FAILURE OF THERMALLY SPRAYED 7YSZ COATING UNDER CYCLIC BENDING

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Abstract

In this study, we have described damage accumulation and failure of micro-cantilevers made of free-standing 7YSZ coatings during cyclic bending in a nanoindentation system of both, as-sprayed coatings as well as after low-temperature thermal cycling up to 700 ^{o}C while coating attached to the substrate. It was observed that the specimens which were subjected to thermal cycling before bending showed less cycle to failure compared to as sprayed specimens. Also, A model is described by analogy with cementitious composites to relate damage from inter-splat sliding to the linkage of vertical microcracks that can lead to the formation of a critical flaw.

1. Introduction

Thermally sprayed (TS) 7 Weight percent Y_2O_3 stabilized ZrO_2 (7YSZ) is used as Thermal barrier coatings (TBC) to insulate metallic components in the hot section of gas turbine engines which are used for power generation and aviation propulsion. TS TBC has ~15-20 % microcracks and pores in as sprayed condition. After high temperature exposure, the pre-existing microcracks and pores get eliminated due to sintering whereas during thermal cycling the preexisting microcracks extend and form a bigger network of macroscopic cracks, which leads to failure of the coating. There is a large volume of literature to discuss the densification induced failure of the coating after high temperature exposure, however, the effect of thermal cycling as a source of fatigue loading in the coating and their impact on microstructure and mechanical properties has been not discussed much.
In this study, we have studied damage accumulation and failure of free-standing micro-cantilevers made of 7YSZ coatings during cyclic bending in a nanoindentation system in both, the as-sprayed condition as well as after low-temperature thermal cycling up to 700 ^{o}C while attached to the substrate. The technique has been established as a means of tracking elastic modulus, hysteresis/creep, and fracture behavior as a function of coating densification during isothermal treatment at high temperatures. In contrast, low-temperature thermal cycling is designed to simulate operating conditions during which crack healing and sintering, which are known to lead to stiffening, are minimal. Further Finite element analysis was carried out to understand the damage accumulation.

2. Results

The following studies were carried out on a miniaturized cantilever of TBC to study damage accumulation due to cyclic loading:

a. The cyclic bending at different load amplitude was performed
b. The effect of cyclic loading on the stiffness reduction of the cantilever was measured and it was observed that there is a continuous decrease in stiffness with an increase in the number of cycles and load amplitude. The failure of the cantilever was associated with the initiation of a macroscopic crack near the tensile surface which was reflected as a sudden stiffness drop during cycling.
c. The effect of cyclic loading on ratcheting (residual displacement after complete unloading the cantilever) was measured and found to be increasing with an increase in the number of cycles.
d. To study the effect of thermal fatigue on TBC, the thermal cycling between RT to 700 ^{o}C was done while coating is attached to the substrate followed by coating was detached from the substrate to fabricate a miniaturized cantilever to perform a cyclic bending test. The cycle to failure on pre-

thermally cycled specimens were found to be decreasing with an increase in the number of prior thermal cycling.

The Finite element analysis was performed using the ABAQUS Commercial software package to visualize and gain further insight into the occurrence of cyclic damage in the coating. The model is described by analogy with cementitious composites to relate damage from inter-splat sliding to the linkage of vertical microcracks that can lead to the formation of a critical flaw.

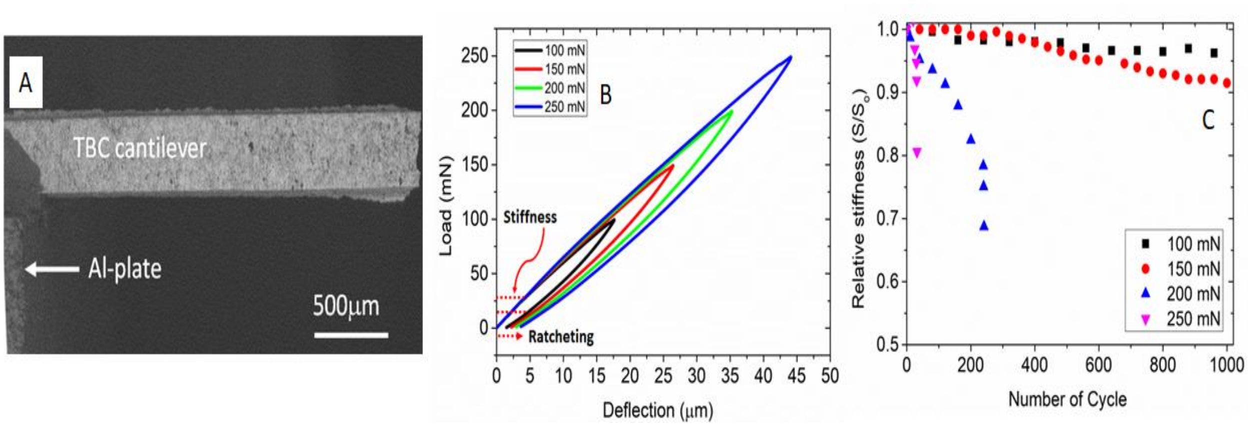

Figure 1: (A) The cantilever made of TBC, (B) The load-deflection plot of the cantilever at diffirent load amplitude, and (C) The decrease in stiffness with progress in the number of cycles.

3. Conclusions

Cyclic loading decreases the stiffness and finally leads to the failure of the coating. Failure appears to result from the formation of a critical size macrocracks after a critical amount of ratcheting. The model is described by analogy with cementitious composites to relate damage from inter-splat sliding to the linkage of vertical microcracks that lead to the formation of a critical flaw.

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