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Inter-granular cracking of a splat of zirconia coating fabricated by plasma spraying technique†

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KEY WORDS: (Zirconia) (TBC) (Inter-granular fracture) (Columnar grain) (Crack) (Crack propagation) (Fracture) (Stress intensity factor) (Energy release rate) (Gas tunnel type plasma spraying)

1. Introduction

The zirconia coating is useful for the thermal barrier coating (TBC). But this ceramic coating has a problem such as cracking in the inside of coating as well as delamination. Therefore to investigate the mechanism of the cracking and fracture is one of the most important issues for the development of high performance TBC. Previously, zirconia coating was fabricated over the surface of the substrate of stainless steel by gas tunnel type plasma spraying system and the crack running in a splat of the coating was observed using a SEM (scanning electron microscope) [1-3]. As a result, it has been shown that crack propagation occurs with many kinks and bifurcations along columnar grain boundaries of zirconia and that regular zigzag crack patterns are sometimes observed. Furthermore, based on simplified assumptions, stress intensity factors of inter-granular cracks with kinks in a splat were calculated and the crack propagation was also simulated in order to reveal the process of cracking and fracture [3]. In this report, previous studies by the authors are summarized and further numerical simulation of crack propagation in a splat of zirconia coating is conducted with a new postulation regarding the energy release rate.

2. Experimental

Kobayashi has developed the gas tunnel type plasma spraying system [4], [5]. **Figure 1** shows an example of the SEM photographs of a splat of zirconia coating fabricated on the substrate of stainless steel using the spraying system [2], [3]. From this figure, it can be seen that the splat consists of honeycomb-like crystal grains.

El-Sheikhy and Kobayashi observed inter-granular cracks running along the boundaries of the columnar honeycomb-like grains of the splat as shown in **Fig. 2** and found that some parts of the cracks are running with regular zigzag pattern like **Fig. 3** [1], [3]. These cracks are anticipated to be extending due to the thermal stress induced by cooling from high temperature during spraying to the room temperature.

3. Numerical Simulation of Crack Propagation

The authors have analyzed inter-granular crack paths in the honeycomb-like grains model shown in **Fig. 4** [3]. In this analysis, the following assumptions are made.

1) Two dimensional model with homogeneous and isotropic material is assumed.
2) Cracks can be propagating only along the grain boundaries and each end of the cracks is on a triple point of the grains.
3) Equi-biaxial tension is applied to the model as the thermal stress.

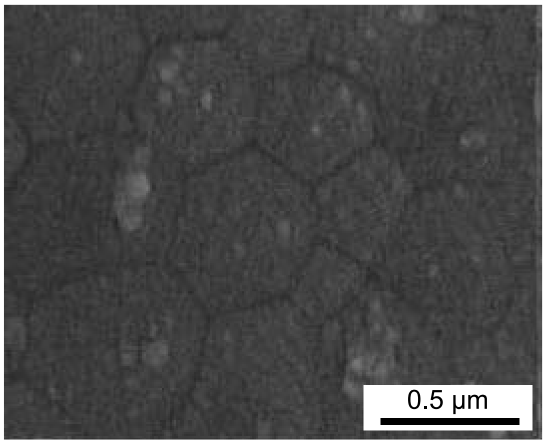

Fig. 1 Honeycomb-like microstructure of a splat of zirconia coating.

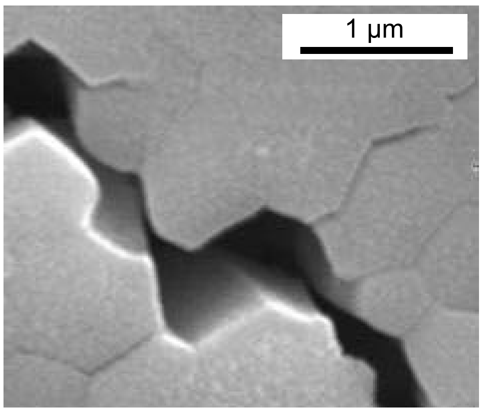

Fig. 2 Inter-granular crack propagation along the honeycomb-like columnar grain boundaries observed in a splat of zirconia coating.

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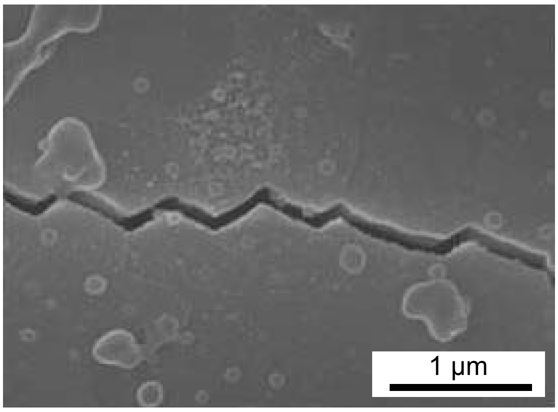

Fig. 3 Regular zigzag crack propagation observed in a splat of zirconia coating.

