COMPRESSIVE CREEP OF KEVLAR-EPOXY RESIN LINEAR COMPOSITE

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Aromatic polyamides represent the major group of man-made fibers with high performance properties for engineering end use. Especially paraamides as Kevlar fibers are useful for engineering applications due to high modulus and high tenacity. These fibers are used as starting material for industrial textiles bearing high strength at higher temperatures. Deformation of these materials in compression is very interesting from point of view of their application in composites, geotextiles etc. Especially compressive creep is one of frequently used characteristics of geotextiles [1]. From experimental point of view is very complicated to realize compressive creep of fibers in the longitudinal direction. One possibility is to use linear composite consisted from matrix with known compressive behavior and parallel-arranged fibers. This thick rod can be compressively deformed with buckling. The main aim of this contribution is investigation of isothermal compressive creep of linear composite based on Kevlar fibers and epoxy resin measured in the longitudinal direction on the special device TMA for thermo mechanical analysis. The estimation of viscoelastic parameters of Kevlar fibers longitudinal compression is based on the simple three-element model.

Compressive creep model

For modeling of compressive creep the simple tensile creep model (see eg. [2]) can be easily adopted. The differences are only in the sign of relative deformation. Therefore the derivation of creep will be made for the tensile loading and the conversion to the compression one will be done in the final form. The starting viscoelasic model is represented formally on the fig 1.

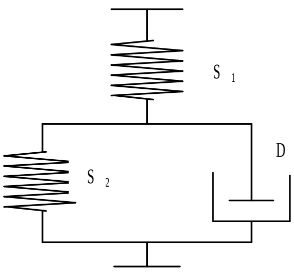

Fig. 1. Model of creep description

Let the spring S_1 and S_2 are described as Hooke's springs.

$$\sigma = \varepsilon.E_1 \quad \text{or} \quad \sigma = \varepsilon.E_2 \tag{1}$$

where E_1 (E_2) is unknown spring modulus. A variety of nonlinear springs are defined as well [3]. The simple linear form characterizes the dashpot

$$\frac{d\varepsilon}{dt} = \frac{\sigma}{\eta} \tag{2}$$

where η is the viscosity. Nonlinear plasticity is described by the Eyring type model [3]. The total strain of model from fig. 1 is $\varepsilon = \varepsilon_S + \varepsilon_V$

where ε_S is deformation of spring S_1 and ε_V is deformation of Voight element (parallel arrangement of S_2 and D). Since the S_1 and Voight element are in the series, the total stress is the same in the both parts $\sigma = \sigma_S = \sigma_V$. After solving the corresponding differential equation the well know creep function results

$$\varepsilon(t) = \varepsilon = \sigma_0\left[\frac{1}{E_1} + \frac{1}{E_2}\left(1 - exp\frac{-t}{\tau}\right)\right] \tag{3}$$

It is clear that for $t = 0$ is $\varepsilon(\infty) = \sigma_0 / E_1$ and for $t \to \infty$ is $\varepsilon(\infty) = \sigma_0\left[1/E_1 + 1/E_2\right]$.

Function $\varepsilon(t)$ expressed by the eqn. (3) is valid for tensile creep. For compressive experiments is valid $\varepsilon_C(t) = -\varepsilon(t)$. Then the dependence of sample height *l(t)* on time t is in the form

$$l(t) = l_0\left[1 - \varepsilon(t)\right] \tag{4}$$

The *l(t)* function is monotonously decreasing functions of time starting from undeformed sample height l_0.

Creep of linear Composite

The linear composite from *N* fibers (phase *F*) embedded in the polymer matrix (phase *M*) is shown on the fig 2a and corresponding two-phase model is on the fig. 2b

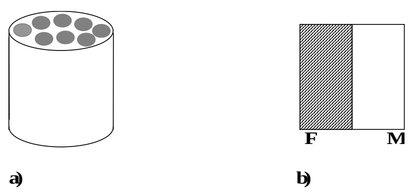

Fig 2. Linear composite and corresponding two-phase model.

For the linear composite of length l_0 and radius *R* and fibers of the same radius *r* is the volume fraction of fiber phase in the form $\phi_F = \frac{N.r^2}{R^2}$

