DEVELOPMENT OF NONDESTRUCTIVE EVALUATION METHODS FOR CERAMIC COATINGS

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May 2002

Distribution
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Invited extended summary for inclusion in the Proceedings of the
16th Annual Fossil Energy Materials Conference
Baltimore, MD
April 22-24, 2002

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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. Two types of coatings are being studied: thermal barrier coatings (TBCs), which are under development for vanes, blades, and combustor liners to allow hotter gas-path temperatures, and environmental barrier coatings (EBCs), which are under development to reduce environmental damage to high temperature components made of ceramic matrix composites. The NDE methods will be used to a) provide data to assess the reliability of new coating application processes, b) identify defective components that could cause unscheduled outages, c) track growth rates of defects during use in engines, and d) allow rational judgment for replace/repair/re-use decisions of components.

Thermal Barrier Coatings

Advances in thermal barrier coatings (TBCs), both electron beam–physical vapor deposition (EB-PVD) and air plasma spraying (APS), are allowing higher temperatures in the hot-gas path of gas turbines (1-3). However, as TBCs become "prime reliant," their condition at scheduled or unscheduled outages must be known. NDE methods are under development to assess the condition of the TBC for pre-spall conditions. One proposed mechanism for spallation (Fig. 1) is that, at the interface between the thermally grown oxide layer (TGO) and the substrate, the topography changes as a function of the number of thermal cycles (4). An NDE method is needed to interrogate this interface and establish whether there is a correlation between the condition of this interface and the potential for spallation. One such NDE method under development is polarized laser back-scattering (Fig. 2), which is based on a modification of the reflectometry method (5). The laser back-scattering method utilizes two detectors, not one. The polarized laser light is incident on the test specimen, and the back-scattered light, which penetrates through the optically translucent coatings, reflects back off the interface and is received by two the detectors. The first detector has a highly polished first-surface mirror in front of it that has a small-diameter aperture, thereby only allowing light that is back-scattered over a narrow angle to be detected, while the second detector has no aperture and, therefore, detects light scattered back over a much larger angle. On the basis of the voltage output from these two detectors, various features related to the scatter pattern can be discriminated. Laser scatter data for an entire test sample are acquired by raster scanning the sample under computer control. Recently, we studied three 25-mm-diameter button samples made with CMSX-4 substrate, plasma-sprayed MCrAlY bond coat, and a 7YSZ TBC applied using EB-PVD methods. These three samples were all produced at the same time, and two of them were thermally cycled. The first sample had no thermal cycles, the second had 5 thermal cycles, and the third had 70 thermal cycles. Each thermal cycle was one hour with a hold temperature of 1121°C. Fig. 3 shows the resulting back-scattered laser data over a 15-mm square region from each sample, along with the gray-scale histogram for each “image.” The histogram shows that as the number of thermal cycles increases, the histogram peak shifts to the right, reflecting the larger number of “black” spots. These “black” spots correspond to increased surface roughness at the interface. It may thus be possible to eventually correlate the peak shift to the condition of the interface and thus predict spallation.

Tests have also been conducted with this NDE method on APS TBCs. Results (Fig. 4) indicate that pre-spallation can be detected.

Environmental Barrier Coatings

Development of oxide/oxide ceramic matrix composites for combustor liners has necessitated the development of a protective coating that can reduce the temperature of the substrate material. Since such coatings are critical to the materials performance, several NDE technologies are under development to detect degradation of these EBCs. Recent results have demonstrated that NDE thermal imaging correctly detected simulated delaminations in an oxide/oxide composite, and x-ray computed tomography was used for verification. The thermal imaging method is based on detection of the time-dependent surface temperature determined with an infrared camera following thermal stimulation with flash lamps (6, 7). The high-frame-rate infrared camera utilizes a focal plane array with 3- to 5-µm band pass. The flash lamps are powered by a 6.4-kJ power supply. Spectral output of the flash can be customized through use of different gases in the flash tube, as well as various external filters. Two modes of operation are used: through transmission, where the thermal stimulation is placed on one side of the test sample and the detector on the opposite side, and one-sided, where the thermal stimulation and the detector are both placed on the same side of the test specimen (Fig. 5). For a recent set of experiments, a special cylindrical test specimen (Fig. 6) was made with intentional delaminations. Results obtained from one-sided thermal imaging of the entire circumference of the cylinder are shown in Fig. 7. By using such methods, with careful attention to the sizes of features, we should be able to calibrate the method and begin to quantify its performance.

