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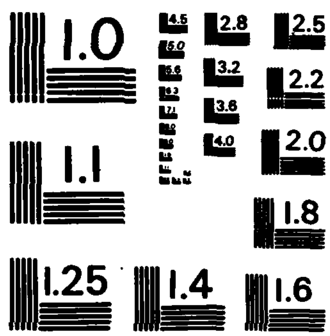

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AIR FORCE SYSTEMS COMMAND

CREEP OF THERMOSOFTENING PLASTICS IN AIR AND IN A PHYSIOLOGICAL SOLUTION

by

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

FOREIGN TECHNOLOGY DIVISION

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

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

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

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CREEP OF THERMOSOFTENING PLASTICS IN AIR AND IN A PHYSIOLOGICAL SOLUTION

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The creep of polymer materials is studied predominantly under conditions of static uniaxial tension [1-4]. Established at present is the existence of elastic, elasto-elastic (nonstationary) and viscous (stationary) components of total creep strain. The total strain at a constant tensile load and temperature and also the duration of the loading are connected with each other [2]:

$$\varepsilon_{\text{п}}=\varepsilon_{\text{у}}+\varepsilon_{\text{уэ}}(\sigma)+v_{\text{т}}(\sigma)t, \qquad (1)$$

where $\varepsilon_{\text{п}}$ is the total creep strain; $\varepsilon_{\text{у}}$ - elastic component; $\varepsilon_{\text{уэ}}$ - elasto-elastic (relaxation) deformation; $v_{\text{т}}t$ - viscous deformation ($v_{\text{т}}$ - rate of viscous deformation, t - time). Liquid media under these conditions do not change the shape of the creep curves. It was of interest to clarify the possibility of using a equation (1) for describing the creep of structural thermosoftening plastics with other forms of the stressed state in air and in liquid media.

We studied the creep of polymers under normal conditions in air and in the model medium - the physiological solution (0.9% solution of NaCl in distilled water) under static bending and compression. The objects of the investigation were polyamide-12 (P-12), the copolymer of trioxane with dioxalane (STD), fluorinated polymethylmetacrylate (PMMAF), and casting polyethylene terephthalate (PETF). The standard bars (for bending with a dimension of 10X15X120 mm, for a compression of 10X10X15 mm) were made by the casting method under pressure (P-12, STD, PETF) and machining from a block (PMMAF). Tests were conducted under stresses σ, which comprise different portions of the short-term breaking load $\sigma_{\text{кр}}$ for each material. The

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short-term bending strength of the thermosoftening plastics was determined at a rate of 50 mm/min and for compression and tension - at a rate of 15 mm/min (Table 1). Creep strain was estimated with a precision of up to 0.01 mm according to results of not less than five experiments.

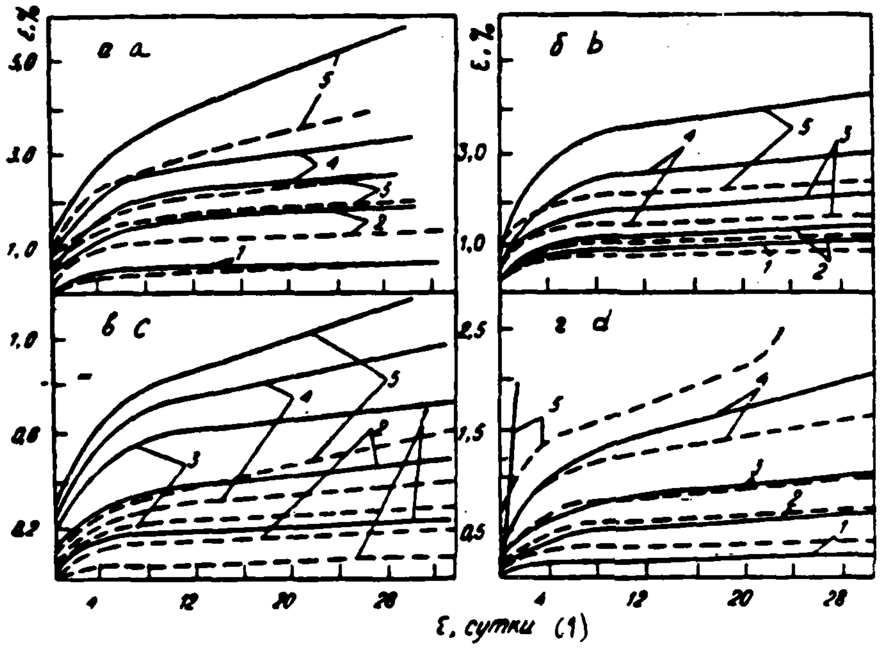

Fig. 1. Creep of P-12 (a), STD (b), PETF (c), and PMMAF (d) in air (dashed lines) and in a physiological solution (solid lines) in the compression process at different values of $\sigma/\sigma_{\text{кр}}$: 1 - 0.05; 2 - 0.1; 3 - 0.2; 4 - 0.3; 5 - 0.4. Key: (1) days.

As is evident from Fig. 1, all the obtained creep curves consist of two main sections: nonstationary and stationary creep strains (the instantaneous elastic strain is not reflected on the figures). These curves concur in shape with the known creep curves under conditions of static tension of the majority of the solid polymer materials. Under static bending the picture was similar. In the physiological solution the intensity of the creep strains is different than it is with tests in air, but the nature of the curves remains unchanged.

