Measurements of Stress in Ceramic Materials Using GHz and THz Reflection-Based Polariscopes

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Abstract. Reflection-based polariscopes, working at GHz and THz frequencies, have been built to measure stress distributions in ceramic thermal barrier coatings. Such coatings are routinely used in aerospace, automotive and energy applications. Understanding stress distributions within these coatings before and after use are vital to improving their performance. Stress optic coefficient measurements of YTZP ceramic, in reflection and at GHz frequencies, are compared to previously measured values in transmission. Additionally, coated samples are measured using both the GHz and THz system. Finally, initial stress images are produced.

Introduction

Ceramic materials are routinely used as thermal barrier coatings in aerospace, automotive and energy applications. High-pressure turbine blades for aerospace engines are a particular area of interest. Due to the harsh environment these components occupy, they are regularly replaced for safety purposes. The time interval between servicing is based on the calculated coating lifetime distribution. Mean lifetimes are calculated from data gathered during pre- and post-use destructive testing. However, these tests produce statistical distributions with variances, forcing engineers to specify servicing intervals based on the lowest portion of the lifetime distribution. Reducing lifetime distribution variances would allow engineers to safely specify servicing intervals closer to the mean coating lifetime, thereby reducing costs significantly. Presented here is a non-destructive testing technique to measure stress distributions in ceramic thermal barrier coatings, with the aim to assist manufacturers in developing a better understanding of coating performance.

GHz Photoelasticity Measurement System

Recently, GHz radiation has been used to measure stress optic coefficients for YTZP ceramic and PTFE bulk material [1] in a transmission based polariscope. To measure the in-situ stress optic coefficient of ceramic coatings, a modified reflection version of this polariscope has been built. A pyroelectric sensor is used to detect the reflected power from a 280-380GHz source beam. Coated dog-bone samples are placed in a tensile testing rig, orientated at 45 degrees to the incident beam (Fig. 1). Complex refractive index values are extracted from the measured power spectra, using a non-linear least squares fit of the Fresnel equations. Real refractive index values are then plotted as a function of applied stress. A comparison between GHz stress optic coefficient values measured in transmission and reflection will be presented.

Figure 1: Coated dog-bone sample in DeBen tensile testing rig.
THz Photoelasticity Measurement System

A similar THz polariscope has been built to achieve a spatial resolution high enough to measure stress distributions in ceramics. A M-Squared Firefly THz source is used to produce a 25mm diameter beam between 800GHz and 2.0THz. A QMC cooled bolometer detector is used to measure power. Additionally, the polariscope is capable of running in transmission or two reflection modes. Before stress distribution measurements are made, the stress optic coefficient of the ceramic materials are measured using the DeBen tensile testing rig to plot refractive index versus applied stress. To measure stress distributions, three linear stages are arranged in an XYZ configuration. The DeBen tensile stage can be mounted to the stage configuration in order to image stress distributions of samples under a known load. Alternatively, aluminium or steel substrate plates with ceramic coatings can be attached to the stages for imaging. These plates can have well-defined, purposeful debonds between the substrate and coating. Imaging across the bonded and debonded region can show stress change within the coating. Initial stress optic coefficients for ceramic thermal barrier coatings will be presented, along with initial imaging results.

Conclusions

Single point stress measurements of bulk ceramic material and ceramic thermal barrier coatings using GHz radiation have been conducted using an improved reflection based polariscope. Results are compared with previously measured values using a transmission based polariscope. A THz polariscope instrument has been devised to measure stress distributions in ceramic coatings. Initial work measured coating stress optic coefficients at THz frequencies, which are compared to those values previously measured at GHz. Finally, the THz polariscope was used to measure high spatial resolution stress distributions in ceramic coatings, with initial results being reported.

References


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