References

1. North Atlantic Treaty Organization. "Thermal Barrier Coatings,” Advisory Group for Aerospace Research and Development report, AGARD-R-823, Neuilly-Sur-Seine, France, April 1998.
2. US National Research Council, National Materials Advisory Board. "Coatings for High Temperature Structural Materials," National Academy Press, Washington, DC, 1996.
3. US National Aeronautics and Space Administration, “Thermal Barrier Coating Workshop,” NASA Conference Publication 3312, 1995.
4. Evans, A. G., Wang, J. S., and Mum, D. “Mechanism-Based Life Prediction Issues for Thermal Barrier Coatings,” in Proceeding of the TBC Workshop, US National Aeronautics and Space Administration, pp. 45-52, 1997.
5. Tompkins, H. G., and McGahan, W. A., "Spectroscopic Ellipsometery and Reflectometry," J. Wiley and Sons, Inc. New York, 1999.
6. Sun, J. G., Easler, T. E., Szweda, A., Pillai, T. A. K., Deemer, C. and Ellingson, W. A., “Thermal Imaging and Air-Coupled Ultrasound Characterization of a Continuous Fiber Ceramic Composite,” Cer. Eng. Sci. Proc., Vol. 20, Issue 3, pp. 200-210, 1999.
7. Deemer, C., Sun, J. G., and Ellingson, W. A., "One-Sided Thermal Imaging for Flaw Characterization of Ceramic Matrix Composites,” Ceram. Trans., Vol. 124, pp. 23-240, 2001.

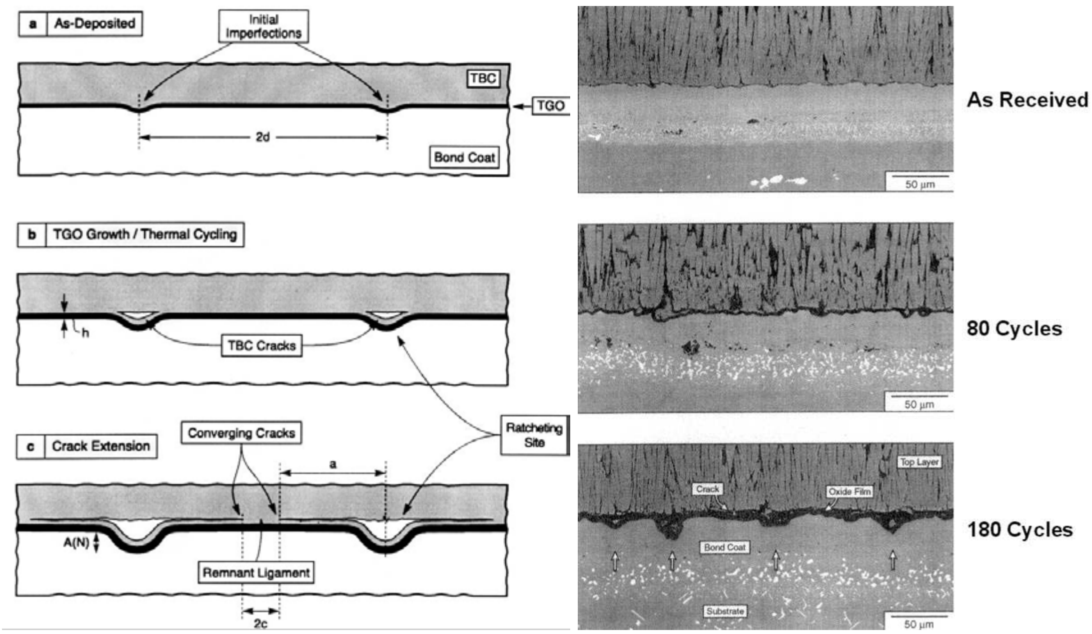


Fig 1. Schematic diagram and optical photomicrographs showing changes in topography between TGO and substrate for EB-PVD TBC (based on Ref. 4)

