Diffraction Notes

LAMBDA RESEARCH 5521 FAIR LANE CINCINNATI, OH 45227 (513) 561-0883 NO. 23 ANNUAL, 1999

LAMBDA'S YEAR IN REVIEW, 1998

RESIDUAL STRESS LABORATORY

Lambda Research has completed a Phase I **NASA SBIR study: "Low Cost Surface Enhancement Method for Improved Fatigue Life of Superalloys at Engine Temperatures."** The study demonstrated the use of low plasticity burnishing (LPB) to improve the fatigue life of Inconel 718 and NASA developmental alloys. Specimens were prepared and exposed to a range of engine temperatures. X-ray diffraction studies before and after thermal exposure show that LPB produces stable compressive stresses approaching 1 mm (0.04 in.) deep with less than 4% cold work. The results were compared to shot peened and laser shock peened (LSP) specimens. Shot peening, like LPB, is inexpensive. However, it produces 20 to 30% cold working at the surface, which can result in relaxation of the compressive layer at engine temperatures. LSP produces deep compression with low cold work, but is an expensive surface enhancement process. The high cycle fatigue life of the LPB prepared specimens consistently exceeded that of shot peened specimens, and arrested the growth of existing cracks up to 0.42 mm (0.017 in.)

The **StressPro_**, the patented x-ray diffraction apparatus developed at Lambda Research, was featured in an article published in the August issue of *Advanced Materials & Processes* (Hornbach, D.J., *AM&P*, Aug. 1998, pp. H33-H37). The article, written by Doug Hornbach, describes a new way to gage residual stresses. Use of the StressPro_ for residual stress measurement of induction-hardened gears is demonstrated to be a more efficient and cost-effective method of determining subsurface residual stress distributions. The apparatus allows multiple specimens to be electropolished and measured in rotation, reducing the cost of manual layer removal and specimen repositioning after every measurement. The technique simultaneously measures diffraction peak breadth, which can be used to determine hardness profiles. The article presents hardness and residual stress profile data for SAE 1552 steel test gears.

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TEXTURE & PHASE ANALYSIS LABORATORY

During 1998, the Texture & Phase Analysis Laboratory had the opportunity to work on many interesting and varied projects. Distinctively different sample materials and application of results provided opportunities for development of new and improved techniques.

Nitriding of steels is one method of case hardening that prevents wear and abrasion of automotive, aerospace and machine components. Optimization of the nitriding process is complex and requires detailed information about the phases formed in the nitrided layer. Lambda Research has developed an x-ray diffraction technique for **qualitative phase analysis of nitrided steels** to identify phases in the surface and subsurface of nitrided components. X-ray diffraction qualitative phase analysis provides information on the nitride layer's crystal structure and composition, which can be used for process development and control of nitriding. Measurements can be made as a function of depth in increments as small as 2.5 μm (0.0001 in.) Lambda provides sample preparation and analysis for both process development and quality control of nitriding.

A new technique for **quantitative phase analysis of zirconia** has been developed to determine the amount of monoclinic zirconia and other phases present in pure and yttria-stabilized zirconia. Its low thermal conductivity makes it desirable for use as a thermal barrier coating for automotive and aerospace components. Zirconia is also used in the medical industry; both as a coating and as bulk material for implant parts. Different zirconia phases or polymorphs (similar chemical composition, different crystal structure) are common and are considered undesirable because of their instability at different temperature or pressure conditions. The quantitative phase analysis uses experimentally calculated Reference Intensity Ratios (RIR) to determine the amount of monoclinic phases present, and provides a more rigorous quantification than the Garvie-Nicholson method (*J Am Ceramic Soc*, **55**, 1972, pp. 303-305).

(Residual Stress Laboratory, cont.)

Finite element (FE) models of the inversion of residual compression into tension due to plastic deformation after shot peening have been developed. Manufacturing processes, such as shot peening or grinding will result in cold worked near surface material. The cold worked layer, which may be in a state of residual compression, but has a higher yield strength, can invert to a state of tension following bulk plasticity. The inversion is due to the localized increase in yield strength caused by plastic deformation during the machining or shot peening process. Yield strength gradients in previously machined components can be quantified by x-ray diffraction. The data can be combined with the finite element model to determine the resulting residual stress field. Finite element models, including the yield strength gradients, can be used to accurately predict the changes in residual stress distributions in machined or shot peened components that experience bulk plasticity either in a manufacturing process or in service.

Optimization of surface enhancement processes through the use of nonlinear FE analysis is a cost-effective means of designing for improved fatigue life. By employing non-linear FE techniques, a surface enhancement process, such as roller burnishing, can be optimized for a specific tool geometry and material. The parameters of a surface enhancement process can be adjusted in the model to determine the depth and magnitude of residual stress produced.

Paul Prevey was awarded **U.S. Patent 5,826,453: "Burnishing Method and Apparatus for Providing a Layer of Compressive Residual Stress in the Surface of a Workpiece."** The method, which was researched and developed at Lambda for over 2 years, utilizes a single-point burnishing process to provide deep compression with a minimal amount of cold work and surface hardening. The invention is superior to conventional roller burnishing apparatus in that it is not limited to cylindrical or flat workpieces. It is capable of producing a zone of deformation in a single pass, preventing excessive cold working, which may leave surface tensile residual stresses and a cold worked layer subject to rapid thermal relaxation. The apparatus can be mounted on a conventional CNC tool holder, providing an inexpensive and effective means of inducing compressive stress to depths exceeding 1 mm. Development will continue under a NASA SBIR Phase II program in 1999.

Lambda Research has had **on-site x-ray diffraction and center hole-drilling residual stress measurement** capabilities for several years. The testing service is available for components that cannot be readily shipped to Lambda for measurement. In 1998, our engineers had the opportunity to work on several on-site projects involving **nuclear applications**. The high spatial and depth resolution achieved by x-ray diffraction is ideally suited for studies of residual stress distributions produced by manufacturing operations such as grinding, milling and turning. Hole-drilling procedures were used for measuring residual stresses in welded pressure vessels.

SURFACE INTEGRITY/PROCESS OPTIMIZATION

Perry Mason will be supervising the Surface Integrity Department at Lambda Research. **Process optimization studies**, employing Taguchi experimental designs, are currently underway for manufacturing processes, such as welding, milling, grinding, heat treating and shot peening. The Taguchi experimental design uses statistical orthogonal arrays to reduce the number of experiments needed while evaluating factors independent of one another. For example, there are over 1.5 million possible combinations for an experiment where 13 factors at three levels are to be tested. Using the Taguchi method to design the same experiment would reduce the number of experiments to 27, while maintaining the quality of the results and reducing the cost significantly.

Lambda Research offers assistance in designing **surface integrity studies** using the Taguchi method. Varying process parameters in an experimental design can optimize surface properties, such as residual stress, cold work levels, and roughness. Surface integrity is important where materials used in critical performance components are exposed to high cycle fatigue (HCF) or stress corrosion cracking (SCC). Lambda Research has the capability to evaluate surface finishing operations for improving surface integrity and performance, using strategic experimental design and testing capabilities.

In July, Lambda Research announced the addition of Dr. Mark Kelly to our staff. Mark received his Ph.D. from the University of Cincinnati, and he has over 15 years of experience in materials analysis by phase extraction and x-ray diffraction. His most recent experience has been with ceramics and aircraft engine materials. He will be supervising the operations of the Texture & Phase Analysis Laboratory.