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Influence of pores on the thermal insulation behavior of thermal barrier coatings prepared by atmospheric plasma spray

L. Wang, Y. Wang *, X.G. Sun, J.Q. He, Z.Y. Pan, Y. Zhou, P.L. Wu

Laboratory of Nano Surface Engineering, Department of Materials Science, School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, PR China

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ABSTRACT

The defects in materials play very important role on the effective thermal conductivity. Especially, the spatial and geometrical characteristics of pores are significant factors for the thermal insulation behavior of thermal barrier coatings (TBCs). In this paper, finite element method was employed to simulate the thermal transfer behavior of TBCs with different spatial and geometrical characteristic of pores. The simulation results indicate that the thermal insulation effect of TBCs would be enhanced when the pore size, pore volume fraction and pore layers which are perpendicular to the thickness direction increase and the space between the adjacent pores decreases. It is predicted that the effective thermal conductivity is different at different directions for the atmospheric plasma spray (APS) TBCs. A novel method, Computational Micromechanics Method (CMM), was utilized to depict the thermal transferring behavior of actual coatings. At the same time, model with different kinds of defects were established, and the effective thermal conductivity as the function of defect orientation angle, defect volume fraction and defect shape coefficient was discussed in detail. The simulation results will help us to further understand the heat transfer process across highly porous structures and will provide us a powerful guide to design coating with high thermal insulation property.

1. Introduction

As vital coating materials, thermal barrier coatings (TBCs) have roles of protecting high temperature alloy substrate, reducing the working temperature and increasing working efficiency of high temperature component [1–3]. So they are currently being used or considered for engine applications in aerospace, aircraft, marine automobiles, nuclear fusion reactors and heavy-duty utilities [4,5]. However, the durability requirements of TBCs for these applications are increasing rapidly. Some researchers have already indicated the need for coatings surviving temperature higher than 1400 °C [6,7]. It was reported that reusable rocket-powered vehicles encounter extremely high heat loads in their engines and air frames [8], and the blades in the high-pressure fuel turbopump on the main engines of space shuttle undergo very large thermal transients on start-up of engines. Moreover, a higher temperature gradient will also be required in these applications. As other properties are kept the same, the property of thermal insulation is very pivotal. The most direct route to ensure that high temperature components coated with TBCs have high flow and Thrust-Weight ratio and a long lifespan [9] is to enhance the thermal insulation property. Demand for TBCs with excellent thermal insulation performance is becoming more and more urgent and the material selection standard is being raised continuously. Based on current research, there are four ways to improve the thermal insulation of TBCs. The first way is to increase the thickness of the coating, but previous investigations have indicated that residual stress will increase with the increase of the thickness. If residual tensile stress exists in the ceramic coating of TBCs, and the magnitude exceeds the inner bonding strength of the coating particles, the TBCs will fail. The second way is to find out other materials with lower thermal conductivities, such as zirconate-based TBCs, which is expected to be a promising candidate for a new generation of TBCs. The third way is to conduct ceramic coating surface treatments, such as laser remelting or coating materials with high infrared external reflection rates in order to impede the heat transference to the substrate. The fourth way is to control the spray powder structure and the plasma spray parameters (as for APS TBCs). This is a direct and effective method to decrease the effective thermal conductivity of TBCs.

Previous investigations have shown that pores are of consequences in decreasing the thermal conductivity of ceramic materials. Much literature has been published about the thermal insulation property of porous materials, such as porous bulk ceramic materials [10]. Gu et al. [11] have investigated the highly porous zirconia based TBCs with zigzag morphology, believing that this type of pore can impede heat flow through the thickness of

* Corresponding author. Tel.: +86 451 86402752; fax: +86 451 86413922.
E-mail address: wangyou@hit.edu.cn (Y. Wang).

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