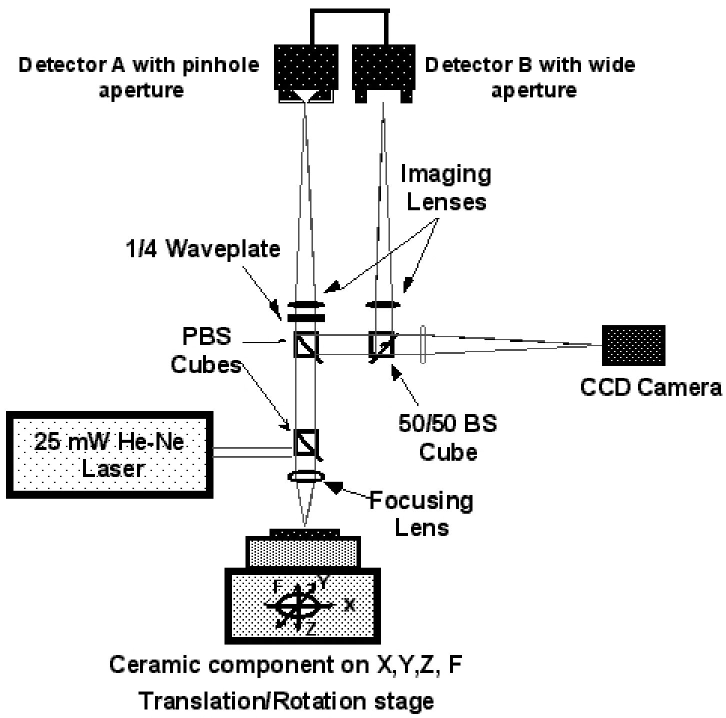
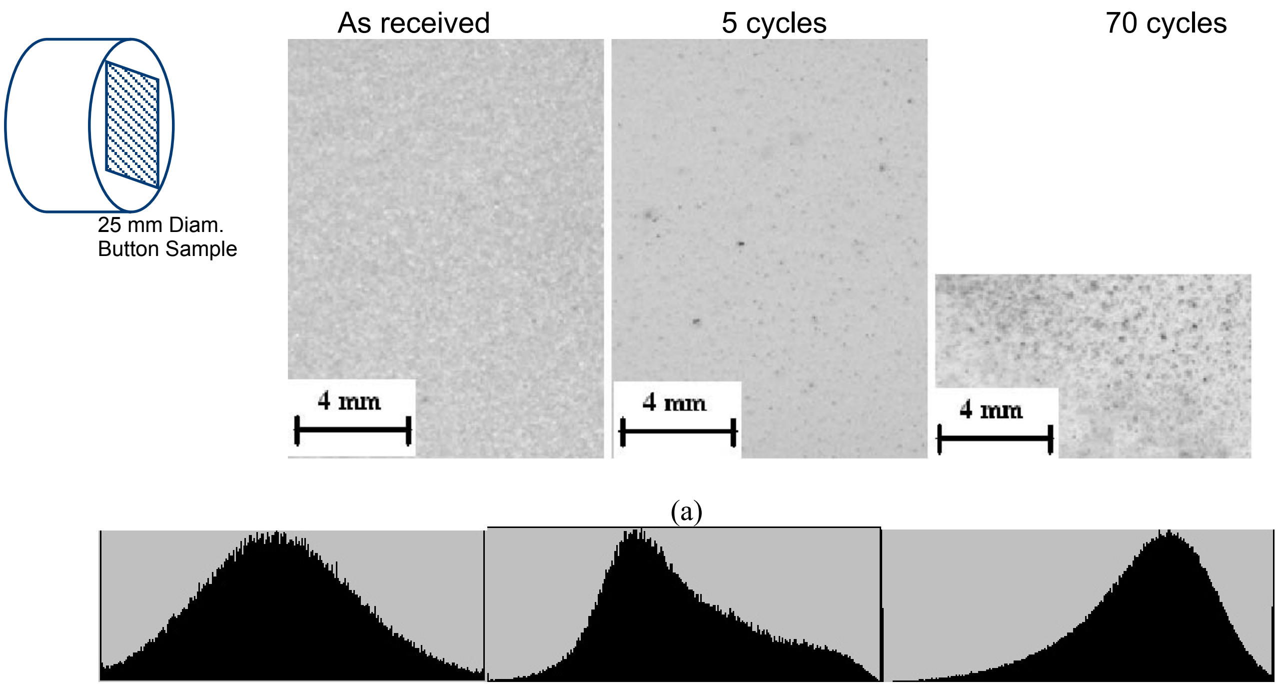


