A CONSTITUTIVE LAW FOR GLASSY POLYMERS AND BLENDS

F. Zaïri*, K. Woznica**, M. Naït Abdelaziz*, J.-M. Gloaguen*
**Polytech'Lille, Avenue P. Langevin, 59655 Villeneuve d'Ascq Cedex, France*
***ENSI of Bourges, 10 boulevard Lahitolle, 18020 Bourges Cedex, France*

Summary This work deals with modified constitutive equations for the viscoplastic behaviour of homogeneous glassy polymers at isothermal loading. A procedure for determining model parameters is proposed. The modified model is next coupled with a micromechanic formulation to investigate the macroscopic mechanical response of RT-PMMA.

VISCOPLASTIC MODEL

The glassy polymers behaviour is known to be highly nonlinear and sensitive to many parameters like strain rate and temperature. Traditionally, viscoplastic behaviour of glassy polymers is studied by testing under constant strain rates. This behaviour is generally characterized by intrinsic strain softening immediately after yield, followed by progressive strain hardening. Since the viscoplastic deformation mechanisms are not very well understood, certain authors have introduced an approach based on phenomenological considerations by using for example models developed for metals. Indeed, although the deformation mechanisms of polymers and metals are different, on a phenomenologic point of view, such viscoplastic constitutive equations can be used to model the nonlinear and strain rate dependent behaviour of polymers. Particularly, by considering macroscopic formulations, constitutive models based upon internal state variables can be used to simulate flow molecular resistance.

The effects of temperature are not considered in order to simplify constitutive equations and the phenomena such as relaxation and recovery are not accounted for in these. The strain rate is decomposed into an elastic and a viscoplastic part. In this study, the Bodner and Partom state variable constitutive equations [1] has been used to describe the highly nonlinear behaviour and strain rate sensitivity of glassy polymers. Such a model is based upon a thermodynamics formalism of irreversible processes and has been originally developed for metals viscoplasticity. The cumulated viscoplastic strain rate expression used in this investigation is a simplified form of that proposed by Frank and Brockman [2]. To account for the effect of strain softening a new internal state variable has been also introduced.

A method for the determination of the seven independent strain rate material parameters is developed, using tension or compression simple tests across a variety of strain rates. The yield stress allows to determine two parameters, the others are determined from the work hardening rate [1].

The nonlinear differential equations, of the viscoplastic modified model, are integrated using an explicit integration scheme. The trapezoidal method is employed in this study. The parameters of the modified model are determined, in a first step, from isothermal uniaxial experimental data extracted from the literature of two representative glassy polymers (amorphous PET and PMMA). A good agreement is observed between experimental data and the predictions of the modified model.

VISCOPLASTIC MODEL INCLUDING DAMAGE

The addition of low modulus rubber particles into brittle glassy polymers is commonly employed to increase their toughness. If the toughening of modified glassy polymers is understood in a qualitative manner, very few quantitative data have been published.

The rubber-toughened material selected in this work consists of a polybutadiene core-shell particles (30% in volume fraction) dispersed in polymethyl methacrylate (RT-PMMA). This blend is known to have favorable properties and significant volumic growth. Tensile test program was conducted on an hydraulic Instron device to determine the effects of strain and strain rate on the global mechanical behaviour and on void volume fraction. Notched specimen have been produced and deformed under uniaxial tension, under constant true strain rate during the test, for a range of strain rates and at room temperature. The true stress-true strain curves and the volume variation have been determined at the same time using video measurements. Data are determined in the region where the deformation is localized and permits evaluation of the mechanisms and their sequence in RT-PMMA.

The viscoplastic constitutive equation, describing the mechanical behaviour of the polymeric matrix, is coupled with internal damage including both cavitation and growth of voids as introduced in [3-4]. The cavitation is here controlled by the hydrostatic stress [5]. The material parameters appearing in the new micromechanical model are determined from this set of uniaxial test. The predictions of the modified model including damage are generated and compared with experimental data at each strain rate and permit to verify the ability of the model to correctly predict qualitatively and quantitatively the nonlinearity, strain rate dependence and growth of voids at the same time.

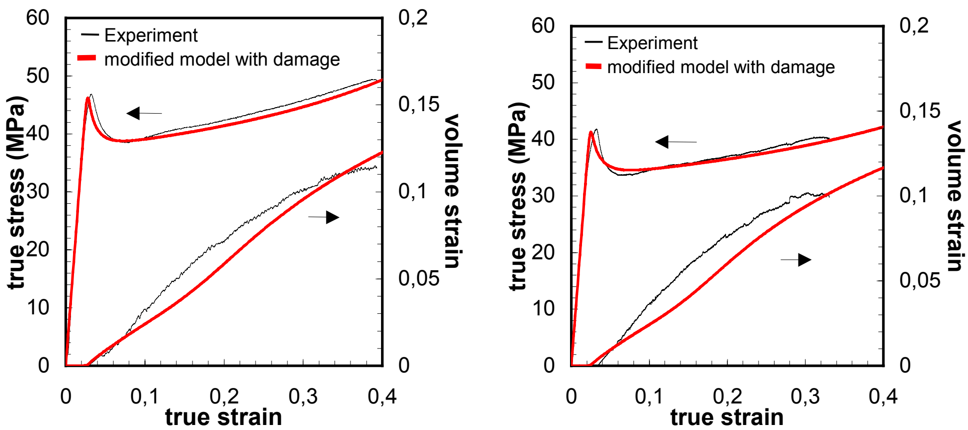

Fig.-True stress-true strain curve and volume strain-true strain curve for RT-PMMA at $10^{-3}s^{-1}$ (left) and at $10^{-4}s^{-1}$ (right).

References

[1] Chan K.S., Bodner S.R., Lindholm U.S.: Phenomenological modelling of hardening and thermal recovery in metals, ASME, J. Eng. Mater. Technol. ***110*** *1-8, 1988*.

[2] Frank G.J., Brockman R.A.: A viscoelastic-viscoplastic constitutive model for glassy polymers, Int. J. Solids Struct. ***38*** *5149-5164, 2001*.

[3] Gurson A.L.: Continuum theory of ductile rupture by void nucleation and growth. PartI: Yield criteria and flow rules for porous ductile media, Trans. A.S.M.E. J. Engng. Mat. Tech. ***99*** *2-15, 1977*.

[4] Tvergaard V.: Influence of voids on shear band instabilities under plane strain conditions, Int. J. Fract. ***17*** *389-407, 1981*.

[5] Jeong H.Y.: A new yield function and a hydrostatic stress-controlled void nucleation model for porous solids with pressure-sensitive matrices, Int. J. Solids Struct. ***39*** *1385-1403, 2001*.