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A nonlinear viscoelastic constitutive model with damage for solid propellant

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In solid propellants, which behave as viscoelastic solid, complex damage phenomena are evolved during deformations. The damage of solid propellant such as dewetting and cyclic loading effects are considered as dominant effects for developing constitutive model. Dewetting is debonding phenomenon of the particle-binder interface and cyclic loading effects are rapid decrease of stress during the unloading and large amount of hysteresis referred to as Mullins' effect. In addition to material nonlinearity caused by the damage, geometrical nonlinearity is also considered.

Damage is represented by reduction of free energy and the energy function is separated by volumetric and deviatoric parts for computational purposes. Softening of the material under deformation is modeled by a damage function which depends on the maximum volume fraction of voids up to the present time. The formation and growth of voids, formed by particle debonding, are incorporated through a dilatation model which is based on the analysis of void-containing elastic materials. The internal state variable of softening function is defined as ratio of void volume fraction to damage initiation void volume fraction. Viscoelastic dewetting criteria is introduced to predict damage initiation. Cyclic loading effects are accounted for damage functions of the octahedral shear strain for unloading and reloading.

The model is calibrated using only a few tests and implemented into a user material subroutine(UMAT) of the commercial finite element code ABAQUS. The predictions of the model are compared with experiments for several loading conditions not used in the calibration. The predicted stress values and volume dilatations show good agreement with the measured ones.

Keywords: Viscoelasticity, Constitutive equation, Solid propellant, Damage