Diffraction Notes

No. 20
Fall 1997

LAMBDA RESEARCH INC. 5521 FAIR LANE CINCINNATI, OH 45227 (513) 561-0883

AUTOMATED MEASUREMENT OF SUBSURFACE RESIDUAL STRESS DISTRIBUTIONS

INTRODUCTION

The measurement of residual stress distributions with depth is critical to understanding the impact of machining, shot peening, induction hardening, and similar processes on fatigue performance. The mean stress and, therefore, the residual stress, strongly influence the fatigue life of elastically loaded components.(1) In the essentially elastically loaded high cycle fatigue (HCF) region, the residual of "self" stresses are simply additive to the applied mean stress. The fatigue endurance limit is then inversely proportional to the subsurface maximum residual stress for a wide range of alloys and surface treatments.(2, 3)

Unfortunately, the subsurface residual stress distribution cannot be determined from non-destructive surface measurements because of the extremely shallow penetration of the radiation. Because distinctly different processes can produce comparable surface stresses, surface measurements alone are often inconclusive, or even misleading, and cannot be used reliably for quality control testing.(4)

The effective depth sampled by the x-rays used for residual stress measurement is on the order of 5 to 10 microns (0.0002 to 0.0004 in.). Subsurface stress distributions are obtained by alternately performing measurements and then electropolishing to remove layers of material. The data must be corrected for x-ray beam penetration and the relaxation caused by layer removal.(5) Traditionally, subsurface stress measurement has required a technician to remove the test specimen from the diffraction apparatus to a hood where electropolishing is performed. The repositioning of the sample on the apparatus can be a major source of experimental error. Moreover, this manual process is tedious and labor-intensive; and, therefore, residual stress-depth profiles have been relatively expensive to obtain.

ANNOUNCEMENTS

Expanded Website

Our website has been expanded to include useful technical information for our clients. Single-screen descriptions of each of our capabilities, with example applications, limitations, and recommended use, are being included to assist in selecting the appropriate test methods for your project. Our many publications and back-issues of Diffraction Notes are listed and can currently be provided by fax. Shortly, they will be available for direct download from the website.

New Assignments

We are proud to announce that Perry Mason has been promoted to Supervisor of Lambda's Texture and Phase Analysis Laboratory, and Doug Hornbach has been promoted to Supervisor of the Residual Stress Laboratory. As such, Perry will no longer handle residual stress analysis projects. In an effort to ensure a smooth transition, we request that, should you have questions or information concerning your current project, you please contact our Customer Service Department.

The development of a manufacturing process, such as shot peening, grinding, or heat treating, usually requires extensive experimentation to achieve optimization. In the past, the high cost of residual stress measurement made large factorial designs prohibitively expensive. Comprehensive experimental development was only practical for high unit cost critical applications, such as shot peening of turbine engine disks. Optimization studies for low unit· cost component processing have been limited by the cost of obtaining residual stress profiles.

APPARATUS

Lambda Research has developed a revolutionary new apparatus which enables fully automated residual stress profiles to be obtained. The StressPro^{SM} device, for which a patent is pending, allows one specimen to be measured while layers of material are removed from a second. The apparatus rotates the specimens alternately into position for measurement and generates residual stress distributions at depths which are predetermined from a file contained on the disk drive of the controlling computer. All data obtained are corrected for the penetration of the radiation into the subsurface stress gradient, for the stress relaxation resulting from removing layers of material for subsurface measurement, and even for prior sectioning using strain gages, if appropriate.

The unattended apparatus allows two residual stress distributions to be developed in as little as an hour. The actual time of polishing and measurement governs the number of depths which can be measured. Twenty data points to a depth of 0.25 mm (0.010 in.) is feasible in steels and nickel, base alloys.

SAMPLES

As currently configured, the new StressPro^{SM} apparatus accepts coupons which fit in an envelope 60 x 40 x 40 mm (2.5 x 1.5.x 1.5 in.). The test specimens may be simple rectangular coupons which have been shot peened, ground, machined, or otherwise processed on the test face. Actual sections of components, such as gears, springs, and similar items, which could be sacrificed for the sampling of a lot, can also be measured. To preserve expensive components, test coupons may be processed along with the production apparatus.

The Metal Improvement Company has employed the coupon concept in the MILAM^{SM} specimen developed for quality control and process development of their shot peening services. The MILAM^{SM} concept employs a test specimen of the same cross-section as the Almen strip, but thicker, placed in a standard Almen strip holder. The MILAMSM coupon is made from the same alloy and subjected to the same heat treatment as the part to be processed so that the mechanical properties are identical. The MILAM^{SM} coupon allows actual residual stress distributions in expensive components to be monitored for quality control without sacrificing the component and at greatly reduced cost compared to conventional x-ray diffraction residual stress measurement.

