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Shear Modified Free Volume Concepts for the Nonlinear Viscoelastic Behavior of Polymers

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Abstract

Many structural polymeric materials exhibit a nonlinear viscoelastic response. Over the years, several models have been developed to account for this behavior. Some are based on the Doolittle concept that the “free volume” controls the mobility of polymer molecules and, thus, the inherent time scale of the material. It then follows that factors such as temperature and moisture, which change the free volume, will influence the time scale. Furthermore, stress-induced dilatation will also affect the free volume and hence the time scale, thereby leading to the nonlinear effect. However, Popelar and Liechti [1, 2] found that dilatational effects alone were insufficient in describing the response of near pure shear tests of an epoxy. Thus, the free volume approach was modified to include distortional effects in the inherent time scale of the material. Since then the model has been successfully applied to a number of other types of polymers.

The approach builds naturally on the small strain viscoelastic response which has lately been based on master curves of shear and bulk relaxation moduli determined on one specimen in combined compression tests. Ramp testing in shear and tension is then conducted in order to extract the free volume parameters. The effects of thermal and solvent expansion have also been incorporated. The shear modified free volume model has been incorporated in the ABAQUS finite element code via a user-defined material subroutine. Successful validation of the model has been achieved through a variety of multiaxial stress states, strain rates, temperatures and solvent contents.

The challenge now is to determine the mechanisms for this effect of shear on the free volume from theoretical and novel experimental developments.

1. *Popelar, C.F., and Liechti, K.M., Multiaxial Nonlinear Viscoelastic Characterization and Modeling of a Structural Adhesive. J. Engineering Materials and Technology., Transactions of the ASME, 1997: p. 119, 205-210.*
2. *Popelar, C.F., and Liechti, K.M., A Distortion-Modified Free Volume Theory for Nonlinear Viscoelastic Behavior. Mechanics of Time-Dependent Materials, 2003. 7(2): p. 89-141.*