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Dynamic Strength of an Energetic Material Simulant: Experiments and Modeling

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ABSTRACT:

While the mechanical behavior of polymer-bonded explosives (PBXs) and their simulants has been widely studied under normal impact, their shearing response under large pressures and shear strain-rates has not been well studied. Such measurements are crucial to inform constitutive models that aim to predict hot-spot formation and ignition behavior of PBXs subject to multi-axial loading. In this study, pressure shear plate impact experiments have been conducted on hydroxyl terminated polybutadiene - HTPB (an elastomeric binder), monolithic sucrose (simulant of -HMX) and their composite, under normal stresses of 3-10 GPa and shear strain rates of the order of 105-106 s-1. While the shearing resistance of HTPB remains constant under large shear strains, the shear strengths of sucrose and the composite show a dramatic fall. The loss of shear strength of sucrose is attributed to the formation of shear localization. However, the composite can lose its shear strength due to several factors such as delamination, fracture and shear localization. The shearing resistance of HTPB is also shown to be highly pressure-sensitive whereas that of sucrose shows relatively small sensitivity to pressure. However, the shear strength of the composite shows a large pressure-sensitivity despite a small fraction of the elastomeric binder. Moreover, at normal stresses of 9-10 GPa, the shear strength of HTPB becomes similar to that of sucrose and beyond these normal stresses, a transition in the localization and failure modes of the composite is expected. A quasi-linear viscoelastic model with pressure-dependent shear wave speeds and shearing resistance is used to describe the experimentally observed dynamic response of HTPB. The model consists of an instantaneous elastic response and viscoelastic relaxation of the elastic response. A thermodynamically consistent constitutive model is presented to model the thermoelastic, thermo-viscoplastic response of sucrose. A complete Mie-Gruneisen equation of state is presented to model the volumetric behavior while the deviatoric response is captured through the Johnson-Cook Model. The material model captures experimental observations and predicts localization in the form of adiabatic shear bands, which explains the catastrophic drop in shearing resistance of sucrose observed in the experiments.

BIOGRAPHY:

Prof. Guduru earned his Ph.D. in Aeronautics (Minor: Materials Science) from Caltech in 2001. Following a postdoctoral position in the Division of Engineering at Brown University, he joined the Solid Mechanics faculty there as an Assistant Professor of Engineering in 2002. He is currently a Professor of Engineering at Brown University. Current problems of interest in his lab include those at the interface between mechanics and chemistry for energy technologies; materials and structures under extreme environments; and development of new technologies for multi-metal additive manufacturing. Guduru is a recipient of the James R. Rice medal from the Society of Engineering Science (2020); a W.M.Keck Foundation award (2021); PECASE - Presidential Early Career Award for Scientists and Engineers in 2007; the National Science Foundation CAREER award in 2006; William F. Ballhaus prize for outstanding doctoral dissertation in Aeronautics, Caltech, 2001; and the Ernest E. Sechler Memorial Award for the most significant contributions to teaching and research in Aeronautics, Caltech, 1998. He serves as the Chair of the ASME Applied Mechanics Division (2021-22). He also serves on the Editorial Advisory Boards of the Journal of the Mechanics and Physics of Solids and Acta Mechanica Sinica.