DOI 10.1007/s10692-021-10194-1
Fibre Chemistry, Vol. 52, No. 4, November, 2020 (Russian Original No. 4, July—August, 2020)

CRITERIA FOR QUALITATIVE EVALUATION OF DEFORMATION AND FUNCTIONAL PROPERTIES OF POLYMER TEXTILE MATERIALS FOR TECHNICAL PURPOSE

N. V. Pereborova

DC 539.434:677.494

New criteria are proposed for the qualitative assessment of the deformation and functional properties of polymer textile materials for technical purposes, obtained on the basis of the study of the parameters and characteristics of mathematical models of deformation processes of these materials. The developed criteria allow for a qualitative assessment of the deformation-functional properties of polymer textile materials for technical purposes, which significantly reduces the technical and economic costs of designing these materials with specified deformation properties, since there is no need to manufacture prototypes of these materials.

The method based on mathematical modeling of the deformation process of polymeric textile materials for technical purposes, developed for determining the functional and consumer deformation and operational properties of these materials [1-3] makes it possible to assess their quality characteristics in terms of deformation and operational parameters.

Consider a mathematical model of the deformation process (creep) of polymeric textile materials for technical purposes [4-6]:

$$D_{\sigma\tau} = D_0 + (D_\infty - D_0)\varphi_{\sigma t}, \tag{1}$$

where the normalized arctangent of the logarithm (NAL), which characterizes the integral Cauchy distribution [7], was chosen as the deformation function $\varphi_{\sigma t}$:

$$\varphi_{\sigma t} = \varphi\left(\frac{t}{\tau_\sigma}\right) = \frac{1}{2} + \frac{1}{\pi}\arctan\left(\frac{1}{b_{n\sigma}}\ln\frac{t}{\tau_\sigma}\right). \tag{2}$$

We use the following notation: τ_σ is the characteristic of the average creep time; $b_{n\sigma}$ is a characteristic of the intensity of the deformation process; ε_t is deformation changing in time t under the action of stress σ; $D_0 = \lim_{t\to 0} D_{\sigma t}$ is the initial elastic compliance; $D_\infty = \lim_{t\to\infty} D_{\sigma t}$ is the limit equilibrium compliance – two asymptotic values of compliance $D_{\sigma t} = \varepsilon_t/\sigma$.

To assess the deformation and functional properties of polymer textile materials for technical purposes, several criteria are proposed that can be combined into a single integrated criterion due to the fact that all deformation parameters for assessing the properties of these materials are subject to the Cauchy probabilistic law and include an assessment of their quality [8-10].

To assess the deformation and operational properties of polymer textile materials for technical purposes, the following criteria are proposed: a criterion for the intensity of deformation of the material during operation; criterion of the degree of deformability of the material during operation; criterion for the possibility of multiple deformation of the material during operation; time criterion of deformation effects on the material during operation; criterion of material resistance to repeated deformation during operation.

It is proposed to carry out a quantitative assessment of the parameters within the framework of the proposed criteria for the deformation-operational properties of polymer textile materials for technical purposes in dimensionless units, which can be described as follows [11-13].

St. Petersburg State University of Industrial Technologies and Design, Russia. E-mail: ninal332@yandex.ru.
Translated from *Khimicheskie Volokna*, No. 4, pp. 37 – 40, July – August, 2020.

1. Criterion of the intensity of deformation of the material during operation

We denote a dimensionless variable characterizing the intensity of deformation of the material during operation by $\beta_1 = b_{n\sigma}$, which is numerically equal to the intensity of the creep process, which is responsible for the deformation-operational functional-consumer properties of the material under consideration. In this case, β_1 it can take any non-negative values ($\beta_1 \geq 0$). The lower the value of β_1, the faster the deformation of the material occurs during operation and the faster it corresponds to its functional purpose [14].

2. Criterion of the degree of deformability of the material during operation

We denote a dimensionless variable characterizing the degree of deformability of the material during operation by $\beta_2 = D_0/(D_0 + D_\infty)$. In this case, β_2 takes non-negative values ($\beta_2 > 0$). The lower the β_2 value, the greater the degree of deformability during operation the material possesses and the more it corresponds to its operational purpose. The higher the value of the parameter β_2, the less deformation the material has and the less comfortable it is during operation [15].

