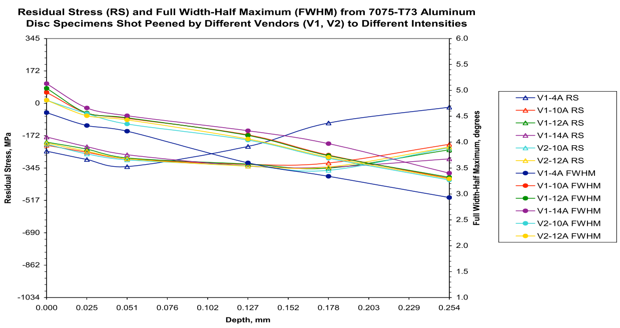


*Figure 6. Residual Stress and Peak Width Profile for 7075-T73 Al*

Although it is outside the scope of this paper, it is interesting to note that the best fatigue response in most cases did not come from the samples with the highest intensity shot peening. In many cases, the best fatigue performance was associated with the minimum intensity shot peening.

## Discussion

X-ray diffraction can non-destructively measure surface stresses. This technique, however, effectively measures stresses in the top few atomic layers of a material. Residual stresses, by definition, are calculated from the elastic strains measured. The diffraction peak width indicates the amount of plastic strain in the part. Coupling surface residual stresses and diffraction peak width can provide information about the effective layer of compressive stresses.

The shot peening study showed that deeper compressive stresses were regularly associated with the higher intensity shot peening. The exceptions were on the Ti 6-4 A-scale intensity samples and the 7075-T73 aluminum samples. For the Ti 6-4 samples, the V1-11.5A shot peening intensity produced a slightly greater residual compressive stress with depth than the V2-14A intensity. And for the 7075-T73 aluminum, the compressive stress in the V2-12A intensity sample was similar but not greater than the V2-10A sample. Although the number of samples tested was small, vendor shot peen processing differences may be the reason these particular samples did not follow the general trend.

## Conclusion

Shot peening a sample imparts compressive stresses in the sample. These plastic deformation processes increase the diffraction peak width relative to the amount of the plastic deformation. The XRD technique non-destructively measures elastic (residual stress) and plastic (diffraction peak width) strains at the surface of a sample. When the level of residual stress is compared to the peak width, the depth of compressive stresses can be qualified.