CHARACTERIZATION OF COMPLEX MODULI FOR PLASTIC MATERIAL UNDER HARMONIC LOADING

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The problem of characterization of material response to harmonic loading is addressed. In the present research, Zaïri unified constitutive model [1] is used to predict the time dependent inelastic response of amorphous glassy polymer, a polycarbonate (PC). The approach that uses the complex-value amplitude relations is preferred rather than direct numerical integration of the complete set of constitutive equation for the material. The key point of the approach adopted lays in determination of complex moduli, i.e. storage and loss moduli under harmonic loading. It is usually done by making use of equivalent linearization technique. It is shown that this technique leads to overestimation of stress amplitude. To avoid this, the modified equivalent linearization technique is used. It relies on special procedure for determination of storage modulus which based on the usage of cyclic stress–strain diagram [2]. The formulae for both storage and loss moduli are listed below

$$G'_N(e_0,\omega)=\left[\frac{\sigma'_{aN}{}^2(e_0,\omega)}{4e_0{}^2}-G''^2_N(e_0,\omega)\right]^{1/2},$$

$$\lambda'_N(e_0,\omega)=\left[\frac{\sigma'_{aN}{}^2(e_0,\omega)}{4e_0^2}-\lambda''_N{}^2(e_0,\omega)\right]^{1/2},$$

$$G''_N=\frac{\langle D'\rangle_N}{\omega\, e_0^2},\quad \lambda''_N=\frac{G''_N}{G_0},$$

$$\langle(\cdot)\rangle_N=\frac{1}{T}\int_{T(N-1)}^{TN}(\cdot)\,dt,\quad T=\frac{2\pi}{\omega},$$

where $\sigma'_{aN}=\sigma'_{aN}(e_0,\omega)$ is generalized cyclic diagram, which relate the ranges of the stress intensity in the N^{th} cycle with the intensity of strain-range tensor $e_0^2=\mathbf{e}':\mathbf{e}'+\mathbf{e}'':\mathbf{e}''$; $\widetilde{G}_N$ is complex shear modulus and $\widetilde{\lambda}_N$ is complex plasticity factor that relates the complex amplitudes of the deviator of total strain, $\widetilde{\boldsymbol{e}}$, inelastic strain, $\widetilde{\boldsymbol{e}}^{in}$, and the stress deviator, $\widetilde{\sigma}'$, in the N^{th} cycle.

Obtained histories of main field variables evolution were used to find the stress–strain cyclic diagram and real as well as imaginary parts of complex shear modulus with making use of both standard and modified equivalent linearization techniques. The prediction of stress amplitude obtained in the frame of the former scheme overestimates the actual value for more than 10% while the latter scheme gives it with desirable accuracy.

Fig. 1 illustrates the mechanical hysteresis phenomenon under cyclic loading that enable one to measure the phase shift between stress and total strain. As it was mentioned above, the actual loop can be approximated with making use of either standard or modified equivalent linearization scheme. In the figure, the actual loop (line 1) is shown along with the loops calculated in the frame of standard (line 2) and modified (line 3) equivalent linearization techniques.

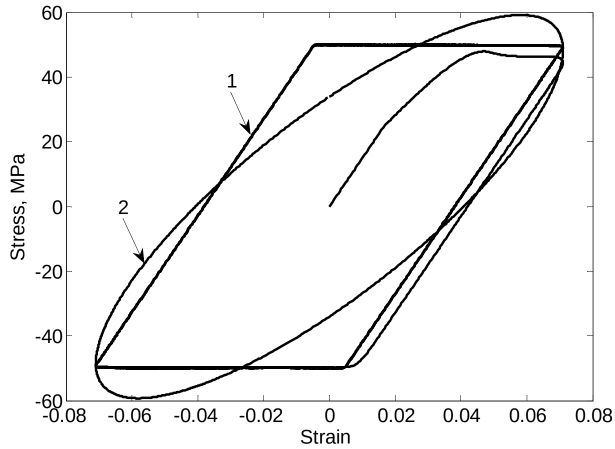

Fig.1. Hysteresis loops

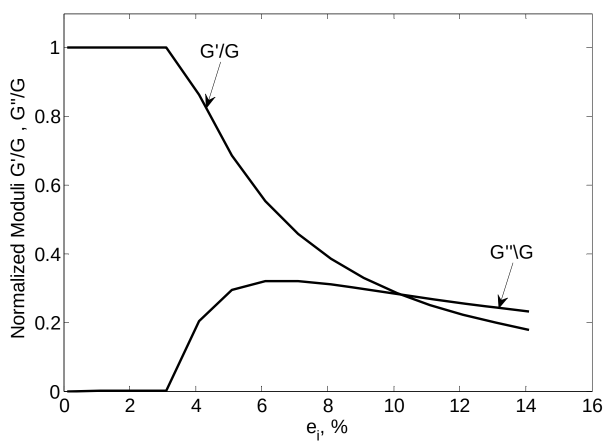

Fig.2. Normalized values of the real and imaginary parts of complex shear modulus for PC polymer

The normalized improved values of G'/G and G''/G found according to the modified scheme for frequency 1 Hz at steady-state cyclic regime and constant temperature are shown in Fig.2 for wide range of loading amplitudes. The behavior is typical for polymeric materials and is characterized by the presence of peak in the loss modulus. This diagram shows the highest losses occur at strain amplitude of about seven percent for this type of polymer.

LITERATURE

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