



Preparation, microstructure, and mechanical properties of ZrB₂-based ceramics with layered Zr₂Al₄C₅ inclusions

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Abstract

ZrB₂/Zr₂Al₄C₅ composite ceramics with different volume contents of Zr₂Al₄C₅ formed in situ were fabricated by the spark plasma sintering technique at 1800 °C. The content of Zr₂Al₄C₅ was found to have an evident effect on the preparation, phase constitution, microstructure as well as the mechanical properties of ZrB₂/Zr₂Al₄C₅ ceramics. The results indicated that sinterability of the composites was remarkably improved by the addition of Zr₂Al₄C₅ compared to the single-phase ZrB₂ ceramic. The microstructure of the resulting composites was fine and homogeneous, the average grain size of the ZrB₂ decreased, and the average aspect ratio of the Zr₂Al₄C₅ increased with the increase in the amount of Zr₂Al₄C₅. As the content of Zr₂Al₄C₅ increased, both the Vickers hardness and Young's modulus of the composites first increased and then decreased. The fracture toughness of the ZrB₂-40 vol% Zr₂Al₄C₅ composite was 4.25 MPa m^{0.5}, which increased by approximately 70% compared to the monolithic ZrB₂ ceramic. The improvement was mainly attributed to the toughening mechanisms such as the layered structure toughening, crack deflection and crack bridging, caused by the in situ formed layered Zr₂Al₄C₅ inclusions.

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1. Introduction

Zirconium diboride (ZrB₂), belonging to ultra-high-temperature ceramics (UHTCs), is currently expected to be a potential candidate material for aerospace applications, such as rocket engines and thermal protection structures for leading-edge parts on hypersonic re-entry space vehicles, attributing to their high melting point, high thermal and electrical conductivities, good chemical stability, low theoretical density, and good chemical inertness [1–6].

However, there are two main bottleneck problems that limit the development of ZrB₂ ceramics. On one hand, the densification of ZrB₂ with additives, typically requires hot pressing at 2100–2300 °C due to its strong covalent bonding and the presence of surface oxide impurities [7]. On the other hand, ZrB₂ is very brittle and does not have sufficient toughness, strength, and thermal shock resistance to be

used successfully for aerospace applications [8]. Considerable efforts have been made to improve the sinterability and the mechanical properties of ZrB₂-based composite ceramics. These efforts include the addition of second phases, various nitrides, silicides, such as MoSi₂, ZrSi₂, HfN, BN, AlN, ZrC, ZrO₂ [1,9–13], or combinations of various second phases. Among these second phases, SiC is a typical second phase particle for ZrB₂, which can not only enhance the oxidation resistance of ZrB₂ ceramics, but also improve the sinterability and fracture toughness of the ZrB₂-based composites [4]. Unfortunately, the ZrB₂-SiC composites have appreciable shortcomings, for instance, the low fracture toughness and the poor thermal shock resistance limit its wider application.

Recent studies showed that the incorporation of ceramic inclusions with different shapes and sizes, including SiC whisker [14], SiC chopped fiber [15], ZrO₂ fiber [16], nanosized SiC [17], short carbon fiber [18], carbon nanotube [19], was attributed to the combination of debonding, pull-out, and bridging of these reinforcements as well as enhanced crack deflection and crack pinning. Meanwhile,

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