Experience Integrity Innovation

LAMBDA TECHNOLOGIES

DIFFRACTION NOTES 5521 Fair Lane, Cincinnati, OH 45227 (513)561-0883 No. 34 Winter 2008

Use of Residual Compression By Design

INTRODUCTION

Residual compressive stresses have been used for many decades to enhance the fatigue strength of critical metallic components.[1-4] Shot peening (SP) or cold working processes are used on numerous components with fatigue strength enhancement as the primary objective. Other surface enhancement processes like low plasticity burnishing (LPB)[5] are used to introduce a controlled distribution of stable residual stresses to enhance fatigue strength, improve damage tolerance and eliminate stress corrosion cracking (SCC).

Lambda has developed a comprehensive set of design tools and laboratory services that provide the means for creating a compressive residual stress field for enhanced component performance. Lambda's design tools, lab services, and expertise streamline the development process allowing for a rapid solution and transition to production.

IN-SERVICE STRESSES

In order to properly design the compressive residual stress field for a particular component it is necessary to understand the operational applied stresses. Lambda uses commercial finite element (FE) software codes and customized macros, along with customer supplied data, to accurately assess the applied stresses. Figure 1 shows an example of a finite element model of a compressor vane with the peak vibratory stress contour shown. Vital information such as the critical regions to be treated, and the level of residual compression necessary to achieve the desired fatigue performance, is obtained through the use of the FE model.

ANNOUNCEMENTS

Lambda Would Like To Wish Everyone A Safe And Happy Holiday Season

Website

Please visit Lambda's recently updated website, www.lambdatechs.com, to see the many laboratory services we offer, as well as a large library of Technical Papers, Diffraction Notes, and Application Notes.

A2LA Accreditation Renewed

Lambda is pleased to announce the approval of their renewal of accreditation by the American Association for Laboratory Accreditation (A2LA) in accordance with internationally recognized ISO/IEC 17025:2005 guidelines. This assures excellence in performance and maintenance of good laboratory practices. An updated certificate can be obtained from our website at our Quality Assurance page.

For more information visit our web site at www.lambdatechs.com.

FATIGUE DESIGN METHOD

Lambda uses a patented[6] design tool for precise determination of the compressive residual stress distribution required to achieve a specific fatigue strength. The Fatigue Design Diagram (FDD) is based on an extension of the traditional Haigh Diagram to include compressive mean stresses and fatigue damage through Neuber's rule. An example of an FDD for Ti-6Al-4V is shown in Figure 2. In using the fatigue design method the optimal compressive residual stress can be determined for a given mean and cyclic applied stress and damage condition. The FDD is described in detail elsewhere.[7]

VERIFY RESIDUAL STRESS & DISTORTION

An accurate residual stress measurement method is critical in the design process. Lambda uses the x-ray diffraction (XRD) method to characterize the residual stresses.[8-14] The high spatial and depth resolution possible with XRD are necessary for the study of residual stresses from machining, heat treatment, and the various surface enhancement treatments. Lambda uses unique diffractometer systems specifically designed and built in-house for the measurement of residual stresses. Specialized apparatus and software have been developed that allow for automated mapping and depth profiling of residual stresses.

Figure 3 shows a plot of the residual stresses on the leading edge of an LPB treated Ti-6Al-4V turbine engine compressor blade. Measurements were made using Lambda's automated sample translation system that allows for the residual stresses to be mapped in two dimensions. Measurements were made at several positions from the leading edge at the depths shown. The results indicate LPB produced through-thickness compression in the treated leading edge. Both the compressive and compensating tensile residual stresses can be measured for a complete assessment of the residual stress state.

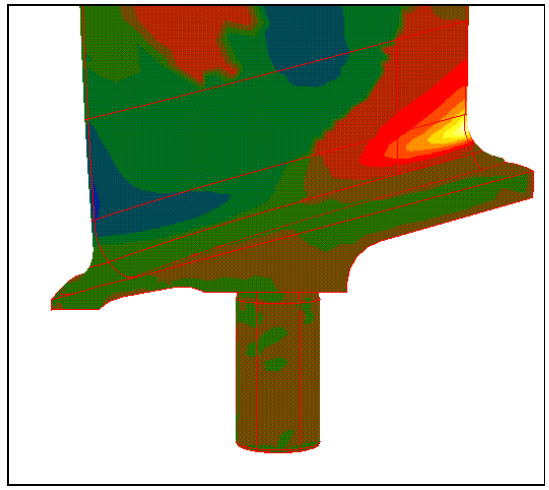

Figure 1 – Vibratory applied stress in compressor vane.

