PREDICTION OF STRESS RELAXATION DURING HIGH-SPEED STRETCHING OF SYNTHETIC THREAD

Z. F. Stalevich

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The viscoelastic characteristics obtained with a "family" of stress relaxation curves can be used to predict distortion of the stress–strain diagram in going to high deformation rates.

The stress–strain diagram of a sample contains important information on the physicomechanical properties of a polymeric material. The conditional modulus is usually determined with the initial segment and the breaking characteristics are determined with the end point. We also know that the defined numerical value of the conditional modulus approaches the value of the modulus of elasticity when the defined deformation rate increases significantly, since only a small fraction of relaxation which distorts the diagram can take place. For a quantitative analysis of the "relaxation content" of the middle part of the stress–strain diagram, it is best to work out a physically substantiated equation for the diagram. For cases of high-speed stretching with a duration of deformation of approximately $10^{-3}$ sec, the solution of this problem was examined on the example of Capron thread in [1]. The urgency of this problem is due to the fact that prediction of high-speed deformation is very directly related to the analysis of the operating properties of synthetic thread. For this reason, research to perfect the solution of this problem is continuing. The simplest variant of prediction of high-speed deformation is reported in the present article.

By analogy with [1], for a constant rate of $k = \text{const}$, the analytical equation for deformation is

$$\sigma_t = \frac{E_0 \varepsilon_t - (E_0 - E_{\infty})}{\frac{E_0}{E_{\infty}}} \int_0^t f(t-S) r_\varepsilon dS,$$

(1)

where $\sigma_t$ and $\varepsilon_t$ are the stress and strain at final time $t$; $E_0$ and $E_{\infty}$ are the modulus of elasticity and modulus of viscoelasticity; $S = t - \Theta$ (where $\Theta$ is the current time in the range from $\Theta = 0$ to $\Theta = t$); $r_\varepsilon$ is the relaxation nucleus.

We see from Eq. (1) that moduli $E_0$ and $E_{\infty}$ have an asymptotic meaning for the values of the relaxation modulus $E_{\varepsilon t}$ (Fig. 1)

$$E_0 > E_{\varepsilon t} > E_{\infty},$$

(2)

and for this reason, the requirements $t < \tau_\varepsilon$ and $t > \tau_\varepsilon$, respectively, where $\tau_\varepsilon$ is the relaxation time, which is a function of the deformation, prevent obtaining their numerical values directly from the stress–strain diagram. The kernel of the equation $r_\varepsilon$ is a function of time $S$, which is a function of the deformation $\varepsilon$ as of the parameter, and analytically expresses the deformation–time analogy.

The following versions of the normalized nuclei are the most appropriate:

$$r_\varepsilon = (2\pi)^{-0.5} a_n^{-1} S_n^{-1} \exp(-0.5V^2_\varepsilon S),$$

(3)

where $a_n^{-1}$ is a constant; $V_\varepsilon$ is an argument functional

$$V_\varepsilon = a_n^{-1} \lg (S/\tau_\varepsilon),$$

(4)

and

Fig. 1. Relaxation modulus $E_c$ of 114 tex Lavsan thread for different deformation levels $e$ (in %): 1) 0.75; 2) 1.0; 3) 1.25; 4) 1.5; 5) 1.75; 6) 2.0; 7) 2.5; 8) 3.0; 9) 3.5.

$$r_{,5} = 0.25 A S^{-1} \text{ch}^{-2} 0.5 A \ln (S / \tau e).$$

where $A$ is a constant.

The advantage of the kernels in the form of (3) — the normal distribution on a logarithmic time scale — and in form (5) — a hyperbolic function on the logarithmic time scale — consists of the content of a minimum number of parameters and convenience of calculation. Kernel (5) is usually used for monitoring calculations using kernel (3). The parameters of the kernels are correlated: $A = 1.15a_n^{-1}$.

Let us examine the question of finding the parameters of indicial Eq. (1) and the subsequent calculation on the example of Lavsan thread with a linear density of 114 tex. Its breaking characteristics for $e = 0.017$ sec$^{-1}$ are: $\sigma_0 = 800$ MPa, $\varepsilon_b = 9.6$%; for $e = 32$ sec$^{-1}$: $\sigma_0 = 900$ MPa and $\varepsilon_b = 6.0$%. The family of relaxation modulus curves used to obtain the following values with the fast method in [2] is shown in Fig. 1: $E_0 = 14.2$ GPa, $E_{\infty} = 4.91$ GPa, $a_n = 9.6$, and the deformation function shown in Fig. 2. These values were determined by approximation of the isochrones

$$E_{\varepsilon t t} \text{ and } E^{* \varepsilon t t} = \frac{\partial E_{\varepsilon t t}}{\partial \ln t} \bigg|_{t_1} < 0,$$

obtained from Fig. 1 with a basal time of $t = 60$ sec with the following equations:

$$\Delta E_\varepsilon = +0.5 \left( E_{\varepsilon t_1} - E_\varepsilon \right) \Phi^{-1} \left( 0 : \pm \sqrt{2 \ln \frac{E_{\varepsilon t}}{E_{\varepsilon t_1}}} \right),$$

(6)

$$a_{-1} = -(0.5 \pi)^{-0.5} E_\varepsilon (\Delta E_\varepsilon)^{-1},$$

(7)

$$E_0 = E_\varepsilon + \Delta E_\varepsilon \text{ and } E_{\infty} = E_\varepsilon - \Delta E_\varepsilon.$$  

(8)

$$\Phi (-\infty, V_{\varepsilon t_1}) = \frac{E_0 - E_{\varepsilon t_1}}{E_0 - E_{\infty}} V_{\varepsilon t_1}.$$  

(9)

$$f_{\varepsilon t_1} = \ln \left( t_1 / \tau e \right) = a_n V_{\varepsilon t_1}$$

(10)