Shock and Impact Response of Glass Reinforced Plastics

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This presentation discusses the application of a hyperelastic continuum damage mechanics (CDM) based constitutive equations, derived from a Helmholtz free energy relationship, to describe the response of fiber composites under shock loading conditions. The energy terms are divided into: shear and bulk deformation of the matrix material, and different fiber systems under both shear and tension.

The CDM model [1] describes various damage modes in a layered woven/planar glass fiber reinforced plastics (GRP). The damage modes are: matrix shear cracking and volume expansion under compressive loading conditions, delamination, fiber breaking under tension and fiber debonding due to bucking of the fiber under compression. The volume increase under compression is modeled using an empirical relationship that captures the effects of wing crack mechanisms based splitting / faulting type mode 1 fracture in the brittle matrix material.

Tsai et al., [2] conducted shock wave propagation experiments to study the compressive failure of GRP and whose data is used extensively in this study. The effects of various damage modes on the free surface velocity profiles in a plate impact shock wave propagation test are studied through ALE 3D finite element code [2] simulations. The comparisons between VISAR data and computed free surface velocity profiles aided the calibration of parameters for the strain-based damage initiation and propagation models.

Based on the simulation results, with the absence of any permanent strains, such as the plastic strain, the HEL point is interpreted as the onset of elastic-elastic cracking (EEC) of the matrix materials under compressive loading. The strain-based damage initiation and propagation models have several model parameters. In the simulations, the matrix damage (microcracking of the matrix) emanates from the impact plane and progressively damage the GRP target plate in the plate impact experiments. A number of plate impact configurations with steel or aluminum flyers are simulated at a range of impact velocities varying between 100 and 500 m/s. The simulation showed that the lateral stresses increased to the shock stress level when the ratio of shear and bulk moduli became zero, and thus generating a hydrostatic pressure condition in the GRP. The code results further revealed that the Hugoniot relaxed to the hydrostat by unloading along the degraded moduli, and the longitudinal shock wave speed reduced to bulk wave speed.

This work further examined the possibility of extending the CDM / hyperelasticity model to predict depth of penetration of a projectile into thick target plates at high velocities. The main focus of the ballistic modeling was to develop a better understanding of the penetration resistance due to fiber stretching under radial tension. While the plate impact captured energy dissipation due to matrix cracking and pulverization, the ballistic impact provided an opportunity to validate the generality of the calibrated model parameters through comparison between the depth of penetration measured in ballistic tests and hydrocode simulations.

References

[1] M. I. Barham, M. J. King, G. Mseis, and D. R. Faux, Hyperelastic fiber-reinforced composite model with damage.” Lawrence Livermore National Laboratory, Technical report LLNL-MI-644243, 2013.

[2] L. Tsai, F. Yuan, V. Prakash, and D. P. Dandekar, “Shock compression behavior of a S2-glass fiber reinforced polymer composite,” *Journal of Applied Physics*, vol. 105, no. 9, p. 093526, May 2009.