Quantitative damage evaluation of thermal barrier coatings subjected to tensile loading using an acoustic emission method

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Summary The fracture process of thermal barrier coatings (TBCs) subjected to tensile loading is monitored using an acoustic emission (AE) method. The surface crack density is calculated based on a modified shear-lag model to obtain the quantitative correlation of damage in TBCs and AE parameters. The calculated crack density shows a well correlated relationship with AE events, which is well agreement with experimental results.

INTRODUCTION

The application of thermal barrier coatings (TBCs) has facilitated a steep increase of the turbine entry temperature and the associated increase in performance and efficiency of gas turbine [1]. Unfortunately, the complex shape, structure, and harsh operating conditions make the failure behavior of TBCs much more complicated than that in metallic, ceramic components or other coating systems, and thus the failure assessment of TBCs is very difficult by using traditional strength theories or experimental mechanics methods [2]. There has been a growing interest in bringing together experiments under destructive load with ideas from in-situ or real time nondestructive tests [2-3], such as acoustic emission (AE) [2]. However, the quantitative assessment of damage evolution in TBCs is still intractable in AE monitoring, which is necessary for the real time testing of TBC failure. In this study, AE monitoring and digital image correlation (DIC) are used to detect fracture in TBCs under tensile loading, and further the relationship between AE events and surface cracks is quantitatively evaluated.

RESULTS AND DISCUSSION

The TBCs specimen is composed of a Ni based superalloy GH3030 substrate, a CoCrAlY bond coating and a ZrO_2-8% (wt.) Y_2O_3 ceramic coating that are prepared by air plasma spraying. The thicknesses of substrate, bond coating and ceramic coating are 1.5 mm, 100 μm and 200 μm, respectively. The dimensions and experimental setup for the tensile specimen are illustrated in Fig. 1. The sampling rate is set to 2 MHz for the PCI-2 AE monitoring system with the threshold of 38 dB. The loading rate of testing machine (REGER 2000) machines is 0.2 mm/min. The full field strain evolution in the specimen is performed using in-situ DIC analysis. The sampling rate of DIC is set as one image per 2.5 seconds, and the measuring accuracy is about 0.05%.

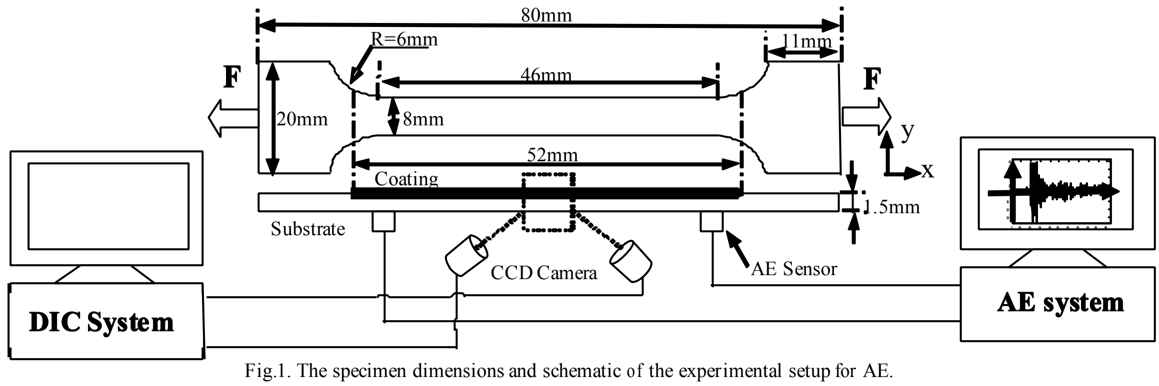

Fig.1. The specimen dimensions and schematic of the experimental setup for AE.

Fig. 2 shows stress and AE events as a function of loading time in substrate and TBCs. Obviously, AE events attributed to plastic deformation of substrate are few and therefore can be negligible in TBCs. Fig. 3 represents AE events from TBCs and the strain history of ceramic coatings measured by DIC . Both the AE events and strain history of TC exhibit obvious break points at about 450 s, which is the starting time of surface cracking. It is seen in Fig. 2 that the onset strain of surface cracking is about 0.35%. Similarly, the stop point of surface cracking can be obtained from break points at the strain history curve of TC/BC interface, as well as the second one in the AE event curve.

For a brittle film on a ductile substrate under tensile loading, a traditional shear-lag model [4] is commonly accepted to evaluate the surface crack density ρ , which is defined as the ratio of multiple crack numbers to the length of a specimen. The model includes an elastic-plastic interlayer, in which the load transfer from thick ductile substrate to thin brittle film can be described. The structure of TBCs is consistent with the shear-lag model except that coating is

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thicker than that in the model. Therefore, such a model is modified by considering the strain gradient in coating, and if substrate is in the elastic-plastic state, the crack density ρ of coating can be expressed as

$$\rho = \frac{\tau_b K}{2}[d_1\sigma_b K + M - \sqrt{M^2+\tau_b^2} + \tau_b arsinh\frac{\tau_b}{M}]^{-1} \tag{1}$$

with $K = \sqrt{\frac{G_s G_c}{d_1 E_c (G_s d_2 - G_c d_3)}}$ and $M = d_1 K[E_c(\varepsilon_s + \varepsilon_c^r) - \sigma_b]$, where subscripts s and c are interlayer and coatings, respectively, G is shear modulus, E is Young's modulus of brittle coating, d_1 and d_2 are thicknesses of brittle coating and interlayer, respectively, σ_b is the tensile strength of brittle coating, τ_b is the interface shear strength, ε_c^r is the residual strain of coating, and ε_s is the tensile strain of substrate. Obviously, if the substrate strain ε is known, the crack density can be determined.

