Diffraction Notes

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

INTRODUCTION

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 by the amount of arc height produced in an Almen strip as a result of shot peening one side of the strip. However, there is no simple relationship between the Almen intensity and the residual stress distribution produced in the 1070 steel Almen strip. Arc height of the Almen strip is a function of the total strain energy, or the area under the residual stress curve. Furthermore, quite different residual stress distributions can produce the same arc height. Shot peening to the same Almen intensity using different shot sizes will generally produce different subsurface residual stress distributions. The depth and magnitude of compression developed in the component being shot peened, generally having mechanical properties very different from the Almen strip, cannot be determined simply from the response of the steel Almen strip. Therefore, the only reliable method of controlling shot peening 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(1) 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)

ANNOUNCEMENTS

Paper on Heat Treatment of 52100 Steel

A paper by Perry Mason and Paul Prevéy of Lambda Research describing multiple Taguchi DOE's to optimize the heat treatment of 52100 steel appeared in the February 2001 edition of ASM's "Advanced Materials and Processes." The Taguchi experimental design allows results to be obtained cost effectively without performing a full factorial experiment. The suggested approach to optimize the hardness and retained austenite content can be used on a wide range of steels.

Nuclear Waste Residual Stress Measurements

Lambda Research has conducted residual stress measurements, using mechanical dissection methods, on nuclear waste containment packages. Incremental ring coring was used in the analysis. Ring coring consists of applying a strain gage rosette to the area of interest and trepanning around the gage. Residual strains, relieved during sectioning, are recorded and used to calculate the principal residual stress as a function of depth.

John Cammett Joins Lambda

Please join us in welcoming Dr. John Cammett to Lambda Research. Dr. Cammett received his Bachelors Degree from Ohio State University and Doctorate in Materials Science from the University of Cincinnati. He has extensive experience with fatigue and fracture mechanics and over 10 years of experience in failure analysis involving fatigue and corrosion mechanisms while he served as Materials Engineer with NAVAIR at the Naval Aviation Depot-Cherry Point, NC. John will assume the role of Director of Materials Research with specific focus in fatigue and corrosion related phenomena in the surface integrity laboratory.

Therefore, it is normally recommended that surface and subsurface measurements be made to fully understand and characterize the residual stress fields that are developed.

Subsurface residual stresses can be determined by a combination of x-ray diffraction strain measurement and electropolishing to remove layers of material. Electropolishing removes material without inducing additional residual stress. The data must be corrected for the x-ray beam penetration[5] and the 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 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 mandate a specific residual stress level at certain depths. Residual stress measurements made by manually electropolishing the sample would be excessively slow, and therefore expensive, for practical quality control.

StressPro™ Device

Lambda Research has the capability to quantify residual stress distributions using a unique automated apparatus. The StressPro™[7] allows the residual stress in one sample to be measured while layers of material are being electrochemically removed from a second sample. The StressPro™ measures 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 apparatus allows two residual stress profiles to be obtained in as little as an hour.

SAMPLE REQUIREMENTS

The current apparatus accepts test 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 strain gaging and sectioning services as needed.

Specimens suitable for the StressPro™ include individual gear teeth removed after shot peening, sections of fan and turbine blades, or other sectioned hardware containing a representative surface in which the residual stresses from shot peening are to be determined.

For the 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 in actually peening the component can be generated rapidly and inexpensively as a quality control tool.

EXAMPLES

The StressPro™ makes it possible to perform extensive residual stress relaxation studies and to utilize Taguchi or other design of experiment (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 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 ranging 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 is observed for the shot peened as compared to the gravity peened specimens. Surface compression from shot peening is below 500 MPa for all of the exposure times. However, the surface compression from gravity peening remains above 700 MPa for all of the exposure times. This is attributed to the difference in prior cold working from the two peening operations.

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

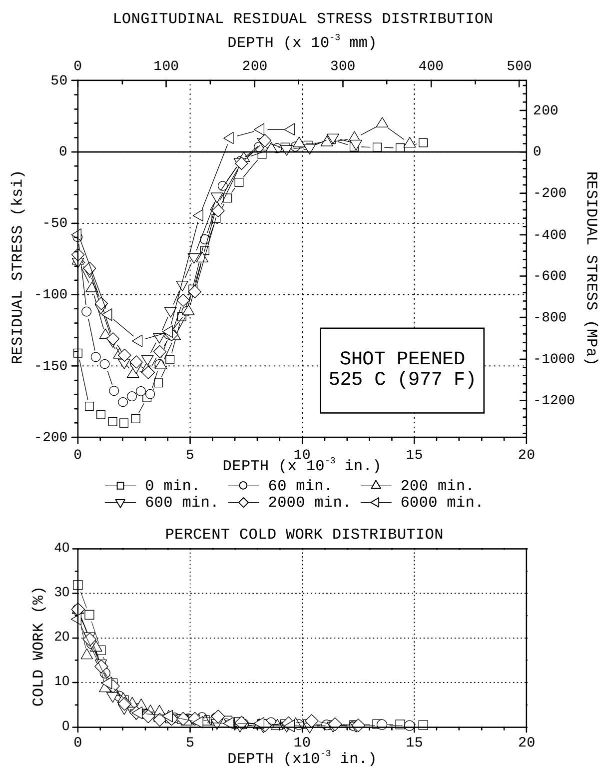

Figure 1

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 to 6-7 Almen C intensity. Three of the four

