

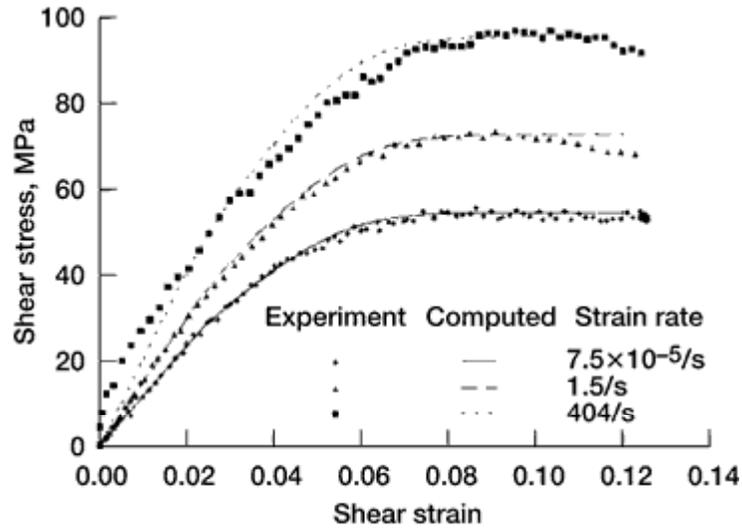
# Hydrostatic Stress Effects Incorporated Into the Analysis of the High-Strain-Rate Deformation of Polymer Matrix Composites

Procedures for modeling the effect of high strain rate on composite materials are needed for designing reliable composite engine cases that are lighter than the metal cases in current use. The types of polymer matrix composites that are likely to be used in such an application have a deformation response that is nonlinear and that varies with strain rate. The nonlinearity and strain rate dependence of the composite response is primarily due to the matrix constituent. Therefore, in developing material models to be used in the design of impact-resistant composite engine cases, the deformation of the polymer matrix must be correctly analyzed. However, unlike in metals, the nonlinear response of polymers depends on the hydrostatic stresses, which must be accounted for within an analytical model. An experimental program has been carried out through a university grant with the Ohio State University to obtain tensile and shear deformation data for a representative polymer for strain rates ranging from quasi-static to high rates of several hundred per second. This information has been used at the NASA Glenn Research Center to develop, characterize, and correlate a material model in which the strain rate dependence and nonlinearity (including hydrostatic stress effects) of the polymer are correctly analyzed.

To obtain the material data, Glenn's researchers designed and fabricated test specimens of a representative toughened epoxy resin. Quasi-static tests at low strain rates and split Hopkinson bar tests at high strain rates were then conducted at the Ohio State University. The experimental data confirmed the strong effects of strain rate on both the tensile and shear deformation of the polymer. For the analytical model, Glenn researchers modified state variable constitutive equations previously used for the viscoplastic analysis of metals to allow for the analysis of the nonlinear, strain-rate-dependent polymer deformation. Specifically, we accounted for the effects of hydrostatic stresses. An important discovery in the course of this work was that the hydrostatic stress effects varied during the loading process, which needed to be accounted for within the constitutive equations. The model is characterized primarily by shear data, with tensile data used to characterize the hydrostatic stress effects.

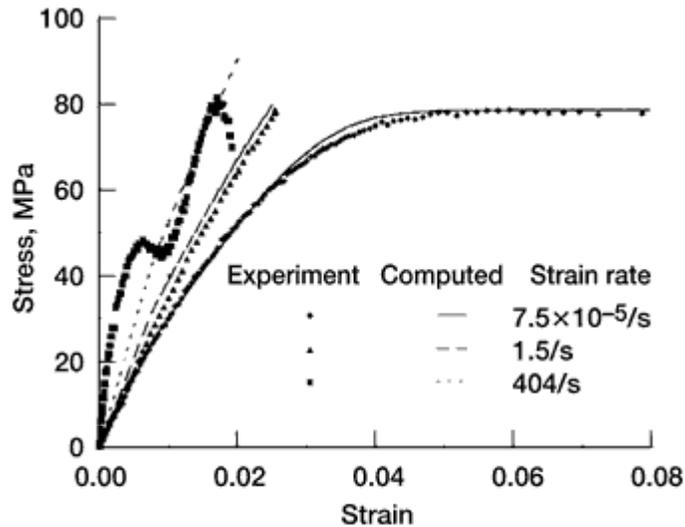
The first graph shows the experimental and computed shear-stress/shear-strain curves over a variety of strain rates for the toughened epoxy, and the second graph shows the experimental and computed tensile-stress/tensile-strain curves over a variety of strain rates for the same material. In both cases, the nonlinearity and the strain rate dependence of the polymer deformation are correctly computed. Although not shown here, if the model was characterized using shear data only and the hydrostatic stress effects were not included, the computed tensile stresses would be significantly higher than their experimental values in the nonlinear portion of the stress-strain curve. The constitutive equations can be

implemented into a micromechanics model to allow for the computation of the nonlinear, strain-rate-dependent deformation of polymer matrix composites.



*Experimental and computed shear-stress/shear-strain curves for representative toughened epoxy at strain rates of  $7.5 \times 10^{-5}/s$ , 1.5/s, and 404/s.*

Long description of figure 1 These experimental shear-stress/shear-strain curves display significant nonlinearity for all strain rates and a significant increase in stress levels as the strain rate is increased. The computed results qualitatively capture the strain rate dependence and nonlinearity observed in the shear deformation response, and quantitatively compare well with the experimental values.



*Experimental and computed tensile-stress/tensile-strain curves for representative toughened epoxy at strain rates of  $5 \times 10^{-5}/s$ , 1.4/s, and 470/s.*

Long description of figure 2 These experimental tensile-stress/shear-strain curves display significant nonlinearity for all strain rates and a significant increase in stress levels as the strain rate is increased. The computed results qualitatively capture the strain rate

dependence and nonlinearity observed in the shear deformation response, and they quantitatively compare well with the experimental values.

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**Programs/Projects:** Propulsion Systems R&T, Ultra Safe