EXPERIMENTAL INVESTIGATION AND MODELING OF NONLINEAR VISCOELASTIC PLASTIC BEHAVIOR OF POLYIMIDE

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Results of experimental research and modeling of deformation under tensile loading of nonlinear viscoelastic plastic material are presented. Viscoelastic response of polyimide (PI) film Upilex-S (UBE Industries) was characterized within a wide range of stresses by tensile tests under different strain rates and by creep/recovery tests. Quasistatic tests showed that the film was sensitive to strain rate; elastic modulus increased by about 10% with strain rate increase. Analysis of the data indicated that Upilex-S possessed a well-defined linearity limit.
Short-term creep tests were performed at ambient conditions. Creep and recovery tests data supplied more detailed information concerning deformability of the material. The creep isochrones were essentially nonlinear; this demonstrated that film response was nonlinear viscoelastic thus corroborated tensile test results. Residual (plastic) strain grew with creep stress and constituted up to 1/5 of the total creep deformation. Creep isochrones of Upilex-S deviated from linearity at stress exceeding c.a. 75 MPa. Plastic strain was negligible up to 75 MPa and then nonlinearly increased with creep stress up to 0.7%. Hence the material was treated as a linear viscoelastic up to this stress level but at higher stresses plastic deformation played essential role and was included into creep model.
The obtained test data were used for development of constitutive model for the PI material considered, accounting explicitly for elastic, non-linear viscoelastic and plastic deformation. The tested polymer was considered as a nonlinear viscoelastic plastic material. Polymer strain during active loading was assumed as an additive function of linear elastic, nonlinear viscoelastic and plastic components. Nonlinearity of viscoelastic behavior was taken into account using principle of time-stress superposition.
Polymer strain recovery was clear viscoelastic function which asymptotically tended to some residual value. This value was assumed as a plastic strain developed in material up to time of stress removal. So the parameters of viscoelastic behavior were taken from description of recovery experiments. Taking into account that elastic response both under loading and unloading was the same, plastic strain was obtained as a discrepancy between experimental full creep strain and calculated viscoelastic strain during active loading experiment.
Special transformation of coordinates was proposed for coinciding creep curves under active loading and creep recovery. Actually that means that a set of creep curves under active loading for different stresses could be accomplished by a set of creep recovery curves. For any given stress initial points of both creep and recovery curves should coincide. The deviation will appear when plastic strain becomes visible. This time moment is stress dependent. All discrepancy was described by time and stress dependent function of plastic strain.
The results obtained by this method are in good agreement with experimental data for a wide range of stresses. It could be concluded that supposed method could be successfully applied for engineer calculations of strain of nonlinear viscoelastic plastic material including time-stress superposition principle.