Fig 2. Schematic diagram of the polarized laser back-scatter NDE method for studying the topography of the TGO-substrate interface.



(b)

Fig 3. Polarized laser back-scatter data from thermally cycled EB-PVD samples.
a) Laser Scan Image data
b) Scale Histograms

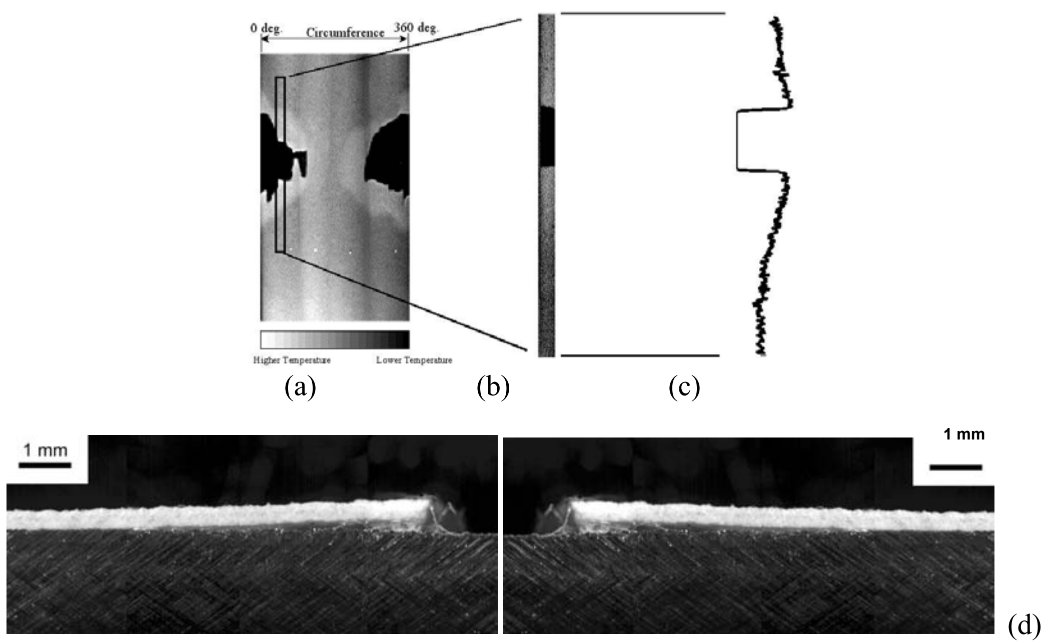


Fig 4. Polarized-laser back scatter for detection of de-bonds in APS TBC. a) One-sided thermal image showing delamination and laser scan position, b) laser scan data, c) line plot of laser scan data, and d) optical photomicrographs of delaminated region.

