Upsetting and Viscoelasticity of Vitreous SiO_2: Experiments, Interpretation and Simulation

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Cylindrical samples of the fused silica type Suprasil 1 were axially and isothermally compressed in the temperature range from 1000°C to 1333°C at strain rates from -10^{-5} to -10^{-2} per second. It is demonstrated in contrast to earlier studies that the elasticity must not be neglected in analyzing the experiments. Likewise, an interpretation using the ‘stress generation modulus’ yields erroneous results. It is further shown that a theory by Nadai on the barreling of axially compressed viscous bodies features inherent contradictions.

Instead, the viscoelastic deformation of the fused silica under consideration can be described as a function of time with sufficient accuracy by a simple Maxwell model. This model is used to determine the Young’s modulus and the tensile viscosity as a function of temperature and stress. The adoption of constant coefficients at a given temperature would be sufficient for reconstructing the recorded curves of the force as a function of time. In reality, however, the Young’s modulus decreases at a fixed nominal strain rate with increasing temperature and at a given temperature with decreasing nominal strain rate. Also the viscosity is weakly load-dependent. It can be fitted by a VFT-fit or by an Arrhenian ansatz, where one parameter is load-dependent. Thus, both Young’s modulus and the viscosity feature deviations from Hooke’s and Newton’s laws, i.e., they are nonlinear. The stress relaxation depends on temperature and stress achieved. When normalized to the initial stress, all recorded isothermal relaxation functions for the longitudinal stress are superposable with sufficient accuracy if the respective time axis is renormalized. This implies a thermorheological simple behavior with respect to both temperature and stress.

Former publications reported a pronounced nonlinear effect of the strain rate on the viscosity. The strong nonlinearity featured by the plots of ’normalized viscosity’ plotted versus ’normalized strain rate’ and their insensitivity to temperature and composition are a consequence of ignoring the elastic behavior of the glasses.

Different simulations of the viscoelastic behavior were carried out with the Finite Element program ABAQUS. From the two simulations that combine elastic behavior with a creep function, the one with stress-dependent Young’s modulus and viscosity mostly generates a better correspondence between computed and measured force.

Cylinder compression is hence suited as a standard procedure for assessing reliable viscoelastic parameters of the material studied.