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Characterization of Cracking within Thermal Spray Deposits by an Acoustic Emission Method—Extended Abstract*

C.C. Berndt, C.K. Lin, and S.-H. Leigh

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Four-point bend tests with in situ acoustic emission (AE) were used to study the cracking behavior of alumina-3% titania materials prepared by gas- and water-stabilized plasma technologies (GSP and WSP, respectively). Catastrophic failure was observed for GSP-sprayed samples while WSP-sprayed samples exhibited microcracking before failure. The amplitude and energy distributions were also investigated, and it was determined that the percentage of macrocracks for GSP-sprayed samples is much larger than for WSP-sprayed samples. The processing effects, which induced differences in microstructure, may account for the differences in AE responses.

Keywords acoustic emission, cracking of composites, cracking mechanisms, thermal spray

1. Introduction

Thermal spray technology has been widely used to deposit coatings to protect the substrate material. The technology also encompasses the manufacture of net shapes, which have been fabricated by using flame spraying (Ref 1, 2) and, more recently, plasma spraying (Ref 3).

The freestanding forms are built up from successively deposited layers of lamellae, consisting of metastable phases, pores, and oxides. The phenomena of crack propagation and growth within materials, not only of the deposits but also of bulk materials, have been studied by acoustic emission techniques (Ref 4, 5). For example, it has been established that the number of AE counts emitted during a hardness test increased as the density of plasma-sprayed ceramics decreased. Similar correlations have been proposed on the basis of AE measurements performed during tensile adhesion tests (Ref 6).

C.C. Berndt, Center for Thermal Spray Research, SUNY at Stony Brook, NY 11794-2275, USA; **C.K. Lin,** Institute of Materials Engineering, National Taiwan Ocean University, Taiwan, R.O.C.; and **S.-H. Leigh,** Research Institute of Industrial Science & Technology, Pohang, Korea. Contact e-mail: cberndt@notes.cc.sunysb.edu.

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2. Experimental

The alumina-3 wt% titania freestanding specimens were prepared by water- and gas-stabilized plasma spray processes with equipment from the Institute of Plasma Physics (the Czech Republic) and Sulzer-Metco (Switzerland), respectively.

A universal test machine was used to perform the four-point bend tests with an AET 5500 system to monitor in situ the cracking behavior. Any AE signals were detected with a transducer (model AC175L), preamplified (model 140B) with a preamplifier filter (model FL12Y), and then output to the AET 5500 system, which was attached to an IBM-compatible personal computer to record the AE responses. Any background noise arising from the mechanical test device was filtered out and removed from the analysis through a compliance calibration.

The experimental setup is shown in Fig. 1. The lengths of the inner and outer spans were 20 and 40 mm. The specimens were ~4 (thickness) × 5 (width) × 50 (length) mm and were tested in the in-plane orientation at a crosshead speed of 1.0 mm/min.

3. Results and Discussion

3.1 *Summary of Preliminary Studies*

Former studies of WSP-sprayed alumina-13% titania found that the difference in the modulus of ruptures (MORs) when tests were performed in the in-plane and cross-section orientations were within one standard deviation range; i.e., the MOR

Table 1 Summary of energy distribution for GSP- and WSP-sprayed samples with respect to cracks

Technique	<45 Micro	45-100 Transitional	>100 Macro	Total events	No. of samples	Events per sample
GSP events	175	759	370	1304	11	119
GSP %(a)	13.4	58.2	28.4	...	...	...
WSP events	356	1320	114	1790	10	179
WSP %(a)	19.9	73.7	6.4	...	...	...

(a) % is calculated with respect to the total events.

values were similar. However, two different types of cracking mechanisms were distinguished: catastrophic failure and microcracking before failure. The distinction of "catastrophic" and "microcracking" features is based on the AE response prior to failure. For example, the total number of events from heat-treated samples was smaller than the value from the as-sprayed materials, and this decrease in total events was due to the change in microstructure. Although the materials (as-sprayed or heat-treated samples) may have similar mechanical properties and the same porosity, their AE responses can be very different due to different failure mechanisms.