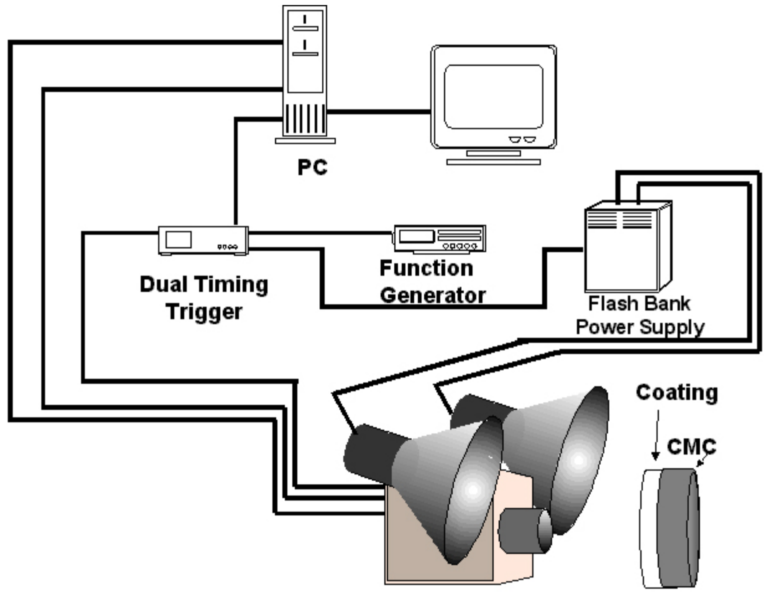
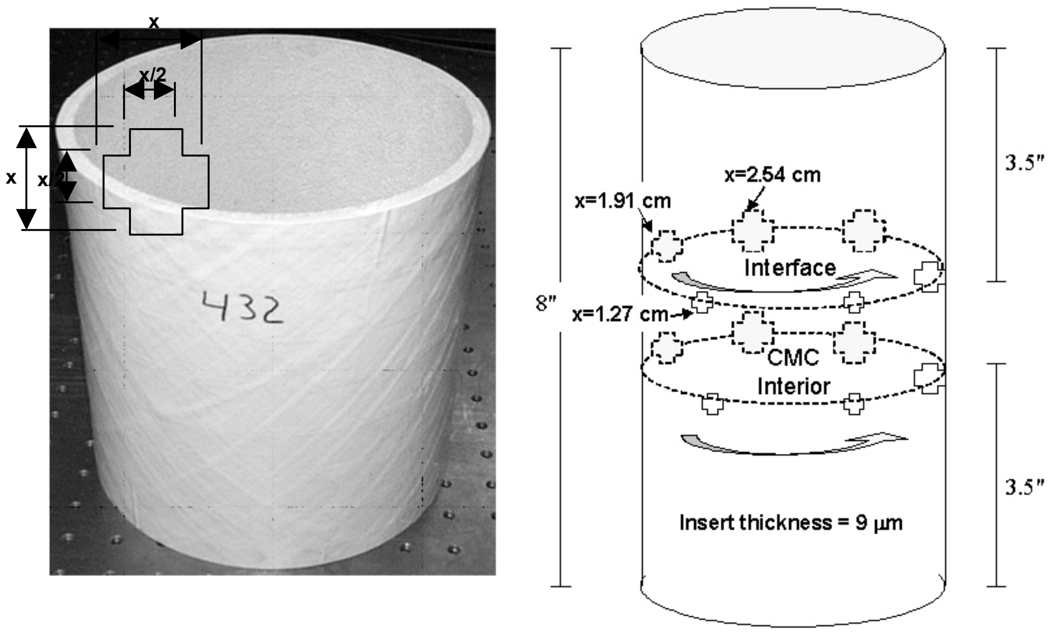


Fig 5. Schematic diagram of one-sided thermal imaging for delamination detection of EBC on ceramic matrix composite (CMC)



(a) (b)

Fig 6. Oxide/oxide delamination test sample. a) Photo of test sample, b) schematic diagram showing position of delaminations.

