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On the Development of Stress State and Rate Dependent FE Model for the Failure Response of Alumina Ceramics: Experimental Dynamic Brazilian Disk Validation

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ABSTRACT

In this study, the tensile strength and failure response of alumina (Al_2O_3) ceramics were investigated under dynamic loading rates through the Flattened Brazilian Disk (FBD) and split-Hopkinson Pressure Bar (SHPB) experimental setups. The strain rates under investigation ranged from 10 to 10^2 s^{-1}. Ultra-high-speed imaging coupled with digital image correlation (DIC) was used to monitor the displacement and strain maps of the specimen during the experiments in addition to the visualization of crack initiation and growth. It was found that primary and secondary cracks are induced in the material with a speed of 4.5 (strain rate of 10) to 6 (strain rate of 10^2) km/s and 1 (strain rate of 10) to 2.5 (strain rate of 10^2) km/s, respectively. Computationally, a rate-dependent viscosity regularized version (i.e., the JH2-V model) of the phenomenological Johnson-Holmquist-2 (JH2) material model was implemented through a VUMAT subroutine in ABAQUS software, which allowed for alleviating the strain softening induced localization problem of the original JH2 model. In the JH2-V model, the hydrostatic tensile strength is formulated as a function of the equivalent plastic strain and a viscosity parameter to account for the rate-dependent spall strength of ceramics. In addition, this rate-dependent definition of tensile strength leads to a viscoplastic yield surface that regularizes the strain softening mesh dependency problem. The implemented model distinguishes between tensile and compressive dominated failure of ceramic materials through defining a pressure-dependent failure strain formulation, resulting in a better prediction of the failure response when the loading condition introduces multiple stress states in the material. The experimental quantitative measurements (i.e., stress versus strain histories, and lateral strain versus axial strain histograms) and qualitative observations (i.e., the initiation and propagation of cracks captured by the ultra-high-speed imaging) were used to validate the FE models for the FBD tests. It was found that the proposed model reasonably reflects (i.e., with an error of 10 ± 2% when compared to the measured values) the rate-dependent response of the alumina ceramics in terms of the tensile strength and damage evolution under FBD testing conditions. Overall, the presented work has implications for the further extension/improvement of the proposed computational model to explore the response of ceramic materials under different stress states and loading rates.