ACADEMICIA

ISSN: 2249-7137 Vol. 11, Issue 4, April 2021 Impact Factor: SJIF 2021 = 7.492

ACADEMICIA
An International Multidisciplinary Research Journal
(Double Blind Refereed & Peer Reviewed Journal)

DOI: 10.5958/2249-7137.2021.01061.2

MODELING THE PROCESS OF DEFORMATION OF VISCOELASTIC TEXTILE MATERIALS

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ABSTRACT

The article covers the analysis of deformed state of textile threads with regard for their relaxation characteristics. As a model, The Boltzmann-Volterre integral relation has been used. For a specific calculation, a kernel with four parameters has been used.

KEYWORDS: *Mechanical Properties, Tension, Deformation, Materials, Viscoelastic Properties, Relaxation Processes, Elastic Modulus, Various Materials, Mechanical Properties, Curve, Kernel, Distribution, Experimental*

1. INTRODUCTION

As we know, to describe relaxation processes the model of the thread considered should be used. The model view is based on fact that textile materials are modeled by a set of interconnected elements that symbolize elasticity and viscosity in pure form. Under the mechanical model is understood not only a set of springs and dampers, but also a system of closed equations that determine the stressed-deformed state of the material. This model approach allows obtaining mathematical description of any new model built of elastic and viscous elements.

It should be noted that correctly chosen model allows more deeply studying the patterns of textile threads and predicting its behavior under certain operating conditions. If the model method of studying relaxation processes in polymer materials can be considered developed, then for textile threads and clothes it is still deficient [1].

A number of models to describe the mechanical properties of textile materials with different deformation times have been proposed.

1. Maxwell model. The model consists of two successively connected elastic and viscous elements. Along with the positive effects, there is a drawback composed of not sufficiently taking into account the tension behavior of the material.

2. Kelvin-Voith model. The model consists of two parallel-connected elastic and viscous elements. However, this model presents only one mechanism of high-elastic deformation.

3. Eyring, Dogadkin, Bartnev, Reznikovsky model. The model is a parallel-connected Maxwell element spring and piston. This model is often used in research of relaxation phenomena in polymer materials, as well as in fibers and threads.

4. Generalized Kelvin-Voith models. The model consists of three components generalized by Kelvin-Voith model.

5. Mathematical models. It is possible to build complex models, which consists of four or more elastic and viscous elements. However, the use of multi-element models leads to lengthy mathematical expressions and does not allow to satisfactorily describing the deformation of real textile materials [2].

2. MATERIALS AND METHODS

Relaxation processes that occur in textile threads can be described by the modeling method. Herewith, it should be observed that the correct selection of the model allows really the laws of deformation of materials in real conditions. Mechanical models are widely used when describing the mechanical properties of various materials, including textiles. They allows simulating the relation between tension and deformation of the materials under study [3].

We use the hereditary Boltzmann-Volterr theory of viscoelasticity to describe the processes of threads deformation taking into account the viscoelastic properties. The mathematical record of the dependence of tension on deformations is as follow [4]:

$$\varepsilon(t) = \frac{\sigma(t)}{E} + \frac{1}{E}\int_0^t K(t-s)\sigma(s)ds, \quad \sigma(t) = E\varepsilon(t) - E\int_0^t G(t-s)\,\varepsilon(s)ds \qquad (1)$$

Where σ – is tension; ε – is relative deformation; E – is elastic modulus; $K(t-s)$ and $G(t-s)$ – are dependence functions; t – is time of observation; τ – is time prior to time of observation.

In (1), formulas for calculating the parameters of viscoelasticity were proposed [5].

$$E = \frac{\sigma_1 \alpha(\alpha+1)}{\varepsilon(\alpha(\alpha+1) - At_1)} \quad t_1^\alpha(\sigma_2 - \sigma_3) - \ t_2^\alpha(\sigma_1 - \sigma_3) + t_3^\alpha(\sigma_1 - \sigma_2),$$

$$A = \frac{((\sigma_1 - \sigma_2)\alpha(\alpha+1))}{\sigma_1(\alpha+1)(t_2^\alpha - t_1^\alpha) + (\sigma_1 - \sigma_2)t_1^{\alpha+1}}, \qquad \beta = \frac{(\sigma_4 - \sigma_1)(\alpha+1)\alpha + E\varepsilon A(t_4^\alpha - t_1^\alpha)(\alpha+1)}{E\varepsilon A(t_4^{\alpha+1} - t_1^{\alpha+1})}$$

Knowing the nature of the distribution of tension and deformation of the thread allows predicting the tension-deformation state of the thread [6].

