

# THERMOMECHANICAL CONSTITUTIVE BEHAVIOR OF AMORPHOUS POLYMERS AT HIGH STRAIN RATES

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Here we report on the development of a theoretical model which is predictive of the rate- and temperature-sensitive mechanical behavior of amorphous polymers over a wide range of processing and operating conditions, with specific focus of predicting behavior under conditions high-rate impact. The model described here was derived from an existing thermomechanical model (Boyce, Parks, and Argon, 1988; Arruda and Boyce, 1993) for the rate-, temperature-, and pressure-dependent three-dimensional finite strain behavior of thermoplastic materials. The model revisions originated from a breadth of experiments aimed at uncovering the macroscopic implications of restricting various molecular mobilities in both polycarbonate (PC) and poly(methyl) methacrylate (PMMA). These experiments included dynamic mechanical analysis (DMA), probing the viscoelastic behavior of the polymers, as well as large strain uniaxial compression tests on a servo-hydraulic machine ( $10^{-4} \text{ s}^{-1}$  to  $1 \text{ s}^{-1}$ ) and a split-Hopkinson pressure bar ( $800 \text{ s}^{-1}$  to  $6000 \text{ s}^{-1}$ ). The experimental results gave rise to the theory that total intermolecular resistance to polymer deformation – both elastic and inelastic deformation - is governed by multiple activated processes, each associated with a particular degree of freedom of the macromolecules, and each with its own unique rate, temperature, and pressure dependencies. In the constitutive model, these multiple processes are represented with independent spring and dashpot combinations which require stress-assisted activation only when the corresponding molecular motion is restricted. In addition, the kinematic framework of the model and governing equations of the constituent components were altered in order to more accurately capture thermal and pressure effects which often dominate mechanical behavior under high-rate impact. These additional modifications included: an incorporation of thermal expansion effects, based on experimental data on the temperature and network orientation dependence of the coefficient of thermal expansion; incorporation of energy storage and dissipation concepts, derived from calorimetry data and experimental measurements of specimen temperature rise under high-rate compression; as well as a pressure-dependent shift of the elastic constants. The model is shown to accurately predict the behaviors of PC, PMMA, and poly(vinyl chloride) (PVC) over a wide range of strain rates.