Quality Assurance of Shot Peening by Automated Surface and Subsurface Residual Stress Measurement

John Cammett
Lambda Research

Shot peening is frequently used to produce compressive residual stress in the surface layer of components for fatigue life enhancement and suppression of stress corrosion cracking (SCC). Shot peening is controlled by monitoring Almen intensity. Almen intensity is determined from the arc heights produced in series of at least four Almen strips peened for progressively longer times on one side of the strips. There is, however, no simple relationship between the Almen intensity and the residual stress distribution produced in the 1070 steel Almen strip. Arc height in Almen strips is a function of the induced total strain energy, or the area under the residual stress-depth distribution. Furthermore, quite different residual stress distributions can produce the same Almen strip arc height. Shot peening to the same Almen intensity using different shot sizes will also generally produce different subsurface residual stress distributions. The depth and magnitude of compression developed in a component being shot peened, generally having mechanical properties very different from the Almen strip, cannot be determined simply from the response of a steel Almen strip identically peened. Therefore, the only reliable method of controlling shot peening of a component is by measuring the subsurface residual stress distribution.

X-ray diffraction (XRD) is the most accurate and best developed method of quantifying the subsurface residual stress distributions that develop as a result of shot peening. XRD methods are well established(and have been standardized by the ASTM(2) and SAE(3).

Surface residual stress measurements alone can often be misleading because the shot peening process can produce high residual stress gradients in the deformed surface layer of material.(4) Therefore, it is recommended that surface and subsurface measurements be made to fully understand the residual stress fields that are developed.

Subsurface residual stresses can be determined by a successive combination of x-ray diffraction measurements and electropolishing to remove layers of material. Electropolishing removes material without inducing additional residual stress. Data must be corrected for x-ray beam penetration(and for residual stress relaxation caused by electropolishing layer-removal.(6) Typically, the sample must be removed from the diffractometer in order to perform the electropolishing. This increases the amount of time required and, therefore, the cost to obtain the residual stress measurements.

In order to maintain quality control of shot peening, both the residual stress and cold work subsurface distributions must be regularly monitored. Shot peening specifications, written by the end-users, usually dictate specific residual stress levels at given depths. Residual stress measurements made by manually electropolishing the sample would be excessively slow, and therefore expensive, for practical quality control.

The Shot Peener, vol. 15, Issue 3
September 2001, pg. 7-8

StressPro™ Device

Lambda Research has capability to quantify residual stress distributions using a unique automated apparatus. The StressPro™(7) allows the residual stress in one specimen to be measured while layers of material are being electrochemically removed from a second specimen. The StressPro™ measures the residual stresses at depths which are defined in a computer file. All of the data obtained are properly corrected for the penetration of the x-ray beam and stress relaxation due to electropolishing layer removal.

The device allows residual stress distributions to be measured with a minimal amount of technician input. Both the cost and time required to obtain residual stress profiles are dramatically reduced. The time required to complete the residual stress profile is directly related to the electropolishing and measurement times. The apparatus allows two residual stress profiles to be obtained in as little as an hour.

SPECIMEN REQUIREMENTS

The current apparatus accepts specimens that fit inside a dimensional envelope of 60 x 40 x 40 mm (2.5 x 1.5 x 1.5 in.). Larger components can be sectioned to fit within this envelope. It is recommended that strain gage rosettes be applied to the residual stress measurement location prior to sectioning in order to record any stress relaxation that may occur. Lambda Research can provide the service of strain gaging and sectioning as needed.

Specimens suitable for the StressPro™ may include such items as individual gear teeth removed after shot peening, sections of fan and turbine blades, or other sectioned hardware containing a representative surface.

For non-destructive monitoring of residual stresses in large or expensive components, individual coupons of the alloy in the same heat treatment can be placed at strategic positions on a component, such as a large turbine disk, and shot peened using the peening program and fixturing to be used for the actual part. Coupons are then placed in the StressPro™ apparatus and residual stress distributions essentially identical to those that would be produced by peening the component, itself, can be generated rapidly and inexpensively as a quality control tool.