The matrix volume fraction is then $\phi_M = 1 - \phi_V$. For the two-phase model is $\varepsilon = \varepsilon_F = \varepsilon_M$, where ε_F is deformation of fibrous phase and ε_M is matrix deformation. The overall stress σ is sum of stress of fiber and matrix phase i.e. In the creep the $\sigma = \sigma_0 = const$. Creep of both phases will be realized at stresses $\sigma_F . \phi_F$ or $\sigma_M (1 - \phi_F)$. Let the creep of both phases is expressed by model from fig. 1, where S_1, S_2, D have linear response. Then the creep of fiber phase is

$$\varepsilon_F = \sigma_F . \phi_F \left[\frac{1}{E_{1F}} + \frac{1}{E_{2F}} \left(1 - exp \frac{-t}{\tau_F} \right) \right] \qquad (6)$$

where E_{1F} is modulus of spring S_1, E_{2F} is modulus of spring S_2 and, retardation time $\tau_F = E_{2F} / \eta_F$ is dependent an viscosity of η_V .For the matrix phase

$$\varepsilon_M = \sigma_M (1 - \phi_F) \left[\frac{1}{E_{1M}} + \frac{1}{E_{2M}} \left(1 - exp \frac{-t}{\tau_M} \right) \right] \qquad (7)$$

where $E_{1M}, E_{2M}, \eta_M = \tau_M . E_{2M}$ are parameters of matrix phase. These parameters can be obtained independently for sample without fibers $\phi_F = 0$ when $\sigma_M = \sigma_0$. Let the parameters estimates $E^*_{1M}, E^*_{2M}, \tau^*_M$ are known. Then

$$\sigma_F = \frac{\sigma_0}{\phi_F} - \frac{1 - \phi_F}{\phi_F} \sigma_M \qquad (8)$$

The creep function of linear composite is in the form

$$\varepsilon(t) = \varepsilon = [\sigma_0 - \sigma_M (1 - \phi_F)] \left[\frac{1}{E_{1F}} + \frac{1}{E_{2F}} \left(1 - exp \frac{-t}{\tau_F} \right) \right]$$

where σ_M can be expressed as

$$\sigma_M = \frac{\varepsilon(t)}{1 - \phi_F} \left[\frac{1}{E^*_{1M}} + \frac{1}{E^*_{2M}} \left(1 - exp \frac{-t}{\tau^*_M} \right) \right]$$

Because the terms $\phi_F, E^*_{1M}, E^*_{2M}$ and τ^*_M are know the simplified form can be used

$$\sigma_M = K(t) . \frac{\varepsilon(t)}{1 - \phi_F}$$

where

$$K(t) = \frac{1}{1 - \phi_F} \left[\frac{1}{E^*_{1M}} + \frac{1}{E^*_{2M}} \left(1 - exp \frac{-t}{\tau^*_M} \right) \right]$$

After rearrangements the final form of creep function results

$$\varepsilon(t) = \sigma_0 \left\{ K(t) + \left[\frac{1}{E_{1F}} + \frac{1}{E_{2F}} \left(1 - exp \frac{-t}{\tau_F} \right) \right]^{-1} \right\}^{-1} \qquad (9)$$

This final form describes the tensile creep behavior of linear composite. For the case of compressive creep $\varepsilon(t)$ has to be included to the eqn (4).

Experimental part

Measurement of compressive creep in longitudinal direction were realized on the Kevlar 149 with fineness 1,7 dtex and mean fiber diameter 12,15 μm. The composite rods containing 90% of Kevlar 149 and 10% of epoxy resin (CHS 1200) were prepared. These rods were cut to the cylindrical sample with length 12.237 mm and diameter 5.137 mm. For comparison the same samples from pure epoxy resin were prepared. The measurements were realized on the TMA CX03R thermo mechanical device. The compressive creep functions i.e. dependencies of sample height l_H on the time t were measured at compressive load 1000 mN and temperatures T = 25, 50, 100 and 200 °C.

Fitting of compressive creep model

The compressive creep data for linear composite and for pure resin were used for estimation of model parameters E_{1F}, E_{2F} and $_{\leftrightarrow F}$. The two-stage procedure has been used. In the first stage the data for pure resin have been used for estimation of parameters E_{1M}, E_{2M} and $_{\leftrightarrow M}$. The least squares criterion has been used. In the second phase function *K(t)* has been computed Then the combination of eqn.(9) and (4) has been used as model for creep data of linear composite. For ease of computation the new parameters $p1M={}_{\leftarrow 0}/E_{1M}$, $p2M={}_{\leftarrow 0}/E_{2M}$ and $p3M=1/_{\leftrightarrow M}$ for matrix phase and $p1F={}_{\leftarrow 0}/E_{1F}$, $p2F={}_{\leftarrow 0}/E_{2F}$ and $p3F=1/_{\leftrightarrow F}$ have been introduced. The results of nonlinear regressions are in the table 1. In the second row are parameter estimates and in the third one are standard errors.

Table 1 Parameters of compressive creep

p1M	*p2M*	*p3M*	*p1F*	*p2F*	*p3F*
0.0179	7.871E-4	0.04448	0.00255	0.00432	5.2728
2.14E-6	1.629E-5	0.00241	3.32E-4	3.30E-4	0.78

The precision of fit was very high (for pure resin was residual standard deviation = 0.00127 and for linear composite was residual standard deviation = 001338).

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