NOVEL BENDING BASED METHODS FOR INTERFACE FRACTURE ENERGY MEASUREMENT OF THERMAL SPRAY COATINGS

Saim Abbas[1]*, Ashwini Kumar Mishra[1], Sudhanshu Mallick[1], and Nagamani Jaya Balila[1]

[1]Indian Institute of Technology, Bombay, India
** Presenting Author email: saimabbas@iitb.ac.in*

Abstract

A novel modified cantilever beam method and modified clamped beam method with DIC (Digital Image Correlation) is developed to measure the interface fracture energy of ceramic/metal interface. The experimental execution for these geometries is demonstrated on an Air Plasma Sprayed (APS) YSZ coating on a steel substrate. For modified cantilever method, a pre-crack is first made along the interface, followed by the interface test. These methods use the same geometry for both pre-cracking and testing. The value of interface fracture energy is obtained as the critical energy release rate, G_c, using numerically computed values of J-integral. The results of both the geometries are compared.

1. Introduction

Thermal barrier coatings (TBC) help to keep the temperature of the substrate within the working range in a gas turbine, and are an essential component. The life of the metal substrate is highly dependent on the life of the TBC system, and hence the lifetime prediction of the TBC becomes a significant study.

To predict the lifetime of a coating, its interface properties also need to be evaluated. In literature, many experimental techniques have been developed to evaluate interface properties but they have limitations associated with them. The popular technique, the four-point bend test [1], has been used for stable crack growth. Hoffinger et al. [2] was able to resolve the problem of thin coating by modifying the four-point bend test. For micron level testing, Mead et al. [3] modified the four-point bend test. Recently, it has been shown that the clamped beam geometry is able to achieve controlled crack growth in homogeneous and in-homogeneous samples and across length scales [4]. Another popular fracture test geometry for thin films and coatings has been the cantilever bending. In the present study, these two geometries have been modified for interface fracture tests and applied for testing one set of samples. More details of the modified clamped beam method can be found here [5]. The results of both geometries are compared.

2. Results

The schematic diagram of the geometries is shown in Fig.1, and the DIC camera image of the two samples after the test is shown in Fig.2. Experiments are conducted and finite element (FE) analyses are performed to obtain the following results:

a. In case of a cantilever beam, a pre-crack is generated by loading the beam in bending and observing the interface by DIC. In case of the modified clamped beam, a pre-crack is generated at a smaller lower offset than the final loading condition. A sudden change in the crack opening displacement indicates initiation of the pre-crack, post which the specimen is unloaded.
b. A further test is performed for the crack propagation along the interface, and the load-displacement curve is plotted for both geometries. A characteristic change in the load-displacement curve indicates crack propagation. This critical load is used to determine interface fracture energy. Further crack propagation point has been correlated with crack opening displacement.
c. Finite element simulations are done for both cases to obtain the normalized G by the contour integral method. Using normalized G and critical load obtained using experiments, interface fracture energy is calculated. For the modified cantilever method, analytical solutions have also been proposed using beam bending theory.
d. The interface fracture energy obtained by these methods for the same batch of YSZ coatings has been compared with their respective phase angles.

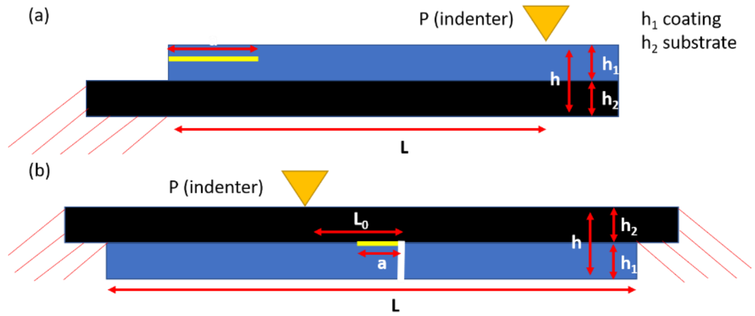

Fig.1 – Schematic diagram of (a) cantilever geometry and (b) clamped beam geometry.

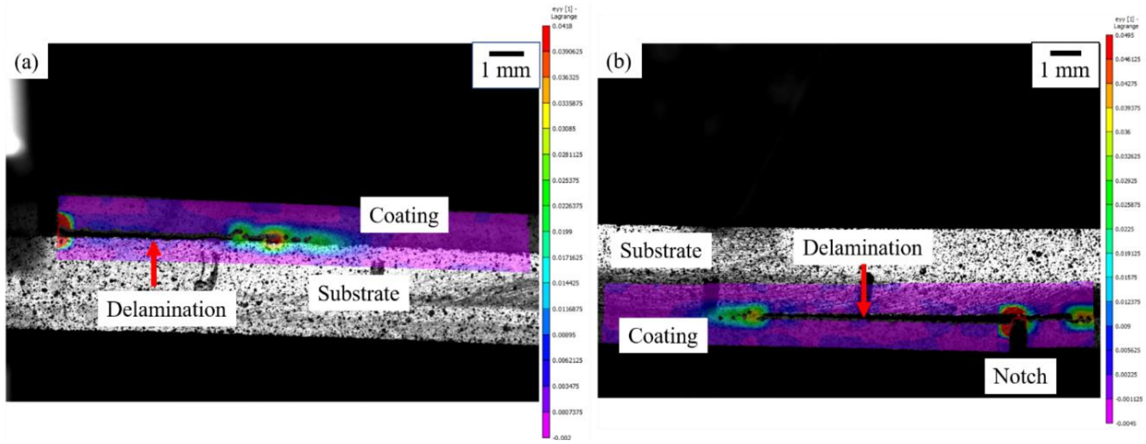

Fig.2 – DIC camera image of the sample after the test of (a) cantilever geometry and (b) clamped beam geometry.

3. Conclusions

Both the geometries used here have the advantage of stable crack growth in measuring the interface fracture energy and have been able to overcome the challenges which exist in the other geometries. The results are comparable to those shown in the literature.

Acknowledgements

We want to acknowledge Pratt and Whitney for partial financial support. We also like to acknowledge Stony Brook University for providing us with the coatings.

References

[1] PG Charalambides, J Lund, AG Evans, and RM McMeeking. A test specimen for determining the fracture resistance of bimaterial interfaces. 1989.

[2] Ines Hofinger, Matthias Oechsner, Hans-Achim Bahr, and Michael V Swain. Modified four-point bending specimen for determining the interface fracture energy for thin, brittlelayers. *International Journal of Fracture*, 92(3):213–220, 1998.

[3] James L Mead, Mingyuan Lu, and Han Huang. Inducing stable interfacial delamination ina multilayer system by four-point bending of microbridges. *Surface and Coatings Technology*, 320:478–482, 2017.

[4] Mishra, A.K., Lambai, A., Jayaram, V. and Jaya, B.N., 2020. The edge-notched clamped beam bend specimen as a fracture toughness test geometry. *Theoretical and Applied Fracture Mechanics*, *105*, p.102409.

[5] Mishra, A.K., Pagare, A., Shinde, S.V., Sampath, S. and Jaya, B.N., 2022. Modified clamped beam bend method for determination of interfacial fracture energy of thermally sprayed Yttria Stabilised Zirconia over steel. *Journal of the European Ceramic Society*, *42*(15), pp.7166-7173.