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MODELING FOR TIME-DEPENDANT MECHANICAL BEHAVIOR OF POLYMERS CLOSE TO GLASS TRANSITION: FUNDAMENTALS AND EXPERIMENTAL VALIDATION

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Introduction

The development of structural applications for polymers or for polymer based composites is now highly demanding for relevant dimensioning protocols and simulations, especially when fatigue behaviour is concerned. One specific trend in composites is to take advantage of micro-mechanics approaches. In consequence, one of the key issues, whatever the material is compounded or not, is our ability to model mechanical behaviour of polymers matrix.

Very often the domain of use of such materials cover a range of temperature close to glass transition of the matrix, which allow a minimum toughening effects. So the true demand are constitutive models for polymers in their viscoelastic range over a wide range of temperatures and strain-rates.

Objectives

Modeling the mechanical behavior of polymers close to glass transition is a nontrivial task due to its nonlinearity and the combination of visco-elastic, visco-plastic, strain-hardening and damaging processes as well as the high sensitivity to temperature and strain-rate.

Usual macroscopic approaches arbitrary decompose global deformation into three elementary components (reversible-instantaneous (elastic part), or irreversible-not dependent upon strain-rate (plastic part) or irreversible-dependent upon strain-rate (viscous part), respectively). Mathematical writings are built up, either on the basis of 1D-model, further extended to 3D case, or in the continuum thermodynamics frame, in which global behavior is ruled by energy potentials and dissipation pseudo-potentials. Whatever the route is, basic assumptions are often equivalent in the most rigorous of those studies. The accounting for the dependence upon strain-rate and temperature in those approaches results in numerous parameters that are not that easy to identify without specific protocol.

This study deals at applying an alternative route to polymer matrix to reproduce all visco elastic effects under fatigue with as less numerous parameters as possible to make them easily used in computations, particularly micro-mechanics approaches.

Methodology

From theoretical point of view developments rely on revisited network concept [1] where the general rubber hyper elastic theory is combined with some evolution of internal variables, induced by microstructure alteration, to model time effects in the constitutive model. General goal is to model visco-hyper-elasticity of polymers above (but close to) Tg without arbitrary decomposition into “viscous” and “elastic” stresses or strains. Edward-Vilgis’ physics-based network theory is used as starting point. Stresses derived from an energy potential that depends on the density of fixed network nodes, the density of sliding nodes or entanglements, a parameter ultimately related to chain extensibility and a parameter ultimately representative for level of freedom of entanglements.

Inelastic processes are assumed to result from kinetics of variation of internal variables that have to be accounted for in the energy balance at any time and that induce time effects in the writing. Variables of interest are related to de entanglement, interaction between chains and/or strain induced crystallization through specific kinetics laws.

The model is written in the framework of Irreversible Processes Thermodynamics (IPT) and in the frame of large strain approximations. Mechanical problem is coupled to thermal problem using Taylor-Quinney coefficient β. Equations are included in a finite difference code (using a θ-method) to calculate temperature and stress through the central section of a sample. Parameters identification is based on the minimization of a two objectives cost function that accounted for average axial stress in the section and for surface temperature at this section. This latter was written in a mean-square approach.
As a first stage non-monotonic or initial cyclic loadings are considered.

Results and analysis

The efficiency of this approach is presented and discussed on the basis of a reach data based on PA 6-6 and PMMA which are semi-crystalline and amorphous, respectively. This model allow reproducing most of the visco elastic effects during uploading-unloading, uploading-relaxation or cyclic loading paths.
This approach seems promising to model behavior during fatigue (though at the moment only the first cycles are encountered) using a small number of parameters. Typical results are given in figure 1.

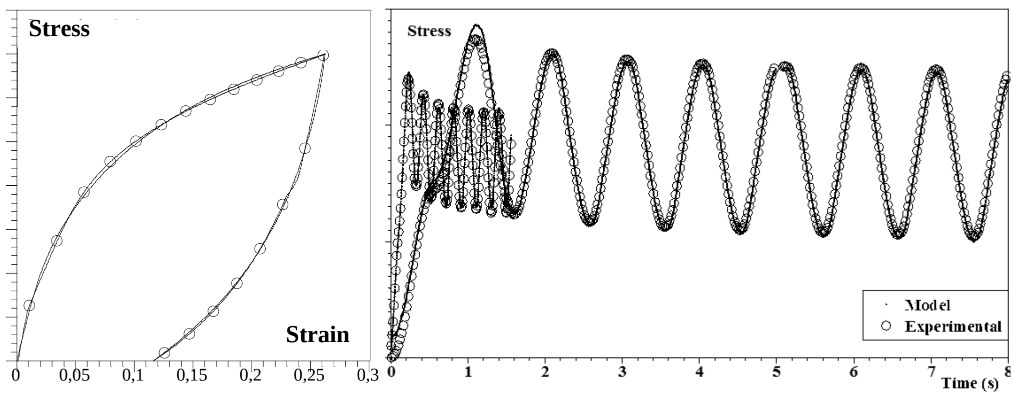

Figure 1 : Comparison between the model (symbols) and experiments (lines) for PA 6-6 and : left-uploading unloading experiment at 0.001 s^{-1}; right- Cyclic loadings at two frequencies.

References (optional)

[1] N. Billon, "New constitutive Modelling for tiem-dependant mechanical behaviour of polymers close to glass transition: Fundamentals and experimental validation", J. Appl. Polym. Sci.., Vol. **125**, pp. 4390-4401, (2012).