EXAMPLES

The StressPro™ makes it possible to perform residual stress relaxation studies and to utilize Taguchi or other DOE techniques to empirically optimize shot peening parameters. Peening parameters can be adjusted to achieve the depth and magnitude of residual stress required while minimizing the undesirable cold working which leads to rapid thermal relaxation. The following examples illustrate such studies.

Figures 1 and 2 show examples of residual stress and cold work results obtained with StressPro™ on shot peened and gravity peened Inconel 718 material. These results are from an extensive thermal residual stress relaxation study in nickel(8) and titanium(9) base materials. Each specimen was exposed, in air, at 525 C (977 F) for times up to 6000 min. Shot and gravity peening produced compression to a depth of nominally 200 µm and 250 µm, respectively. Maximum compression occurred at a depth of approximately 50 µm for both processes. A considerable amount of stress relaxation was observed for the shot peened coupons as compared to the gravity peened specimens. Surface compression from shot peening was below 500 MPa for all exposure times. However, the surface compression from gravity peening remained above 700 MPa for all exposure times. This is attributable to the difference in prior cold working from the two peening operations.

Cold working distributions are shown in the bottom graph of each figure. Both shot and gravity peening exhibited the highest amount of cold working at the surface. Gravity peening produced relatively less cold working than shot peening near the surface although the depth of the cold working was greater for gravity peening. Cold work was reduced during the first thermal exposure and then remained relatively stable.

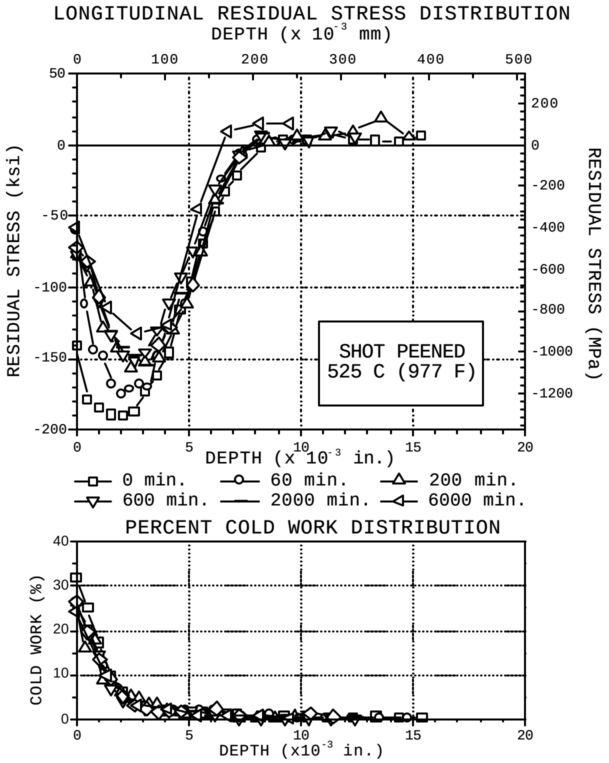

Figure 1

Examples of residual stress distributions in shot peened 1018 carbon steel with a hardness of Rb 80 are shown in Fig. 3. The four coupons were shot peened with MI-460H shot at 6-7 Almen C intensity. Three of the four coupons were thermally exposed for a total time of 30 min. Temperatures of 500, 700 and 900 F were used in the study. Residual stresses of over –420 MPa were achieved in the coupon with no thermal exposure. Residual stress relaxation was much greater at highest temperature, but acceptable at lower temperature exposures. Surface residual stresses are near zero after the 900 F sample exposure.