3.2 *AE Responses versus Normalized Displacement*

The AE responses from GSP- and WSP-sprayed samples were pooled together to avoid bias from individual test results. The total AE responses versus normalized displacement are illustrated in Fig. 2. Note that the WSP-sprayed samples exhibited AE events after a normalized displacement of 0.3 while the GSP-sprayed samples exhibited the majority of AE events after a normalized displacement of 0.6. Note also that WSP-sprayed samples exhibited a gradual increase in the normalized AE responses between a normalized displacement of 0.36 and 0.96. However, GSP-sprayed samples exhibited a sharp increase in the normalized AE responses between a normalized displacement of 0.59 and 0.86.

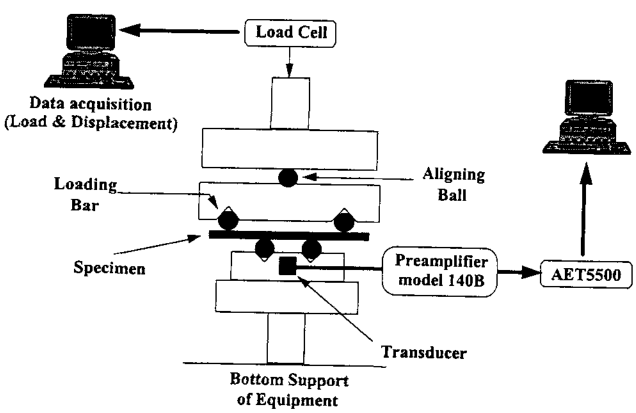

Fig. 1 Experimental setup for four-point bending with in situ acoustic emission

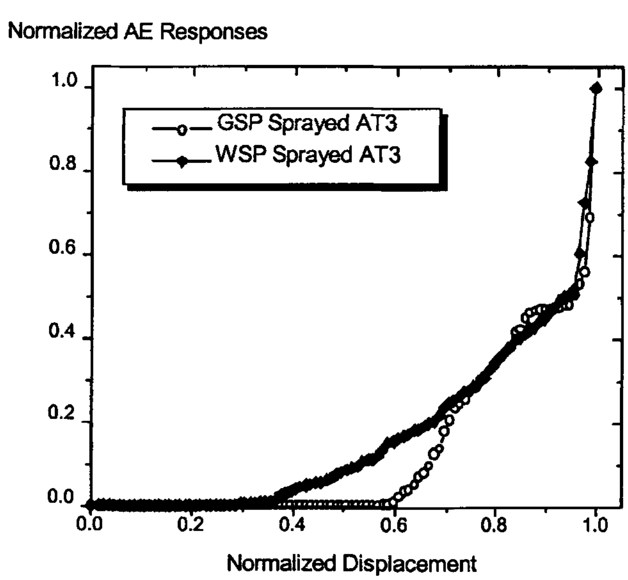

Fig. 2 Normalized AE responses versus normalized displacement for WSP- and GSP-sprayed samples

3.3 *Population Analyses*

There is a significant difference in the population of microcracks, transitional cracks, and macrocracks for the specimens prepared by the two different techniques (Table 1). Note that the GSP-sprayed samples, possess a large proportion of macrocracks (28.4%); more than 4 times the value (6.4%) of WSP-sprayed samples.

Table 1 also indicates that the average events per sample (119) for GSP-sprayed specimens, which showed catastrophic failure, was lower than the value (179) for WSP-sprayed specimens, where microcracking was observed. The same trends were found for thermal barrier coatings subjected to thermal cycling (Ref 7) where macrocracking occurred at a low average events per sample.

4. Conclusions

The normalized AE release rate, defined as the normalized AE response divided by the normalized displacement, is a good analytical procedure to determine the cracking mechanism. Thus, the normalized AE release rate is high for samples that show catastrophic failure but low for samples that exhibit microcracking before failure.

In summary, although there is only a slight variation in microstructure, the AE responses were significantly different for the same material processed by the two methods. The through-splat growth of the columnar structure for GSP-sprayed materials gave rise to a high percentage of macrocracks; however, the WSP spray process generated distinct splat boundaries for these specimens, and extensive microcracks evolved. The differences in the AE responses indicate that the two methods may induce different types of failure. By use of AE technology, more information concerning material responses to stress can be collected, and interpretation of these results enable a better understanding of cracking mechanisms for these materials.

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