DEVELOPMENT OF NONDESTRUCTIVE EVALUATION METHODS FOR CERAMIC COATINGS

W. A. Ellingson, R. J. Visher, R. Lipanovich, H. Jasti, and M. Shields
Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439
E-mail: ellingson@anl.gov; Telephone (630)252-5068; FAX (630)252-4798

ABSTRACT

Nondestructive evaluation (NDE) technologies are being developed as noncontact, remote sensing methods for determining the condition or "health" of high temperature ceramic coatings used to protect components in the hot-gas path of advanced, low-emission, high-efficiency gas turbines. The ceramic coatings presently under study include yttria-stabilized zirconia (YSZ) for metal vanes, blades, and combustor liners and several compositions of environmental barrier coatings (EBCs) for advanced ceramic matrix composites. While such coatings have not been developed for hydrogen-fueled turbines such as those for the FutureGen program, it is likely that similar coatings would be required and similar NDE technologies would be useful. The TBC effort is a task within the recently established memorandum of understanding on Fossil Energy materials between the United Kingdom and the United States.

The primary NDE technologies being developed at Argonne for high temperature ceramic coatings involve laser-based methods. One method, elastic optical back-scatter (EOBS), has been awarded three patents. The second and more recently developed laser-based method is called Optical Coherence Tomography (OCT). Correlations between EOBS data and condition of these coatings are developed through cooperative efforts with industry and academia. Partners with whom we actively cooperate on TBCs include : The University of Pittsburgh, Praxair Surface Technologies located in Indianapolis, IN, and DLR(The German Aerospace Institute) in Koln, Germany. Work related to EBCs is being done in cooperation with Siemens-Westinghouse Power Corporation (SWPC) and ATK-COI ceramics in San Diego, CA. Work on EBCs for SiC- effort is being done in cooperation with NASA-Glenn Research Center. In the work on TBCs, test specimens are provided with various substrate materials, bond coats, surface preparation, controlled thermal cycles(temperature, duration and number of cycles), and coating thickness. Several new test samples were prepared using both electron-beam physical vapor deposition(EB-PVD) and air plasma spray (APS). Additional correlations were established between the EOBS data and number of cycles before spallation. The predictions were within a few 10's of cycles. Analysis of the EOBS data using digital image analysis continues to suggest a strong correlation exists between EOBS data and the topography at the TBC/bond coat interface. This finding is important as several theories directed toward understanding the pre-spall condition suggest that the topography at the interface between the thermally grown oxide layer and the bond coat changes significantly as a function of the number of thermal cycles. The analytical model described last year for analysis of the EOBS was more extensively studied this year. The software package is a "field-solver" for Maxwell's equations and allows prediction of EOBS patterns as a function of various features including the topography of the interface of the TGO/Bond coat, input laser power, polarization angles, effect of wavelength and so on. Initial models show a direct prediction of scatter patterns for a "V" notch below the TGO layer

with a 75um EB-PVD coating. The single "V" notch represents one "peg" in the topographical pattern. The OCT system described last year was modified with the addition of new electronics, mew laser and better fiber optics. Tests were run on both EBCs and TBCs. This technology has now been demonstrated to allow a direct measurement of thickness of the TBC as well as EBCs. Direct measurement of the thickness of TGO is possible but spatial resolution limits in the vertical direction limit the data at the moment. This presentation will discuss these NDE methods, the theoretical model and provide recent results.

INTRODUCTION

Nondestructive evaluation (NDE) methods are being developed for use with ceramic coatings for components in the hot-gas path of advanced gas-fired turbine engines with low emissions. The main coatings studied are thermal barrier coatings (TBCs) for vanes, blades, and combustor liners to allow hotter gas-path temperatures. The NDE methods will be used to: (a) provide data to assess the reliability of new coating processes, (b) identify defective components that could cause unscheduled outages, (c) track growth rates of delaminations and defects during use in engines, and (d) provide data for reaching rational decisions for replace/repair/re-use of components.

THERMAL BARRIER COATINGS

Advances in thermal barrier coatings (TBCs), applied by two deposition methods, electron beam–physical vapor deposition (EB-PVD) and air plasma spraying (APS), are allowing higher temperatures in the hot-gas path of gas turbines, including syn-gas fired turbines.[1-3] However, as TBCs become "prime reliant," it becomes important to know their condition at scheduled or unscheduled outages.

Work at Argonne National Laboratory (ANL) is underway to develop NDE methods to assess the condition of the TBC primarily from the point of view of detecting pre-spall conditions.[4] Prior to spallation of EB-PVD coatings, it has been shown, see Fig. 1, that the interface topography between the thermally grown oxide layer (TGO) and the substrate changes as a function of the number of thermal cycles.[5] The growth and change in topography for APS coatings are less clear. However, if an NDE method could be developed that would allow interrogation of this interface for either EB-PVD or APS coatings, it would seem possible to begin to develop a method for pre-spall prediction. One such NDE method under development utilizes polarized laser light in a back-scattering mode, see Fig. 2. This method is based on a modification of the reflectometry method[6] and was described previously.[7] Laser scatter data for an entire test sample are acquired by raster scanning the sample under computer control.