3. Criterion of the possibility of multiple deformation of the material during operation

We denote a dimensionless variable characterizing the ability of a material to withstand multiple deformation effects without significant deterioration of its operational properties by $\beta_3 = \sigma_0/\sigma_b$, where σ_b is the value of the breaking stress, and σ_0 is some basic stress value, for example. $\sigma_0 = 1$ MPa. In this case, β_3 takes positive values $\beta_3 > 0$. The smaller the value of β_3, the greater the ability of the material to withstand multiple deformation effects [16].

4. Time criterion of deformation effects on the material during operation

We denote a dimensionless variable characterizing the temporary ability of the material to maintain its functional and consumer properties during deformation during operation by $\beta_4 = \overline{\tau}_\sigma / t_1$, where t_1 is some value of the base time, for example $t_1 = 60$ s, $\ldots_\sigma$ is the average deformation time, determined by the formula

$$\overline{\tau}_\sigma = \frac{\sigma_0}{\sigma_2 - \sigma_1} \cdot \int_{\sigma_1/\sigma_0}^{\sigma_2/\sigma_0} \tau_\sigma d\frac{\sigma}{\sigma_0}, \tag{3}$$

where ε_1, ε_2 – are the smallest and largest values from the interval of the investigated deformations [17-20].

In this case, β_4 can take on any non-negative values ($\beta_4 > 0$). The lower the σ_4 value, the faster the material deforms during operation, which provides greater comfort.

5. Criterion of material resistance to repeated deformation during operation

Let us denote a dimensionless variable characterizing the resistance of the material to repeated deformation during operation by $\beta_5 = D_0/(D_\infty - D_0)$. In this case, β_5 can take on any non-negative values ($\beta_5 \geq 0$). The lower the β_5 value, the more resistant the material to repeated deformation during operation. The value $\beta_5 = 0$ corresponds to the condition of the material's complete resistance to repeated deformation during operation.

Due to the fact that the main deformation characteristics D_0, D_∞, $b_{n\sigma}$ and τ_σ are obtained using mathematical modeling of deformation-operational properties based on the Cauchy probability distribution, the integral distribution function of which is the NAL function, all the variables $\beta_1 - \beta_5$ also obey the Cauchy probability distribution due to the additivity of this law [20, 21].

The Cauchy probability distribution is quite close to normal, differing from it in some properties, for example, the slower convergence of the integral function to its asymptotic values. This property of the Cauchy distribution makes it possible to more reliably process statistical samples with a significant degree of diffusion, which just characterizes the sample sets of deformation characteristics of polymer textile materials for technical purposes [22, 23].

In view of the above, it should be noted that the probabilistic deformation characteristic of σ_b also obeys the Cauchy law.

6. Integrated criterion of deformation and performance properties

Since all introduced probabilistic characteristics $\beta_1 - \beta_5$ are distributed according to the Cauchy law, it is advisable to consider a new deformation-operational parameter

$$B_d = \beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5, \tag{4}$$

also distributed according to Cauchy's law.

Based on the properties of terms $\beta_1 - \beta_5$, the variable B_d takes on non-negative values ($B_d > 0$), and the deformation-operational properties of polymer textile materials for technical purposes will be the better the lower the value of the deformation-operational parameter B_d.

Clearly, in the ideal case, the best, in terms of the quality of materials, functional-consumer deformation-operational characteristics correspond to those polymer textile materials for technical purposes, in which B_d has a minimum value [24-26].

Thus, the criterion for optimizing the deformation and operational properties of polymeric textile materials for technical purposes can be formulated as follows:

$$\frac{\sum_{k=1}^{N} B_{dk}}{N} = \frac{\sum_{k=1}^{N} (\beta_{1k} + \beta_{2k} + \beta_{3k} + \beta_{4k} + \beta_{5k})}{N} = \overline{B}_d \rightarrow \min, \tag{5}$$

where N is the number of material samples under study (sample size); $\overline{B}_d$ is the average value of the deformation-operational parameter.

As noted above, the developed criterion for optimizing the deformation and operational properties of polymer textile materials for technical purposes is of an integrated nature and includes optimization according to five partial criteria of the deformation and operational properties of these materials:

- the criterion of the intensity of deformation of the material during operation;
- the criterion of the degree of deformability of the material during operation;
- the criterion for the possibility of multiple deformation of the material during operation;
- time criterion of deformation effects on the material during operation;
- the criterion of material resistance to repeated deformation during operation.

