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APPLICATION OF X-RAY DIFFRACTION RESIDUAL STRESS MEASUREMENT TO SHOT PEENED SURFACES

(Reprinted from Diffraction Notes #7—Lambda Research, Paul Prevey)

In This Issue

Shot Peening is commonly used to produce a layer of compressive residual stress at the surface of components subject to fatigue or stress corrosion failure. The shot peening process is controlled by monitoring the Almen intensity. However, no simple relationship exists between the peening intensity measured with the Almen strip and the residual stress-depth distribution produced. The Almen arc height depends upon the form of the residual stress-depth curve, and quite different stress distributions can produce equivalent arc heights. Conversely, peening to the Almen intensity with different shot sizes will generally produce different subsurface residual stress distributions. The stress distribution produced by shot peening depends upon the properties of the material being shot peened, prior to processing, and the specific peening parameters used. Shot peening can only be reliably controlled and optimized by measuring the subsurface residual stress distributions produced.

X-ray diffraction (XRD) is the most accurate and best developed method of quantifying the residual stresses produced by surface treatments such as shot peening. XRD is capable of high spatial resolution, on the order of millimeters, depth resolution on the order of microns, and can be applied to a wide variety of sample geometrics. The macroscopic residual stress and information related to the degree of cold working can be obtained simultaneously by XRD methods. XRD is applicable to most polycrystalline materials, and is non-destructive at the sample surface. XRD methods are well established, having been developed and standardized by the SAE (1) and ASTM (2). Shot peened metallic alloys are usually nearly ideal specimens for XRD residual stress measurement.

The drive to improve quality through non-destructive testing has led inevitably to the attempt to monitor shot peening processes using only the surface residual stress measured by XRD. Unfortunately, XRD surface results are commonly subject to errors in both measurement and interpretation which cannot be overcome without obtaining subsurface data. Surface results alone must be interpreted with caution. The nature of the problems are highlighted in this article.

Inaccessible Locations

The areas of primary interest, such as bolt holes, fillets, the root area of gear teeth, dovetail slots, etc., are often inaccessible to the x-ray beam. In these cases, sectioning, after strain gaging to measure any stress relaxation, is required to allow access to the surface interest.

In order to avoid sectioning and keep the test non-destructive, it is common to make XRD measurements using accessible locations and directions, assuming that the stresses induced by shot peening will be the same at the inaccessible area of interest. Although the surface stresses may be similar, the subsurface magnitude and depth of the stress distribution is often quite different at different locations on a complex geometry. These differences arise from variations in hardness, impingement angle of the shot, and restriction of shot flow. Alternate locations and directions of measurement should only be used after carefully determining, by destructive testing, that the assumption of comparable stress distributions is valid.

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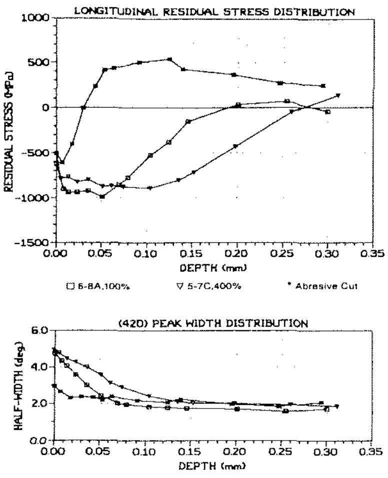
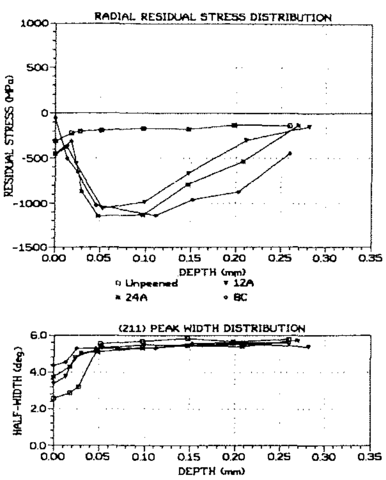
Stress Gradients

Near surface residual stress gradients (the rapid change of residual stress with depth) are a primary source of error (3) in non-destructive XRD surface measurement. Many surface treatments produce residual stress distributions which vary rapidly near the surface of the material. Shot peening of work hardening or decarburized materials, particularly after prior surface deformation caused by turning, grinding, etc., can produce a pronounced "hook" in the form of a rapid increase in compressions, just beneath the sample surface. Typical subsurface residual stress gradients are evident at the surface of the residual stress profiles shown for various methods of processing Inconel 718 in Fig. 1 and 4023 steel in Fig. 2.



