Shock Wave-Material Interaction in ZrB 2 -SiC based Ultra High Temperature Ceramics for Hypersonic Applications

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ORIGINAL ARTICLE

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Shock wave-material interaction in ZrB_2–SiC based ultra high temperature ceramics for hypersonic applications

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Abstract

We investigate the thermochemical stability of ZrB_2–SiC based multiphase ceramics to hypersonic aerothermodynamic conditions in free piston shock tube with an objective to understand quantitatively the role of thermal shock and pressure. The developed ceramics sustained impulsive thermomechanical shock, under reflected shock pressure of 6.5 MPa and reflected shock temperature of 4160 K in dissociated oxygen, without structural failure. The conjugate heat transfer analysis predicts the surface temperature of ZrB_2–SiC to reach a maximum of 693 and 865 K, for ZrB_2–SiC–Ti. The transient shock-material response is characterized by surface oxidation of the investigated ceramics, when exposed to high enthalpy gaseous environment, as a consequence of the interaction with ultrafast-heated (10^6 K/s) gas for ~5 ms. Spectroscopic and structural characterization reveals that addition of Ti improves thermomechanical shock resistance, which is attributed to the assemblage of refractory phases. Taken together, ZrB_2–SiC–Ti based multiphase ceramics exhibit favorable shock-material response under impulse loading.

KEYWORDS

ceramics, oxidation, shock-material interaction, simulation, surface analysis

1 | INTRODUCTION

Advanced structural ceramics, based on the borides and carbides of 4d group elements, are well known for their attractive properties such as high melting temperatures, strength retention at high temperatures, good oxidation, and corrosion resistance, etc.[1,2] In particular, ZrB_2-based Ultra High Temperature Ceramics (UHTCs) have high thermal conductivity as required for enhanced heat dissipation from the hot spots and can support formation of refractory oxide rich multioxide scale, as needed for effective oxidation resistance, etc.[1–4] These advantageous combinations of properties make ZrB_2 a suitable candidate for leading edges of hypersonic cruise vehicles.

Extensive research over last two decades primarily centers around UHTC development with significant attempts to establish processing-structure-property linkages, along with performance qualification tests using arc-jet, plasma wind tunnel, etc. However, there is a limited focus on integrated experimental-computational approach, coupled with performance qualification and performance limiting tests, for accelerated development of advanced technologies, such as thermal protection systems for hypersonic vehicle.[4–11] When UHTCs are employed as the leading edges, intense shock loading adversely affects the performance due to high thermomechanical loads generated by shock interaction. This aspect consequently demands the characterization and performance qualification by evaluating the shock-material response under high enthalpy hypersonic conditions. Shock tubes are one of the means through which hypersonic aerothermodynamic environment can be recreated in ground. Free piston shock tubes (FPST) belong to this kind of ground facilities, which can generate high enthalpy flow with rate of temperature rise as high as million K/s and enthalpies up

