Characterization and modeling of temperature- and rate-dependent mechanical behaviors applied to an epoxy resin from room to cryogenic temperatures

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Abstract

The mechanical behavior of epoxy resin, used as an impregnation material in superconducting coils, was investigated under uniaxial compression from ambient to cryogenic temperatures across a range of strain rates (10ˆ-4 to 10ˆ3/s). The viscoelasticity and yield stress exhibit strong dependence on temperature and strain rate, with a notable change in yield stress slope at higher strain rates and lower temperatures, likely associated with the side-chain mobility dominated secondary transition in polymers.

An effective Ree-Eyring equation, capable of describing yield stress across a wide range of temperatures and strain rates, separates stress contributions into two molecular processes: the -process, related to main-chain segmental mobility, and the β-process, associated with partial main-chain or side-chain mobility. The latter activates only under high strain rates or low temperatures. Using a nonlinear fractional Maxwell model with a time-temperature superposed relaxation spectrum enables a smooth transition from elastic to viscous behavior with only two material parameters. The reduced relaxation time approach, employing horizontal shifts by stress and temperature factors, successfully fits experimental data and predicts the extrapolated responses under dynamic tests.

The 1D Ree-Eyring model is extended to a full 3D constitutive model, known as the Eindhoven Glassy Polymer (EGP) model, utilizing the same spectrum of relaxation times represented through a multi-mode approach by each individual process. The elasto-visco-plastic model, implemented in finite element software, effectively captures the intrinsic behaviors of the epoxy resin across a broad range of temperatures and strain rates.

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