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CREEP OF THERMOPLASTICS IN AIR AND IN PHYSIOLOGICAL
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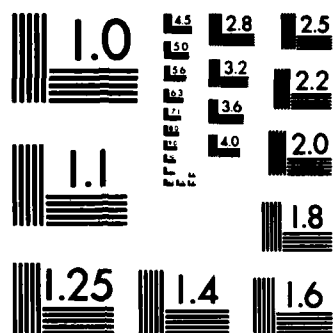
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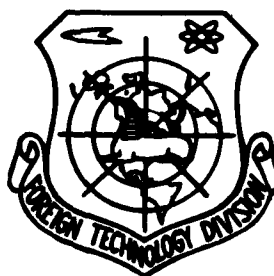
FOREIGN TECHNOLOGY DIVISION



CREEP OF THERMOPLASTICS IN AIR AND IN PHYSIOLOGICAL SOLUTION

by

G.I. Roitberg, V.N. Kestel'man, R.Z. Rakhimov



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EDITED TRANSLATION

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U. S. BOARD ON GEOGRAPHIC NAMES transliteration SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

*ye initially, after vowels, and after ъ, ы; e elsewhere.
When written as ё in Russian, transliterate as yě or ě.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	sinh ⁻¹
cos	cos	ch	cosh	arc ch	cosh ⁻¹
tg	tan	th	tanh	arc th	tanh ⁻¹
ctg	cot	cth	coth	arc cth	coth ⁻¹
sec	sec	sch	sech	arc sch	sech ⁻¹
cosec	csc	csch	csch	arc csch	csch ⁻¹

Russian English

rot curl
lg log

GRAPHICS DISCLAIMER

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CREEP OF THERMOPLASTICS IN AIR AND IN PHYSIOLOGICAL SOLUTION

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Creep of polymeric materials has been studied mainly under conditions of static monoaxial tension [1-4]. We have now established the existence of elastic, resilient-elastic (nonsteady-state) and viscous (steady-state) components of total creep. In this case, the full deformation under constant tensile load and at constant temperature, as well as the duration of load, are interrelated [2]:

$$\epsilon_{\eta} = \epsilon_y + \epsilon_{y_s}(\sigma) + \nu_e(\sigma)t, \quad (1)$$

where ϵ_{η} - total creep; ϵ_y - elastic component; ϵ_{y_s} - resilient-elastic (relaxation) deformation; $\nu_e t$ - viscous deformation (ν_e - rate of viscous deformation, t - time. Liquid mediums under these conditions do not alter the creep curves. We were interested to look into the possibility of using Equation (1) to describe the creep in structural thermoplastics under other types of stress in air and in liquid mediums.

We studied the creep of polymers under normal conditions in air and in a liquid medium - a physiological solution (0.9% NaCl solution in distilled water) under static bending and pressure. The subjects of the study were polyamide - 12 (P-12), a copolymer of trioxane with dioxalene (STD), fluorinated polymethyl methacrylate (PMMAF), and

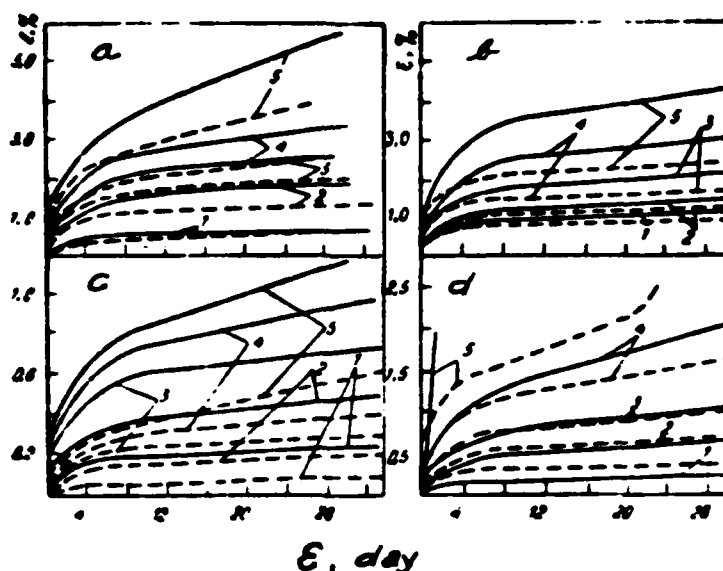


Figure 1. Creep in P-12 (a), STD (b), PETF (c), PMMAF (d) in air (broken lines) and in physiological solution (solid lines) under compression at different σ/σ_{kp} :
1 - 0.05; 2 - 0.1; 3 - 0.2; 4 - 0.03; 5 - 0.4

molding polyethylene terephthalate (PETF). Standard bars 10x15x120 mm for bending and 10x10x15 mm for compression) were fabricated by injection molding (P-12, STD, PETF) and machining from a block (PMMAF). The experiments were conducted on special spring devices under stresses σ constituting varying components of the short-duration breaking load σ_{kp} for each material. The short-duration bending strength of thermoplastics was determined at the rates of 50 mm/min for compression and 15 mm/min for tension (Table 1). The creep was determined with an accuracy of 0.01 mm on the basis of the results of at least five experiments.

As is seen in Fig. 1, all obtained curves of creep consist of two basic segments: nonsteady-state and steady-state creep (instantaneous elastic deformation is not shown). In form, these curves coincide with known curves of creep under conditions of static tension for the majority of hard polymer materials. Under static bending, the picture was similar. In the physiological solution, intensity of creep differs from that observed in tests conducted in air, although

the nature of the curves remains unchanged.

Table 1. Short-term strength of thermoplastics (kg/cm²).