At $\sigma = const$, from relation (1) we obtain the creep equation

$$\varepsilon(t) = \frac{\sigma(t)}{E}[1 + \int_0^t K(s)ds] \qquad (2)$$

If the influence function is known, then equation (2) can be used to construct a constant curve of tension creep. The latter is determined from the known creep curve. In particular, if the influence function $K(t)$ has the form of an exponent, then we obtain the Kelvin model. If the kernel of the integral equation is in the form of a sum of damped exponential functions, then the integral equation (1) is equivalent to a linear differential equation of the $n-$order .

There are different types of kernels. For example, the kernels of Rabotnov, Slonimskiy, Ilyushin, etc. In computational practice have found great application the kernels proposed by Yu.N. Rabotnov, A.R. Rjanitsyn, M.A.Koltunov [7]. For example, the relaxation kernel proposed by A.R. Rjanitsyn has the form

$$R(t-s) = \frac{Ae^{-\beta(t-s)}}{(t-s)^{1-\alpha}}, \qquad (3)$$

Where A, α, β are material parameters. The resolvent of this kernel is obtained by M.A.Koltunov in a form [8]

$$K(t-s) = \frac{\exp(-\beta(t-s))}{(t-s)} \sum_{n=0}^{n=\infty} \frac{[A - \Gamma(\alpha)]^n (t-s)^{n\alpha}}{\Gamma(n\,\alpha)} \qquad (4)$$

For materials with a finite long-term modulus of elasticity, a four-parametric kernel is used, which has a form

$$K(t-s) = \frac{Aexp\,(-\beta\,(t-s))}{T^q\,(t-s)^p}, \qquad 0 < p < 1; q = 1 - p \qquad (5)$$

Where A, T, p, q, β are - material parameters determined by graphical method [8].

Corresponding relaxation kernel has the form

$$R(t-s) = \frac{\exp(-\beta(t-s))}{(t-s)} \sum_{n=0}^{n=\infty} (-1)^{o+1} \frac{[A\Gamma(q)]^j}{\Gamma(jq)} (\frac{t-s}{T})^{qj} \qquad (6)$$

For a constant load applied at time t=0, according to expressions (5) and (1), we have

$$\varepsilon(t)=\frac{\sigma(t)}{E}[1+\frac{A}{T^{q}}\int_{0}^{t}\frac{e^{-\beta(t-s)}}{(t-s)^{p}})ds \;=\frac{\sigma}{E}[1+\frac{A}{(T\beta)^{q}}\gamma(\beta t,p)]\,, \quad \gamma(\beta t,p)=\int_{0}^{\beta t}e^{-s}/s^{p}ds\infty$$

Where $\gamma(\beta t,\rho)-$ is incomplete gamma function, whose values are tabulated [9]. When $t\rightarrow\infty$ then deformation is equal to

$$\varepsilon(\infty)=\frac{\sigma}{E}[1+\frac{A}{(T\beta)^{q}}\Gamma(\mathrm{q})]$$

An algorithm to determine the parameters based on experimental creep curves has been developed, and practical techniques based on graphical constructions has been developed for approximate engineering estimates [10].

3. RESULTS AND DISCUSSION

Let us show the efficiency of using a kernel of the form (3) in comparison with other types.

Fig. 1 shows the graphs of tension relaxation changes according to three theories in comparison with the experimental curve. Hence, we clearly see that for the deformation of textile materials, the best description is given by the weakly singular kernel (3) and Rjanitsyn-Koltunov function-resolvent. As an example, we consider the process of deformation of a cotton thread with a linear density of 28 tack.

Instantaneous modulus of elasticity E, breaking load and breaking deformation are determined before the creep test. The tests are carried out at constant temperatures and relative humidity of the material. Wherein, machines, equipment and stands designed for long-term static tests are used. Therefore, for example, one end of a thread or fabric is fixed motionless, and a load is suspended from the other end. In this case, tensile deformation relaxes in the thread or fabric at constant tension. In this position, the sample is kept in an unloaded state at a given test temperature for 30-60 minutes. After that, the sample is loaded at loads up to 5% of the short-term strength limit. In this case, the possibility of sliding of the sample in the clamps during the test should be excluded.