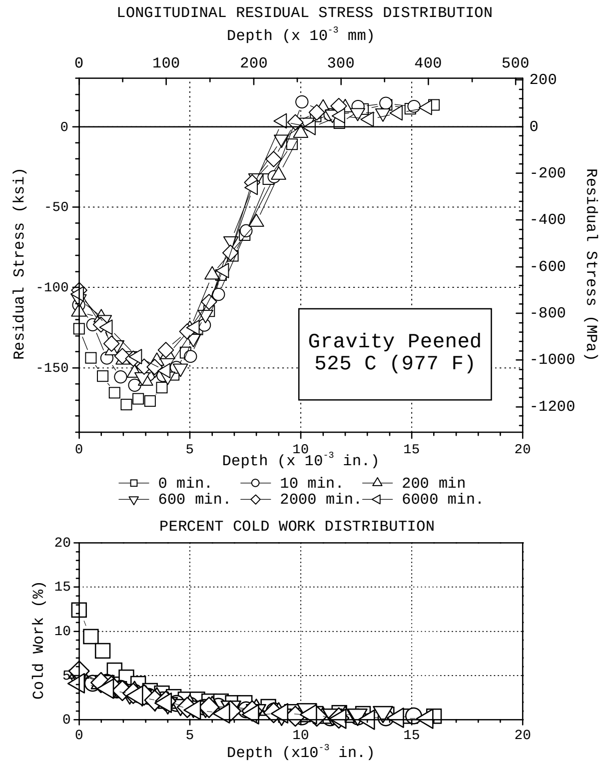

Figure 2

coupons were thermally exposed for a total time of 30 min. Exposures were at 500, 700 and 900 F. Residual stresses of over –420 MPa were achieved in the coupon with no thermal exposure. Residual stress relaxation was much greater at the highest exposure temperature, but acceptably less at lower temperature exposures. Surface residual stresses were near zero after the 900 F exposure.

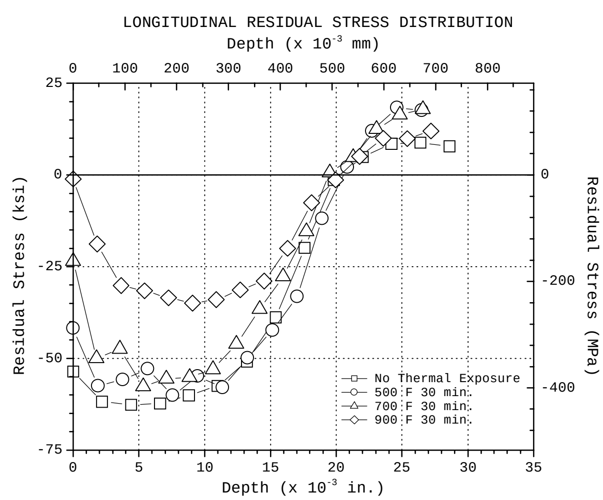

Figure 3

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ANNOUNCEMENTS (cont'd)

Conferences and Shows

Paul Prevéy will be presenting two papers at AeroMat 2001 in June. The first, entitled "Thermal and Mechanical Relaxation of Surface Compression in Shot Peened Turbine Engine Alloys," covers the fatigue and damage tolerance of low plasticity burnished and shot peened IN718. The second, entitled "Improved HCF Performance and FOD Resistance of Low Plasticity Burnished IN718," will address comprehensive studies on thermal, mechanical and cyclic relaxation in IN718.

John Cammett will be a speaker at AeroMat 2001 in June. His topic "Corrosion Damage Mitigation and Improved Fatigue Performance of Low Plasticity Burnished 7075-T6" discusses in detail the benefits and empirical evidence of low plasticity burnishing over salt fog corroded 7075-T6 which fully restores the endurance limit by developing a layer of compression deeper than the pit depth.

Doug Hornbach will be presenting his paper "The Effect of Prior Cold Work on Tensile Residual Stress Development in Nuclear Weldments" at PVP 2001, held July of 2001 in Atlanta, Georgia.