Residual Stress and Peak Width Distributions in Shot Peened and Abrasively Cut and Etched Inconel 718.
Figure 1

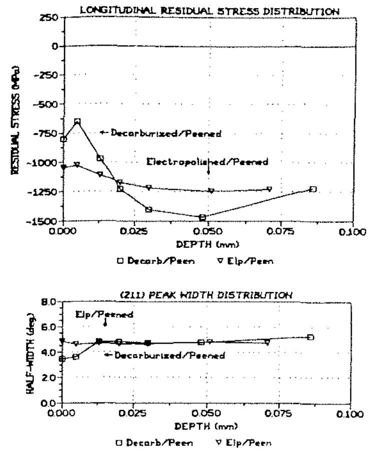
The rate of attenuation of the x-ray beam can be determined by calculating the linear absorption coefficient from the density and composition of the alloy. If XRD measurements are made at fine increments of depth by electropolishing, the true residual stress distribution can be calculated from the apparent distribution (4). Failure to make the correction can lead to errors as high as 300 MPa, and can even change the sign of the surface results. Non-destructive surface XRD stress measurements cannot be corrected, and must, therefore, be used with caution.



Residual Stress and Peak Breadth Distributions in Unpeened and Shot Peened 4023 Stee (From R.P. Garibay and N.S. Chang).
Figure 2

Effects of Prior Processing

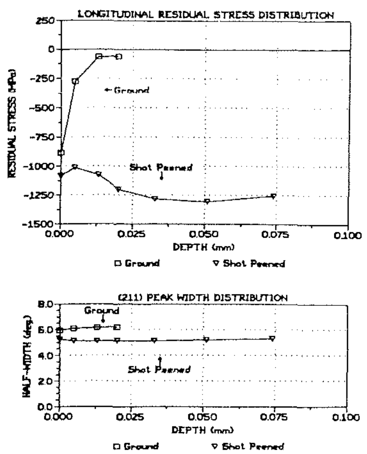
When employing residual stress measurement to monitor shot peening, it is important to realize that the residual stress distribution after shot peening will depend not only on the peening parameters used, but on the prior processing of the materials as well. Fig. 3 shows the near-surface residual stress distributions produced by shot peening carburized 8620 steel to 22A intensity with 230H steel shot for 200% coverage. The stress distributions are shown immediately beneath the surface for areas on the same sample on the original decarburized surface, and in an area electropolished to remove the decarburized layer. A reduction in surface residual stress is evident in the decarburized area, even though the two areas were identically shot peened. The presence of the decarburized layer is evident in the (211) peak width distribution shown at the bottom of Fig. 3. Without subsurface residual stress measurement, the anomalous results would likely be attributed to the shot peening process rather than decarburization.



Residual Stress and Peak Width Distributions Produced by Shot Peening (22A) Decarburized and Electropolished Surfaces of 8620 Steel.
Figure 3

Ambiguity of Surface Results

Virtually all cold-abrasive processes, such as grinding, wire brushing, polishing, sand blasting, shot peening, etc. will produce compressive surface stresses, often of comparable magnitude. The desirable compressive residual stress distributions produced by shot peening are characterized not only by the surface stress, but also the magnitude of the peak subsurface compressive stress and the depth of the compressive layer.



Residual Stress and Peak Width Distributions Produced by Shot Peening (18A) and Grinding of Carburized 8620 Steel..
Figure 4

Fig. 1 shows the residual stress and peak width distributions produced by shot peening Inconel 718 to 6-8A and 5-7C intensities, and abrasive cut-off and etching. The surface residual stresses are virtually identical (approximately 600MPa), and the peened surfaces have both been cold worked to approximately 20%. The surface stresses, even on the abrasively cut and etched specimen, are nearly identical. Fig. 2 shows the residual stress distributions in 4023 steel, unpeened and after peenir to 12A, 24A, and 8C intensities. (5) Even though the fatigue life

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is improved by over a factor of three as a result of peening, the surface results are not correlated to the subsurface residual stress distribution. Fatigue life increased with the depth of the compressive layer. Fig. 4 shows comparable surface residual stresses developed by shot peening to an 18A intensity, and grinding the surface of the same coupon of 8620 steel. Nondestructive surface XRD residual stress measurement is often inadequate to characterize residual stresses produced by shot peening or other surface treatments.

CONCLUSIONS

1. The assumption that the residual stress distributions at inaccessible locations and measurement directions are comparable to those which are directly measurable must be verified by prior subsurface studies.

2. Subsurface residual stress measurement, with correction for penetration of the x-ray beam, is generally necessary to accurately and reliably characterize even the surface residual stress produced by shot peening.

3. The residual stress distributions produced by shot peening will depend upon the prior thermal-mechanical history of the surface layers. Surface residual stress measurement alone may be inadequate to verify that shot peening was performed to a specific specification. Subsurface measurement, coupled with line broadening information, offers the most reliable tool for quality control of shot peening.

4. A given level of surface compressive residual stress is a necessary, but not sufficient, condition to indicate that shot peening was performed properly. Many surface treatments other than shot peening produce similar levels of surface compressions, as will shot peening to different Almen intensities.

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