EXAMPLE APPLICATIONS

Figure 1 shows an example of data obtained on shot peened coupons using the StressPro^{SM} automated apparatus. The same data obtained by conventional manual means of removing the sample, electropolishing, and returning it for measurement are compared directly to the results obtained by automated StressPro^{SM} apparatus on shot peened 8620 steel at two adjacent locations.

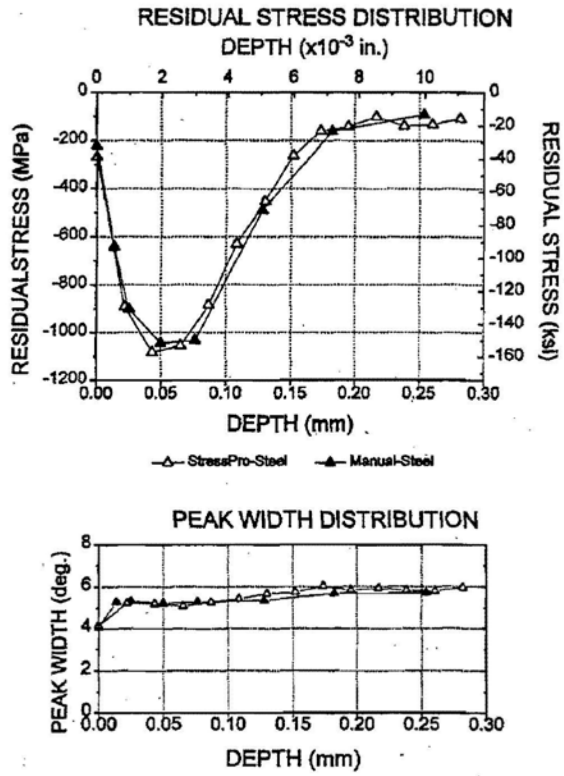


Fig. 1 - Comparison of residual stress and peak width distributions as measured manually and by StressPro^{SM} on 8620 steel.

The stress distributions obtained using the StressPro^{SM} apparatus induction hardened 1552 steel gear teeth are shown in Figure 2. Depending upon the rate of heating and the geometry of the part, induction hardening may produce either compressive or tensile residual stresses. Lambda's new capability makes quality control testing practical and provides an inexpensive means of developing new coil designs and heating cycles.

In addition to the residual stress distribution, the hardness distribution can be calculated simultaneously from the diffraction peak widths by using an empirical calibration' for the alloy. The corresponding hardness distributions developed in the induction hardened 1552 steel gear tooth are shown at the bottom of Figure 2.

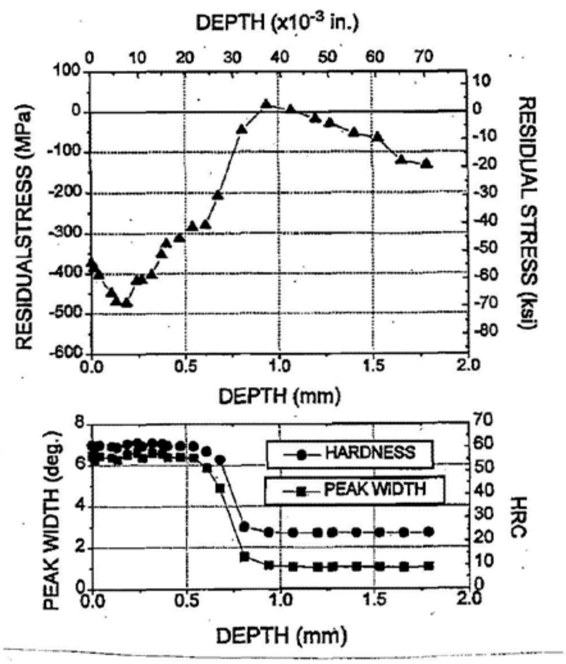


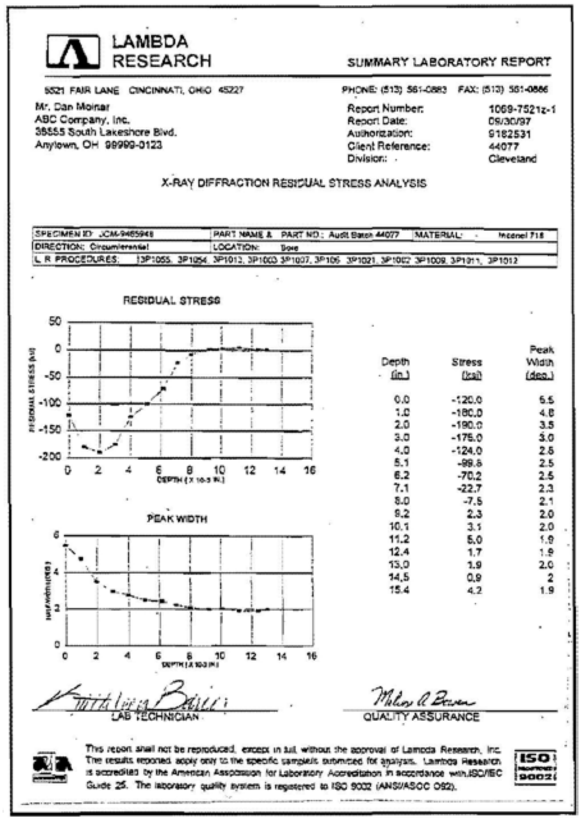
Fig. 2 - Residual stress, peak width, and HRC hardness distributions in an induction hardened 1552 steel gear tooth pitch line location.

