

Simulation mechanical behavior ultra high temperature ceramic composites under intensive dynamic loading

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Abstract

The influence of mesoscopic substructures on the dynamic strength of ultra high temperature ceramic (UHTC) and hybrid nanocomposites (HC), which can be formed using additive manufacturing, was numerically investigated. Response of composites to the shock pulse impacts with amplitudes in the range of 5 GPa to 15 GPa was simulated. Multi-scale computer simulation approach was applied to research of mechanisms of failure in ceramic nanocomposites under dynamic loading. Smooth Particle Hydrodynamics (SPH) method was used for a simulation of deformation and fracture of representative volume element (RVE) of material. Model RVE takes into consideration of porous structure, phase concentrations and morphological parameters of matrix grains and reinforcing phase particle. At weak shock wave loadings the shear strength and the spall strength of ceramic and hybrid nanocomposites depends not only phase concentration and porosity, but size parameters of skeleton substructures. The influence of skeleton-frame parameter on the shear strength and the spall strength of ceramic nanocomposites with the same concentration of phases decreases with increasing amplitude of the shock pulse of microsecond duration above the double amplitude of the Hugoniot elastic limit of nanocomposites. The probability of fracture was estimated for $\text{ZrO}_2 - \text{ZrB}_2$, and $\text{ZrB}_2 - \text{B}_4\text{C}$, $\text{ZrB}_2 - \text{SiC}$ composites under pulse loadings. The critical fracture stress on meso-scale level depends not only on relative volumes of voids and inclusions, but also on the parameters of inclusions clusters. Damage of $\text{ZrO}_2 - \text{ZrB}_2$, $\text{ZrB}_2 - \text{SiC}$ and $\text{ZrB}_2 - \text{B}_4\text{C}$ nanocomposites can be formed under stress pulse amplitude of less than the Hugoniot elastic limit of matrix. These damages caused the changes of the spall strength of nanocomposites. The Hugoniot elastic limit of ceramic nanocomposites decreases with increasing volume concentration of nano-void clusters. The spall stress of ceramic nanocomposites depends on relative volumes and sizes of voids and inclusions. Self-organization process of micro-damages and occurrence of mesoscale shear band were observed in the ceramic nanocomposites under compression at high strain rates. It was shown distributions of particle velocity, pressure and equivalent stress at the mesoscale level are changed in a shock front. The distribution of these parameters in elastic precursor and behind shock wave can be described using by the 3 parameter Weibull distribution function. The multimodal distribution of these parameters in front of volume compression wave can exist during a short time in consequence of meso-cracks growth and expansion a damaged zone near collapsing voids. Results of simulation show that damage of nanocomposites near voids can be formed under stress pulse amplitude less than the Hugoniot elastic limit of matrix. Fracture of UHTC nanocomposites is realized via microcracks coalescence mechanism. Thereby fracture of $\text{ZrO}_2 - \text{ZrB}_2$, $\text{ZrB}_2 - \text{B}_4\text{C}$, $\text{ZrB}_2 - \text{SiC}$ ceramic nanocomposites under pulse loadings has a quasi-brittle behavior.

Keywords: Multi-scale simulation, high strain rates, quasi-brittle fracture, probability, nanocomposites