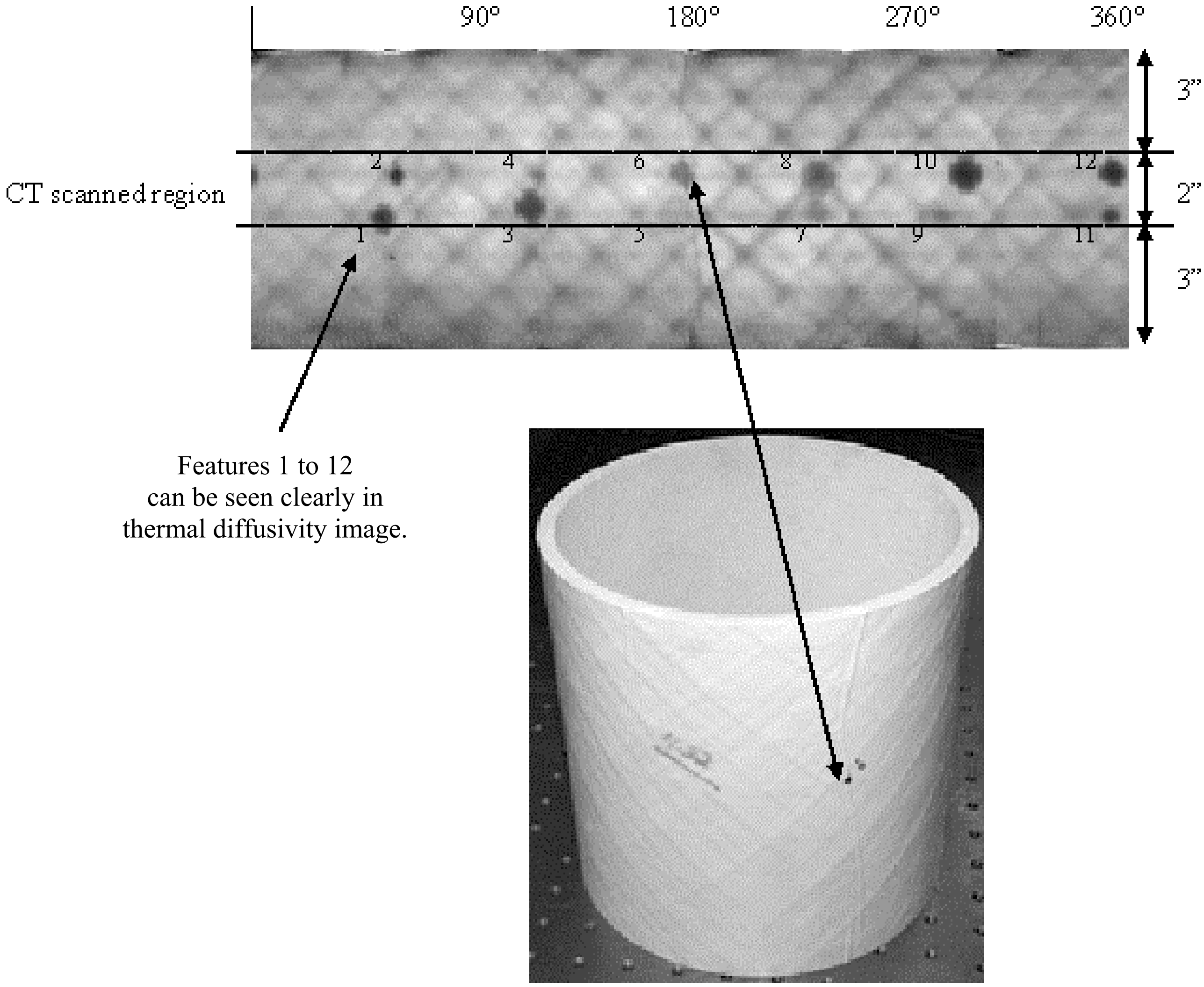


Figure 7. Example of detection of delaminations in sample shown in Fig 6. The thermal image as obtained using one-sided data acquisition.