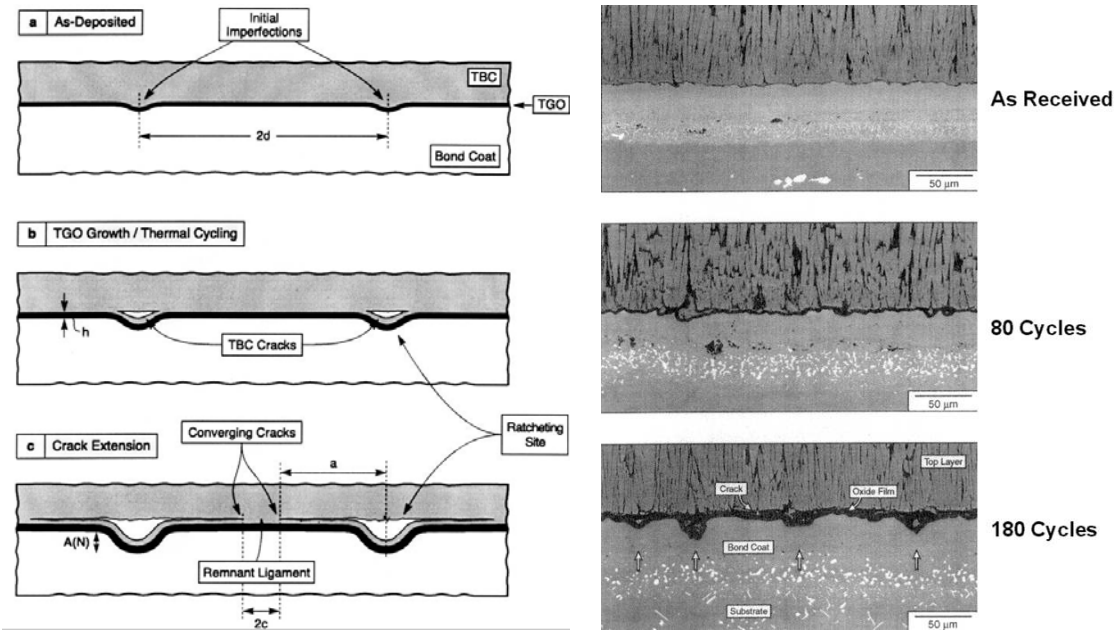

Fig 1. Schematic diagram and optical photomicrographs showing changes in topography between TGO and substrate for EB-PVD TBC (based on Ref. 4)

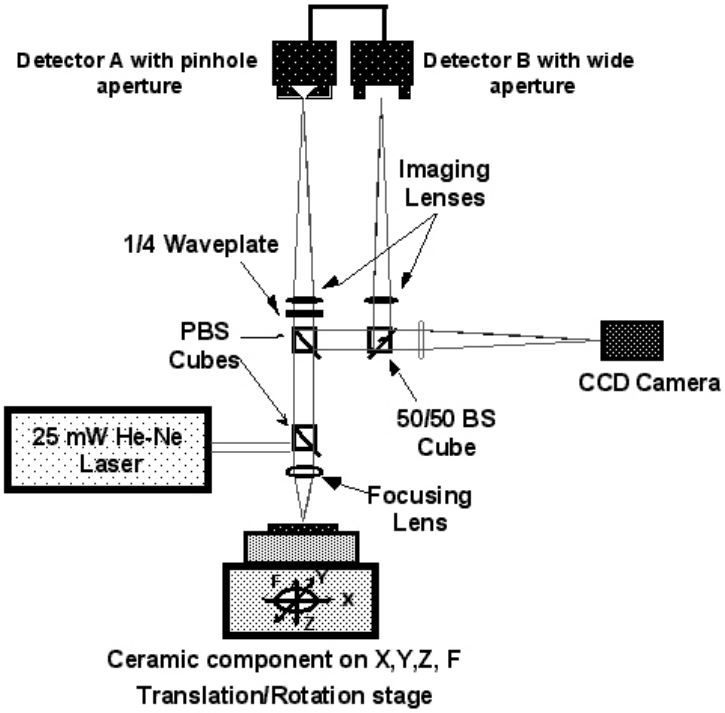

Fig 2. Schematic diagram of the polarized laser back-scatter NDE method for studying the topography of the TGO-substrate interface.

During this past year, we have focused on developing an analytical model that would predict the laser back scatter signal given a specific set of conditions. The analytical model we are developing is based on finite element analysis and is a so-called "field-solver" for Maxwell's equations[4] and yields signal intensity and amplitude. A schematic diagram of the TBC cross-section we modeled is shown in Fig. 3. The metal substrate and the bond coat were modeled as perfect electrical conductors. The thermally grown oxide layer was modeled as aluminum oxide and the TBC top layer was modeled as zirconia. The region above the TBC was modeled as free space or vacuum. The results of a comparison between the theoretical result and an experiment is shown in Fig. 4. In addition, this year we changed the laser scatter parameter used to correlate laser scatter data to the exposure conditions. In the past we had used the statistical parameter, coefficient of variation. We changed this year to measure the electrical power signals coming from the optical detectors. This has been significant and now the changes in the detected signals are much stronger. This can be seen by looking at Fig. 5 which shows the detected laser scatter power as a function of the number of thermal cycles for an APS TBC sample set. We will explore this and other parameters next year.