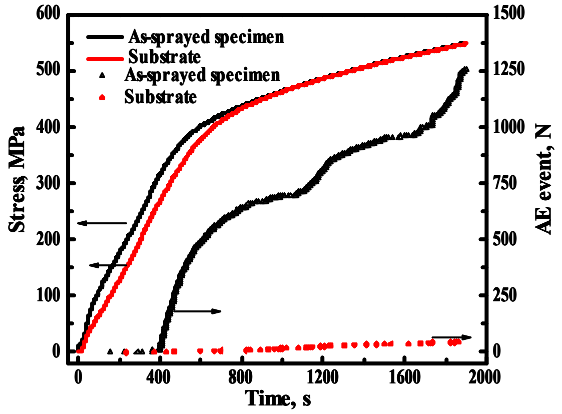

Fig.2. Measurement results of AE event and tensile stresses for specimens.

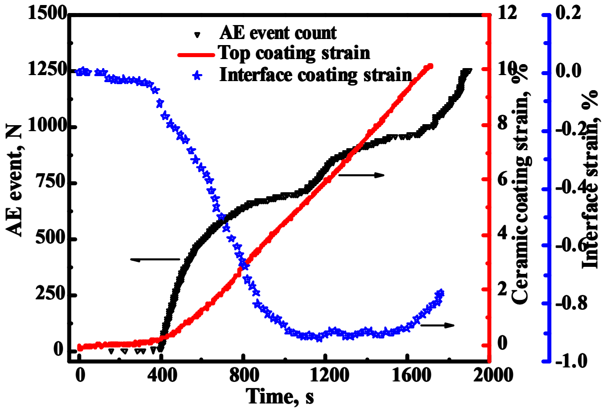

Fig.3. Coatings stress and AE event curve of TBCs specimen.

As shown in Fig. 4, it is obvious that the surface vertical crack density determined by the shear-lag model is well consistent with experimental results. The results indicate that the correlation between crack densities and AE activities determined by the shear-lag model is reliable and accurate to quantitatively assess the damage evolution in TBCs. Fig. 4 also reveals that the surface cracking has undergone starting, proliferation and ultimate saturation, which is verified experimentally [4]. The surface crack density seems to be a linear relationship with the logarithm of AE events, as shown in Fig. 5, but this is a very primitive deduction due to the limited experimental data.

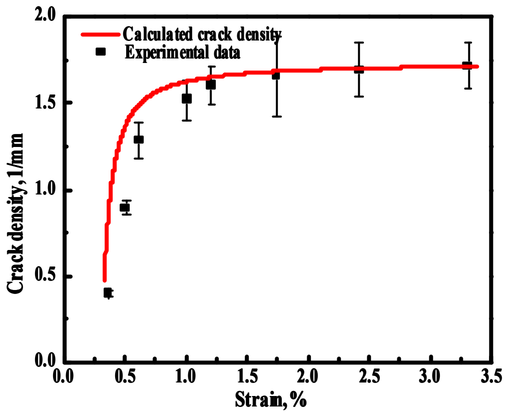

Fig. 4. Relationship between surface vertical crack density and substrate strain.

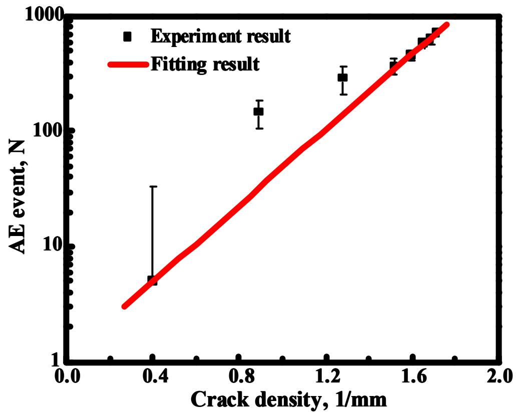

Fig. 5. Relationship between surface vertical crack density and AE event.

CONCLUSIONS

In this paper, a quantitative assessment of the surface crack evolution in TBCs, subjected to tensile loading, has been carried out by using a real-time AE method. The main results can be summarized as follows: (1) The modified shear-lag model is suitable for calculating the surface crack density in TBCs. (2) The start and stop times of surface cracking can be obtained according to the AE behavior. (3) The surface crack density seems to be a linear relationship with the logarithm of AE events in the case of tensile loading.

References

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