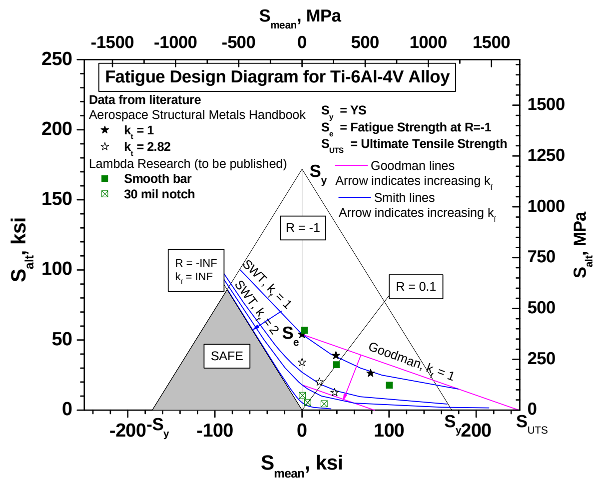

Figure 2 – Fatigue design diagram for Ti-6Al-4V showing allowed alternating and mean stresses at 10^7 cycle life for different R-ratios and fatigue notch sensitivity factors k_f.

The introduction of compressive residual stresses into a part will cause distortion. The level of distortion will depend upon the depth and magnitude of the compression and the overall stiffness of the part. An essential element of the residual stress design process is maintaining an acceptable level of distortion. Lambda uses finite element analysis in the preliminary design stages to predict the level of distortion and, if needed, refine the residual stress distribution to produce an acceptable level of distortion. Once a process has been designed the resulting distortion is directly measured to verify the parts are within the specified dimensional tolerances.

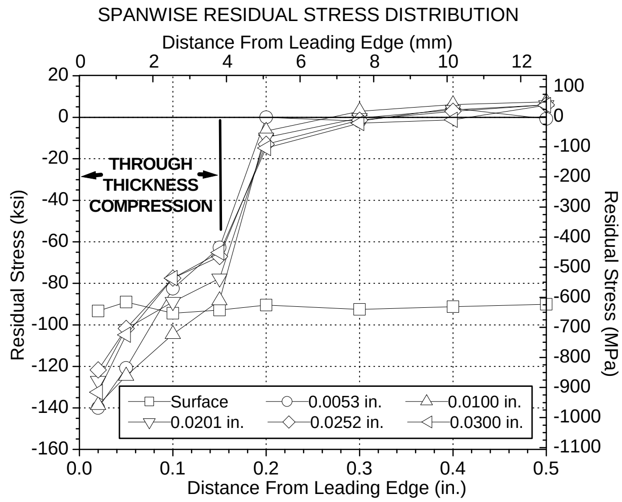

Figure 3 – Residual stress distribution for LPB treated leading edge of Ti-6Al-4V compressor blade showing through thickness compression

VALIDATION OF PERFORMANCE

Lambda provides validation of fatigue and SCC performance through lifing analysis and fatigue testing of full components or feature samples. Using the compressive residual stresses measured via XRD as input, the fatigue strength and life improvement can be accurately assessed using computer lifing models. In addition, Lambda provides unique full component fatigue and SCC testing capabilities to empirically determine the performance benefits. In the event that full components are not readily available, feature samples can be manufactured to replicate the critical region of a component. A component's operating environment, and the damage mechanism, can be simulated for an accurate assessment of the overall performance enhancement provided by the compressive residual stress. A photograph of a fatigue test set up for a compressor blade is shown in Figure 4.

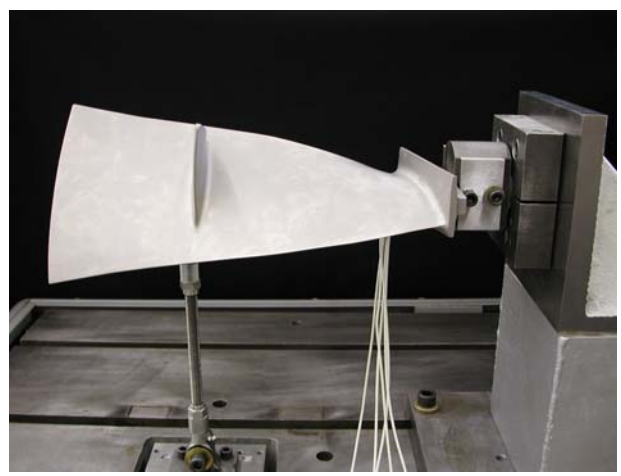

Figure 4 – Residual stress design is validated through full component fatigue tests. Photo shows fatigue test set-up of a compressor blade.

SUMMARY

With the appropriate compressive residual stress field, significant gains in component performance, life, and damage tolerance can be achieved. Lambda offers the services and expertise necessary to accurately and efficiently design a customized compressive residual stress field. Software tools and laboratory services have been specifically developed at Lambda to streamline the residual stress design process.

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