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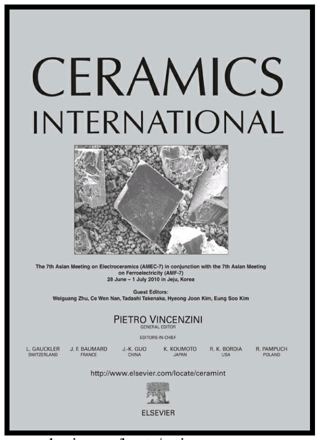

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Effect of surface heat transfer coefficient gradient on thermal shock failure of ceramic materials under rapid cooling condition

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Abstract

A rapid thermal processor (RTP) device as well as quenching technique is employed to systematically investigate the effect of surface heat transfer coefficient (*h*) gradient on thermal shock failure of a hot-pressed ZrB_2-based ceramic. Two typical kinds of quenchant with different surface *h* gradients during quenching tests, water and boiling water, are used for this study. When water as the cooling medium, two different cooling modes of indirect contact cooling by RTP device and direct contact cooling by quenching are also studied. The experimental results and related numerical simulations illustrate that surface *h* gradient plays an important role in thermal shock failure. This study confirms the previous presumption that the combination of body temperature gradient and surface *h* gradient leads to thermal stress damage and thermal shock failure. Under water quenching condition, water phase changes form bubbles randomly and produce great surface *h* gradient. Accordingly, critical body temperature gradient ($V(max)_c$) is small (~270 ℃ s^{-1}). Under aqueous polymer quenching condition, the introduction of polymer chains into water lowers the random formation of steam bubble and mediates the surface *h* gradient. The corresponding $V(max)_c$ hence become larger (~500 ℃ s^{-1}). Under boiling water quenching condition, there is no surface *h* gradient and $V(max)_c$ is even larger (> 600 ℃ s^{-1}). This study provides useful complementary information for understanding the thermal shock behavior and gives suggests for predicting materials performance in actual service.

Keywords: Ceramic; Thermal shock; Instantaneous cooling rate; Heat transfer coefficient gradient

1. Introduction

ZrB_2-based ultrahigh-temperature ceramics (UHTCs), possessing excellent comprehensive properties of high melting points, good strengths, high thermal conductivities, excellent oxidation and ablation resistances, are promising candidates for high temperature applications of thermal protection systems (TPS) such as leading edges and nose-cones for a new generation of sharp re-entry space vehicles [1-11]. However, due to their inherent brittleness, they are susceptible to catastrophic failure when exposed to strong aerodynamic forces and serious aerodynamic heating during the launch and reentry processes in the atmosphere. Under this extreme heating environment, the material faces great challenges of thermal shock resistance (TSR) [12-19]. Therefore, for reliable engineering design and optimum material selection, it is imperative that the thermal shock behavior and TSR of UHTCs should be well understood. This can be accomplished on the basis of theoretical principles and/or by actual tests [20].

One popular test method, due to its simplicity, consists of quenching specimen in a given geometry from a