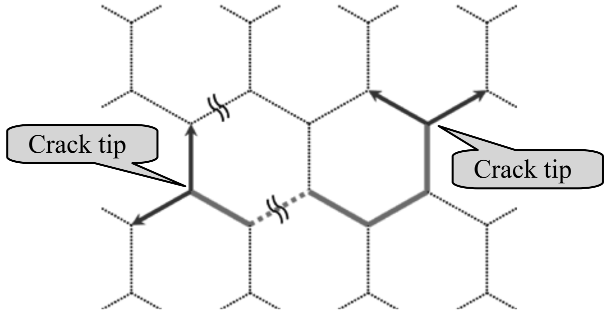

Fig. 5 Direction of inter-granular crack propagation in the model shown in Fig. 4. The red line and the blue arrows show the crack and the directions of crack propagation, respectively.

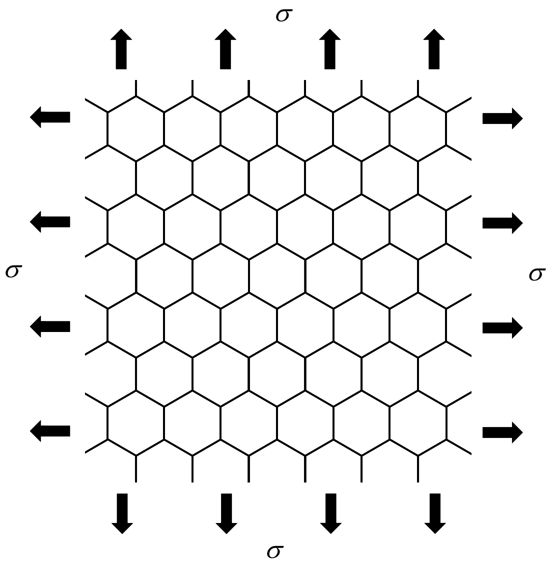

Fig. 4 Model of a splat of zirconia coating with honeycomb-like crystal grains under equi-biaxial tension.

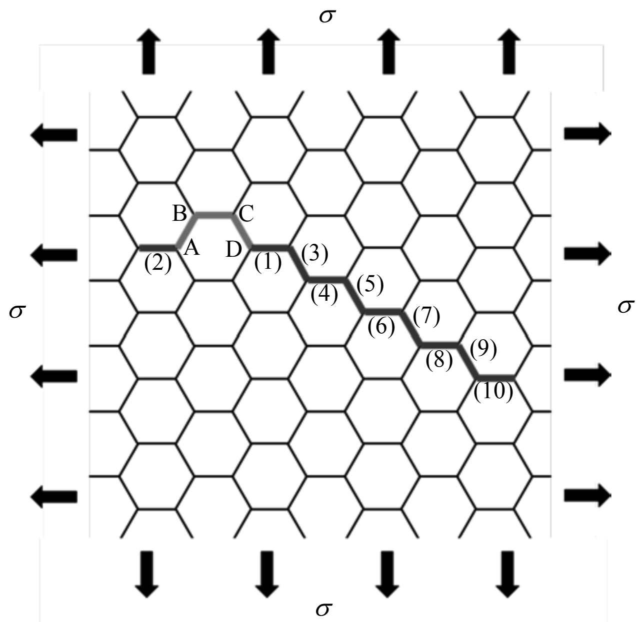

Fig. 6 An example of numerically simulated crack path in a splat of zirconia coating. The red line ABCD is the assumed initial crack and the crack is spreading in the order of (1), (2), (3), ⋯.

4) The size of the model is sufficiently large comparing with the cracks.
5) According to the maximum tangential stress criterion [6], the crack is running in the direction $\theta = -60°$ when $K_{II} > 0$ and $\theta = +60°$ when $K_{II} < 0$, where K_{II} is the mode II stress intensity factor. (Regarding the detail, refer to [3].)

Here, instead of the above assumption 5), the following postulation is adopted.

6) Crack propagation occurs by the length a to the direction in which the energy release rate is the largest among four directions shown in **Fig. 5**, where a is the side length of the hexagon of the crystal grain. The crack does not extend in multiple directions simultaneously.

The stress intensity factors at the tips of the inter-granular crack are calculated by the method shown in [3] and the energy release rates of four directions are calculated using the method proposed by Nuismer [7]. An example of numerically simulated crack paths is shown in **Fig. 6** in which the red line ABCD indicates the assumed initial crack and the blue lines are the predicted crack paths. The crack is simulated to be propagating in the order of (1), (2), (3), ⋯ without the branch (2) extending any more. Some other numerical simulations suggested that a crack is extending only at one of its tips showing regular zigzag pattern, and at another crack tip, it extends only in one branch or never extends.

4. Conclusions

Based on the inter-granular crack propagation observed in a splat of the zirconia coating fabricated by the plasma spraying technique, numerical simulations of crack propagation were conducted using a simplified model of honeycomb-like crystal grains based on the energy release rate. As a result, the regular zigzag crack propagation has been simulated.

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