QUALITY CONTROL TESTING

The automated StressPro^{SM} apparatus makes rigorous subsurface x-ray diffraction residual stress measurement a practical tool for quality control in a wide range of applications. Residual stress profiles developed by shot-peening of automotive springs and gear teeth, heat treating of gears, finish grinding of bearing races, all can now be checked rapidly and inexpensively. Coupons can be used for process control of expensive components.

Lambda Research has developed a summary report for the transmittal of StressPro^{SM} results. The typical report is shown in Figure 3. Both a tabular and graphic representation of the data are provided along ,with the citations to Lambda's QA system appropriate for our ISO Guide 25 Accreditation and ISO 9002 Registration.

If you have an interest in utilizing the new StressPro^{SM} automated stress profiling for a quality control or process development application, please contact Lambda Research's Customer Service Department.


LAMBDA RESEARCH

SUMMARY LABORATORY REPORT

5521 FAIR LANE CINCINNATI, OHIO 45227 PHONE: (513) 561-0883 FAX: (513) 561-0886

Mr. Dan Molnar
ABC Company, Inc.
35555 South Lakeshore Blvd.
Anytown, OH 99999-0123

Report Number: 1069-7521z-1
Report Date: 09/30/97
Authorization: 9182531
Client Reference: 44077
Division: Cleveland

X-RAY DIFFRACTION RESIDUAL STRESS ANALYSIS

SPECIMEN ID: JCM-9465948	PART NAME & PART NO.: Audit Batch 44077	MATERIAL: Inconel 718
DIRECTION: Circumferential	LOCATION: Bore	
L.R. PROCEDURES: 13P1055, 3P1054, 3P1012, 3P1003 3P1007, 3P106 3P1021, 3P1002 3P1009, 3P1011, 3P1012		

Depth (in.)	Stress (ksi)	Peak Width (deg.)
0.0	-120.0	5.5
1.0	-180.0	4.8
2.0	-190.0	3.5
3.0	-175.0	3.0
4.0	-124.0	2.6
5.1	-99.6	2.5
6.2	-70.2	2.5
7.1	-22.7	2.3
8.0	-7.5	2.1
9.2	2.3	2.0
10.1	3.1	2.0
11.2	5.0	1.9
12.4	1.7	1.9
13.0	1.9	2.0
14.5	0.9	2
15.4	4.2	1.9

LAB TECHNICIAN QUALITY ASSURANCE

This report shall not be reproduced, except in full, without the approval of Lambda Research, Inc. The results reported apply only to the specific sample(s) submitted for analysis. Lambda Research is accredited by the American Association for Laboratory Accreditation in accordance with ISO/IEC Guide 25. The laboratory quality system is registered to ISO 9002 (ANSI/ASQC Q92).

Fig. 3 - Sample StressPro^{SM} report for shot peened Inconel 718 coupon.

REFERENCES

1. Fuchs, H. and R. Stevens, Metal Fatigue in Engineering, Wiley, NY, 1980, pp 125-133.

2. Mattson, R.L. and T.G. Roberts, "The Effect of Stresses Induced QY Strain Peening upon Fatigue Strength," Internal Stresses and Fatigue in Metals, G.W. Rassweiler, ed., Elsevier, NY, 1959, pp 348, 349.

1. Koster, W.P., et al., "Surface Integrity of Machined Structural Components:' AFML-TR-70-11, Air Force Materials Laboratory, Wright Patterson AFB, 1970.

2. Prevey, 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, pp45-54.

5. Hilley, ME, ed., Residual Stress Measurement by X-Ray Diffraction, J784a, 2nd ed. Society of Automotive Engineers.

StressPro[SM] is a service mark of Lambda Research, Inc.

MILAMSU is a service mark of The Metal Improvement Co., Inc.

Retained Austenite Development

Lambda Research has always offered retained austenite measurements only rigorously in accordance with the SAE SP-453 and ASTM E975 standard practices using Bragg-Brentano goniometers. Standard practice requires keeping the x-ray beam entirely on the sample, which makes measurement of small specimens difficult. Constant area correction software has been developed and proved to facilitate these measurements. The new technology broadens the scope and applicability of austenite measurement for quality control of heat treatment.