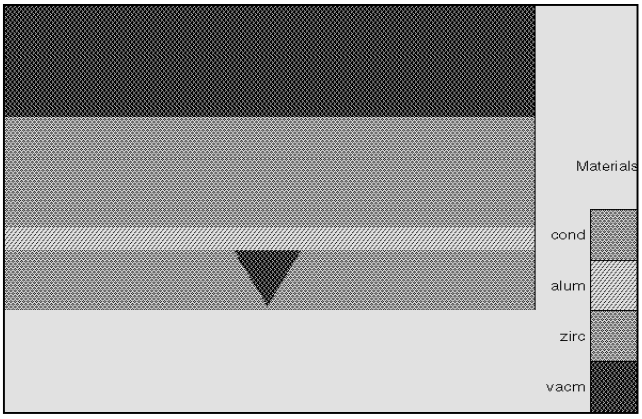

Fig 3. Schematic Diagram Showing TBC Cross-Section Used for Analytical Model

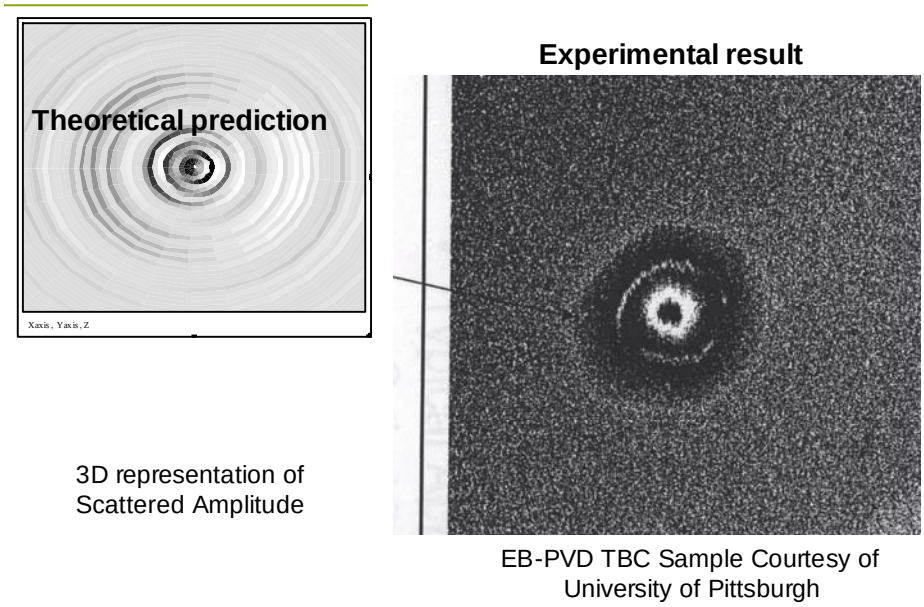

Fig. 4 Comparison Between Theoretical Laser Scatter and Experimental Data

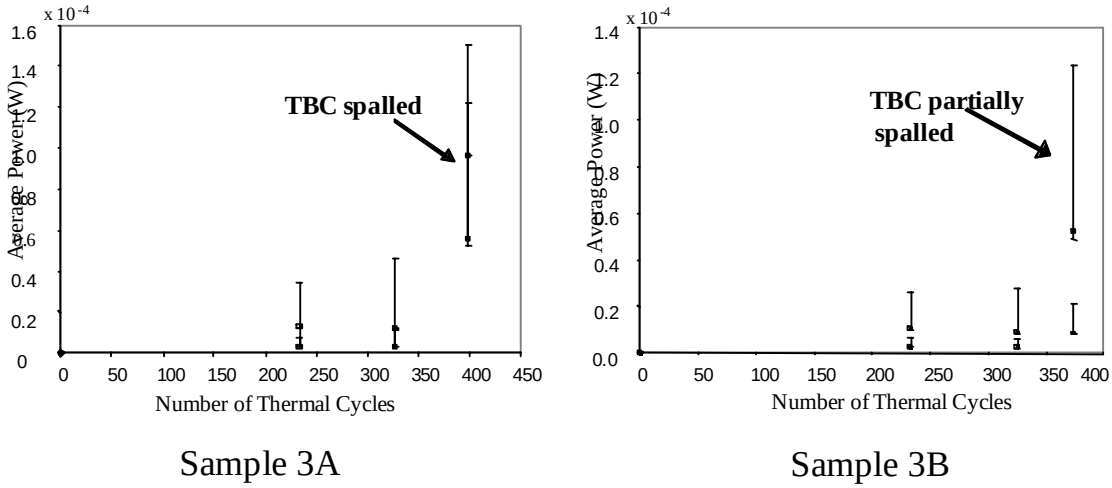

Fig. 5 Detected Back Scattered Laser Light Power Levels as a Function of the TBC Exposure Time. These are from an APS sample.

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