This work was funded within the framework of the state assignment of the Ministry of Science and Higher Education of the Russian Federation, Project No. FSEZ-2020-0005.

REFERENCES

1. P. P. Rymkevich, A. A. Romanova, et al., *J. Macromol. Sci. Part Â: Physics*, 52, No. 12, 1829-1847 (2013).
2. A. G. Makarov, G. Y. Slutsker, and N. V. Drobotun, *Techn. Phys.*, 60, No. 2, 240-245 (2015).
3. A. G. Makarov, G. Ya. Slutsker, et al., *Fiz. Tverd. Tela*, 58, No. 4, 814-820 (2015).
4. A. G. Makarov, A. V. Demidov, et al., *Khim. Volokna*, No. 6, 60 – 67 (2015).
5. A. G. Makarov, N. V. Pereborova, et al., *Ibid.*, 68-72.
6. A. G. Makarov, N. V. Pereborova, et el, *Izv. VUZov Tekst. Prom-sti.*, No. 5 (359), 48-58 (2015).
7. A. G. Makarov, A. V. Demidov, et al., *Izv. VUZov Tekhnol. Tekst. Prom-sti*, No. 6, (360), 194-205 (2015).
8. A. G. Makarov, N. V. Pereborova, et al., *Khim. Volokna*, No. 1, 37-42 (2016).
9. A. G. Makarov, A. V. Demidov, et al., *Khim. Volokna*, No. 2, 52-58 (2016).
10. A. V. Demidov, A. G. Makarov, et al., *Izv. VUZov Tekhnol. Tekst. Prom-sti*, No. 1 (367), 250-258 (2017).
11. A. G. Makarov, N. V. Pereborova, et al., *Izv. VUZov Tekhnol. Tekst. Prom-sti*, No. 2 (368), 309-313 (2017).
12. A. G. Makarov, N. V. Pereborova, et al., *Izv. VUZov Tekhnol. Tekst. Prom-sti*, No. 4 (370), 287-292 (2017).
13. A. G. Makarov, N. V. Pereborova, et al., *Khim. Volokna*, No. 1, 69-73 (2017).
14. A. G. Makarov, N. V. Pereborova, et al., *Khim. Volokna*, No. 2, 59-63 (2017).
15. A. V. Demidov, A. G. Makarov, et al., *Khim. Volokna*, No. 4, 46-51 (2017).
16. N. V. Pereborova, A. V. Demidov, et al., *Khim. Volokna*, No. 2, 36-39 (2018).
17. A. G. Makarov, N. V. Pereborova, et al., *Khim. Volokna*, No. 3, 94-97 (2018).
18. N. V. Pereborova, A. G. Makarov, et al., *Khim. Volokna*, No. 4, 54-56, 117-120 (2018).
19. N. V. Pereborova, A. G. Makarov, et al., *Khim. Volokna*, No. 5, 89-92 (2019).
20. N. V. Pereborova, A. G. Makarov, et al., *Khim. Volokna*, No. 6, 3-6, 87-90 (2018).
21. N. V. Pereborova, A. V. Demidov, et al., *Izv. VUZov Tekhnol. Tekst. Prom-sti*, No. 2 (374), 251-255 (2018).

22. N. V. Pereborova, A. G. Makarov, et al., *Izv. VUZov Tekhnol. Tekst. Prom-sti*, No. 3 (375), 253-257 (2018).
23. N. V. Pereborova, A. G. Makarov, et al., *Khim. Volokna*, No. 5, 68-70, 71-73 (2019).
24. N. V. Pereborova, A. V. Demidov, et al., *Izv. VUZov Tekhnol. Tekst. Prom-sti*, No. 2 (380), 192-198 (2019).
25. N. V. Pereborova, A. V. Demidov, et al., *Izv. VUZov Tekhnol. Tekst. Prom-sti*, No. 3 (381), 242-247 (2019).
26. N. V. Pereborova, A.V. Demidov, et al., *Izv. VUZov Tekhnol. Tekst. Prom-sti*, No. 4 (382), 229-234 (2019).