The loading rate is taken constant for the entire series of tests. The loading time should not exceed five seconds. The moment of full load of the test sample is taken as the reference point for creep. Moreover, deformations are recorded in 0.5;1;2;3;5;10;30;60 min after loading, followed by approximate doubling of period between indications.

After the creep tests have been performed, the samples are unloaded and the unloading creep is observed. All tests are repeated on samples at least three times, and processed by the method of complex analysis. The values of the averaged deformations for each tension level and time are recorded in a table and presented in the form of graphs indicating the experimental confidence intervals.

Figure 1 shows the deformation curves at different load levels

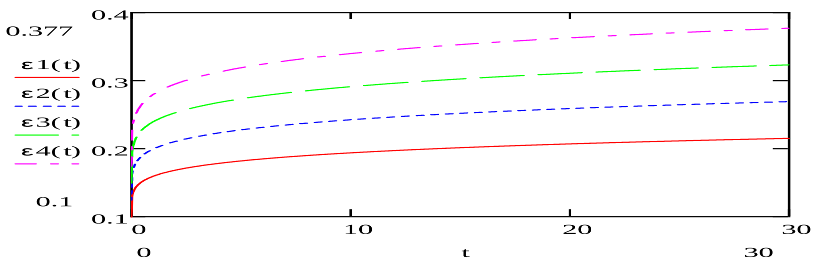

Fig. 1. Deformation curves of 28 tack cotton thread at different load levels

The mentioned curves show that the deformation is linear with respect to the tension. The determination of the modulus of elasticity and the parameters of the kernel is carried out by combining the experimental curves of flexibility and theoretical curves [11]. Having this experimental theoretical curve (Fig. 1), determined by the parameters α_t, β_t, A_t, we can easily determine the parameters of experimental curve α_e, β_e, A_e for a given material, and its instantaneous modulus of elasticity E is found by the formula

$$E = \frac{1 + \int_0^t K dt}{\varepsilon_x(t)\sigma_k} \tag{7}$$

Thus, the found parameters α_e, β_e, A_e can be introduced into the relaxation equation and into the constraint equation $\sigma \sim \varepsilon \sim t$.

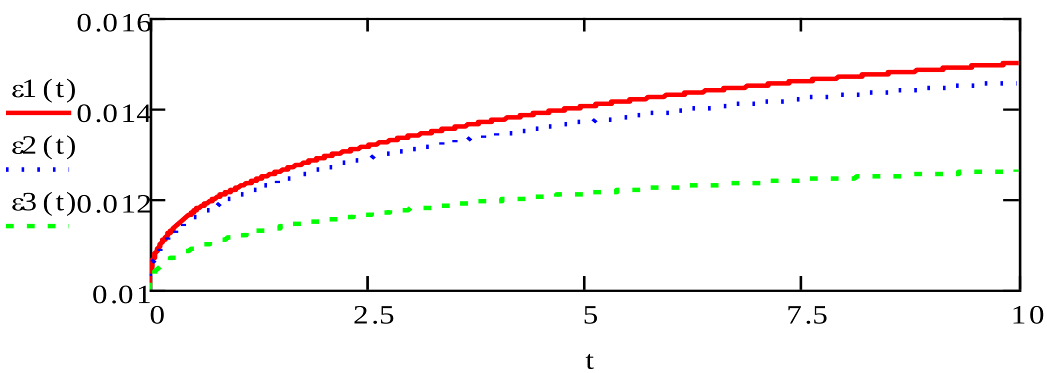

Fig. 2. Creep curves for different kernels ($\varepsilon_1(t)$ is experimental curve; $\varepsilon_3(t)$ is Rjanitsyn kernel; $\varepsilon_2(t)$ is four-parameter kernel)

4. CONCLUSION

Analysis of the studies carried out allows concluding that it is necessary to use a model method to calculate the values of deformation of textile materials in the process of relaxation. It was determined that Boltzmann-Volterr model, generalizing other known models for textile materials, is the most acceptable. To describe the behavior of textile materials with viscoelastic properties, it is necessary to use weakly singular heredity kernels, for example, the Rjanitsyn-Koltunov kernel (3), which very satisfactorily reflects the quasi-static and dynamic behavior of viscoelastic material, and is most convenient for carrying out quasi-static and dynamic calculations and determining mechanical constants. However, as numerical experiments show, a kernel of the form (5) is the most acceptable for a number of materials (Fig. 2). In the case of kernel with four parameters, the creep curve is closer to the experimental one than the kernel with three parameters.

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