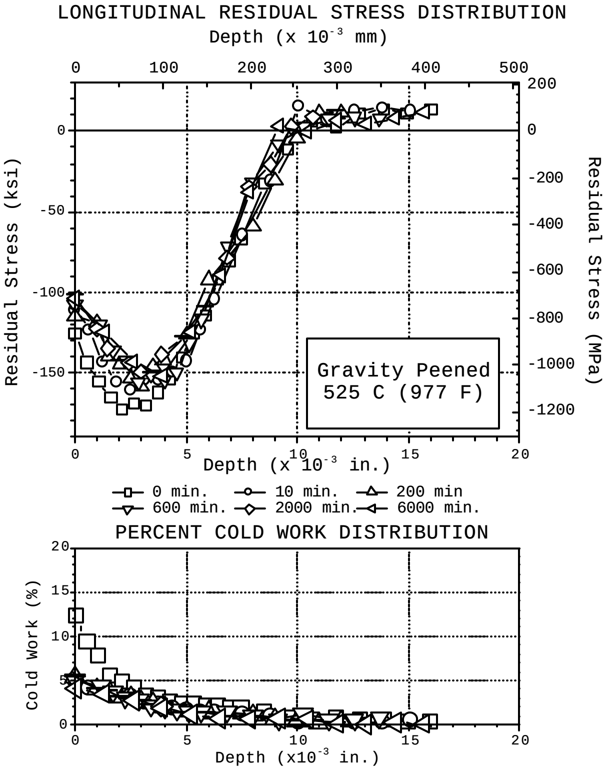

Figure 2

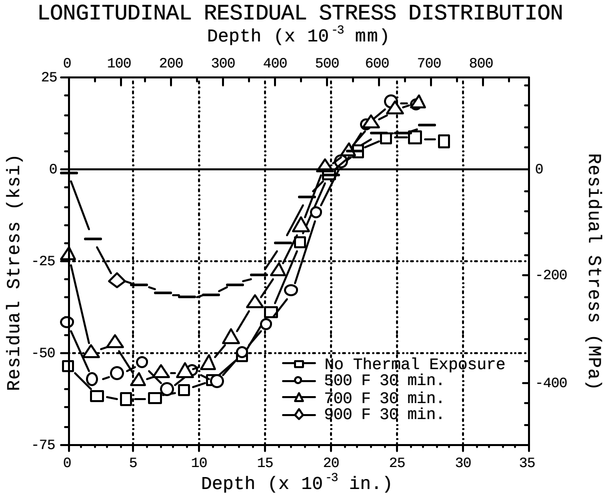

Figure 3

REFERENCES

1. Prevéy, P.S., “X-ray Diffraction Residual Stress Techniques,” Metals Handbook: 9th ed., Vol. 10, Metals park, OH: ASM, 1986, pp. 380-392
2. ASTM, “Standard Method for Verifying the Alignment of X-Ray Diffraction Instrumentation for Residual Stress Measurement,” E915, Vol. 3.01, Philadelphia, PA, 809-812, (1984)
3. Hilley, M.E., ed., Residual Stress Measurement by X-Ray Diffraction, J784a, 2nd ed. Society of Automotive Engineers.
4. Prevéy, P.S., "Problems with Non-Destructive Surface X-Ray Diffraction Residual Stress Measurement," Practical Applications of Residual Stress Technology, C. Ruud, ed., ASM, Materials Park, OH, 1991, pp 45-54.
5. Koistinen, D.P. and Marburger, R.E., Transactions of the ASM, Vol. 67, (1964).
6. Moore, M.C. and Evans, W.P., “Mathematical Corrections for Stress in Removed Layers in X-Ray Diffraction Residual Stress Analysis,” SAE Trans., Vol. 66, (1958).
7. U.S. Patent 5,737, 385, April 7, 1998.
8. Prevéy, P.S., “The Effect of Cold Work on the Thermal Stability of Residual Compression in Surface Enhanced IN718”, Proc. 20th ASM Mat.Sol. Conf., St. Louis, MO, Oct., (2000)
9. Prevéy, P.S., Shepard, M.J., and Smith, P.R., “The Effect of Low Plasticity Burnishing (LPB) on the HCF Performance and FOD Resistance of Ti-6Al-4V”, Proc. 6th Nat. Turbine Engine HCF Conf., Jacksonville, FL, March, (2001)

StressPro is a service mark of Lambda Research

For more information, contact Lambda Research, 5521 Fair Lane, Cincinnati, Ohio, 45227 or telephone 513.561.0883.