(1) Material	(2) Tensile strength	(3) Compressive strength	(4) Bending strength
1112	112	805	710
CT-1	650	880	1000
11MMAF	870	1333	1350
113T	180	1040	852

Key: 1 - material; 2 - tensile strength; 3 - compressive strength; 4 - bending strength.

It is generally assumed that in the region of steady-state deformation, when the rate of the process is constant, we observe viscous, and in the nonsteady-state region resilient elastic deformation. To isolate resilient elastic deformation, some researchers [5] have continued the linear curve segment within coordinates ϵ_{π} -t until it intersects the ordinate ϵ_{π} , thereby disregarding the time required to reach the limit of nonsteady-state creep. Under the conditions we are assuming here, however, nonsteady-state creep time is extremely important with respect to the total time the load is applied and can therefore not be disregarded.

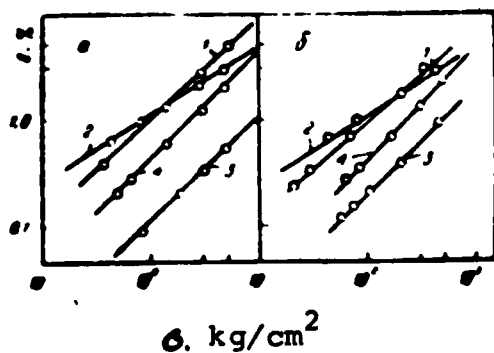


Figure 2. Nonsteady-state creep strength of P-12 (1), STD (2), PETF (3), PMMAF (4) as a function of compressive stress σ in air (a) and in physiological solution (b).

Figure 2 shows resilient elastic deformation as a function of compressive stress σ in air and a model medium within a system of logarithmic coordinates. The rectilinearity of the curves confirms the earlier suggested exponential relationship between deformation and stress [5]:

(2)

where A - parameter depending on the medium; k - coefficient determined by the type of load (Table 2). Lines of nonsteady-state creep in the physiological solution are located somewhat higher than the analogous lines obtained in tests in air.

Table 2. Parameter values in creep equation for P-12.

(1) Type of deformation	(2) Stress, kg/cm ²	(3) Time to limit of nonsteady-state deformation, days		(6) Constants				v_t	
		(4) Days	(5) Percent	(4) Days	(5) Percent	(4) Days	(5) Percent	(4) Days	(5) Percent
Bend (7)	30	2	3					0.0100	0.0154
	70	3	5					0.0230	0.0416
	156	5	7					0.1454	0.0578
	244	4	11	$3.2 \cdot 10^{-2}$	$4.07 \cdot 10^{-2}$	1.0	1.0	0.0033	0.0020
	112	8	9					0.1010	0.1020
	340	10	9					0.1430	0.2040
Compression (8)	210	4	7					0.000057	0.000057
	510	10	12					0.000007	0.001270
	110	11	11	$2.40 \cdot 10^{-2}$	$1.62 \cdot 10^{-2}$	0.85	0.85	0.001240	0.001660
	170	10	10					0.002500	0.003300
	330	8	10					0.00017	0.01000

* v_t for bending measured in mm/day, for compression [illegible]/day.

Key: (1) Type of deformation; (2) stress kg/cm²; (3) time to limit of nonsteady-state deformation in days; (4) Air; (5) physiological solution; (6) constants; (7) bend; (8) compression.



Figure 3. Dependence of rate of steady-state creep on static bending stress σ for P-12 (1) and STD (2) in air (broken lines) and in model medium (solid lines).

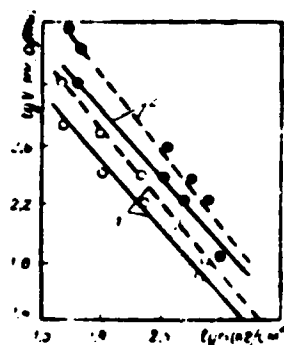


Figure 4. Dependence of time to limit of nonsteady-state deformation on static bending stress σ for P-12 (1), and STD (2) in air (broken lines) and in a model medium (solid lines).

Taking into account relationship (2) and the time required to reach the limit of nonsteady-state creep, Equation (1) can be written in the following form:

$$\epsilon_{\eta} = \epsilon_{ys} + A\sigma^k + v_t(\sigma)(t - t_1(\sigma)), \quad (3)$$

where $t_1(\sigma)$ is the time within which the limit of nonsteady-state deformation is reached. Creep values obtained using Eq. (3) deviated from those arrived at experimentally by no more than 6% for P-12, 8% for STD, 6% for PMMAF, 9% for PETF.

In Formula (3) the rate of steady-state creep v_t and the time required to reach the limit of nonsteady-state deformation t_1 are also functions of stress. Under the conditions of our tests, time t_1 , on account of the comparatively short total test time, cannot be disregarded. Considering this, we attempted to describe steady-state creep as a function of stress mathematically. It turned out that for thermoplasts P-12 and STD subjected to static bending, functions $v(\sigma)$ and $t_1(\sigma)$ in air and in the model medium are linear in logarithmic coordinates (Figs. 3 and 4), and consequently, are described by the exponential function:

$$v = B\sigma^m \quad (4)$$

and

$$t_1 = C\sigma^n \quad (5)$$

where B, C, m and n are constants. For STD under bending stress in the model medium, the linearity is preserved up to $\sigma = 200 \text{ kg/cm}^2$.

Thus, for thermoplasts with a high degree of crystallinity (P-12 and STD), the creep during static bending with low stress in air and in physiological solution can be described by the following equation:

$$\epsilon_{\text{st}} = \frac{\sigma}{E} + A\sigma^k + B\sigma^m(t - C\sigma^n). \quad (6)$$

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