Usually, it is accepted to consider that in the region of the stationary strain, when the rate of the process is constant, a viscous deformation is observed, and in the region of the nonstationary strain, an elasto-elastic deformation is observed. To separate the elasto-elastic deformation, individual investigators [5] continued the linear segment of the curve in coordinates $\varepsilon_n - \tau$ to the intersection with the ordinate ε_n, thereby disregarding the time to the approach of the maximum of the nonstationary creep strain. But under the conditions accepted by us, the time of the deformation of the nonstationary creep is very significant with respect to the total time of action of the load, and, therefore, we cannot disregard it.

Table 1
Short-term strength of thermosoftening plastics (kg/cm^2)

(1) Материал	(2) При растяжении	(3) При сжатии	(4) При изгибе
П-12	112	598	780
СТД	659	890	1000
ПММАФ	800	1333	1350
ПЭТФ	180	1040	552

Key: (1) Material; (2) Under tension; (3) Under compression; (4) Under bending.

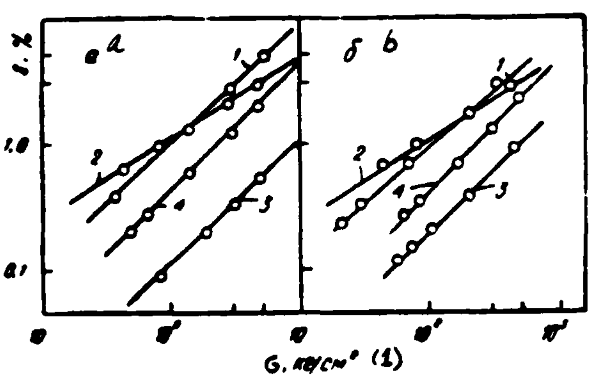

Fig. 2. Dependence of the maximum of nonstationary creep P-12 (1), STD (2), PETF (3), and PMMAF (4) in air (a) and a physiological solution (b) on stress σ under compression. Key: (1) kg/cm^2.

In logarithmic coordinates Fig. 2 gives the dependence of the magnitude of the elasto-elastic strain on stress σ under compression in air and a model medium. The rectilinearity of the graphs confirms the earlier proposed exponential function between the strain and stress [5]:

$$\varepsilon_{\tau n} = A\sigma^{h}, \qquad (2)$$

where A is the parameter dependent on the medium; k - the coefficient determined by the form of loading (Table 2). Straight lines of the nonstationary creep in a physiological solution are located somewhat higher than the similar curves obtained during the test in air.

Table 2

Values of parameters for the creep equation for thermosoftening plastic P-12

(1) Вид деформирования	(2) Напряжение, кг/см²	Время до наступления предела неустановившейся деформации, сутки (3)		(6) Константы				v_T	
				A		k			
		(4) Воздух	(5) Физраствор	(4) Воздух	(5) Физраствор	(4) Воздух	(5) Физраствор	(4) Воздух*	(5) Физраствор*
	39	2	3					0,0100	0,0154
	78	3	5					0,0230	0,0416
	156	5	7					0,0454	0,0578
Изгиб (7)	234	4	11	$3{,}2\cdot10^{-3}$	$4{,}07\cdot10^{-3}$	1,0	1,0	0,0833	0,0920
	312	8	9					0,1010	0,1820
	390	10	9					0,1430	0,2040
	29,8	4	7					0,000667	0,000867
	50,6	10	12					0,000867	0,001270
Сжатие (8)	119,2	11	11	$2{,}46\cdot10^{-2}$	$3{,}62\cdot10^{-2}$	0,85	0,85	0,001200	0,001660
	178,8	10	10				—	0,002600	0,003300
	238,4	8	10					0,00617	0,01000

(9) * Размерность v_T при изгибе мм/сутки, при сжатии 1/сутки.

Key: (1) Form of deformation; (2) Stress, kg/cm^2; (3) Time to approach of maximum of nonstationary deformation, days; (4) Air; (5) Physiol. solution; (6) Constants; (7) Bending; (8) Compression; (9) *Dimensionality v_T with bending - mm/days and with compression - 1/days.

In considering the dependence (2) and also the time to the approach of the maximum of the nonstationary deformation of creep, we can present equation (1) in the following form:

$$\varepsilon_n = \varepsilon_{y0} + A\sigma^k + v_{T(\sigma)}(t - t_{1(\sigma)}), \qquad (3)$$

where $t_{1(\sigma)}$ is the time during which the maximum of the nonstationary strain is achieved. The deviation of values of creep strain, obtained according to relation (3), from the experimental values for the P-12 was more than 6%, for the STD - 8%, the PMMAF - 6%, and PETF - 9%.

In formula (3) the rate of the stationary creep strain v_T and the time of achievement of the maximum of nonstationary strain t_1

are also a stress function. In conditions of our experiment, it is impossible to disregard the time t_1 due to the comparatively short total time of the test. Considering this, we made an attempt mathematically to describe the dependence of the deformation of the stationary creep on stress. It was found that for thermosoftening plastics P-12 and STD undergoing static bending, the dependences $v(\sigma)$ and $t_1(\sigma)$ in air and in a model medium are linear in logarithmic coordinates (Figs. 3 and 4) and, consequently, are described by the exponential function:

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

and

$$t_1 = C\sigma^n, \qquad (5)$$

where B, C, m, and n are constants. For the STD with bending in a model medium, the linearity is retained to σ=200 kg/cm^2.

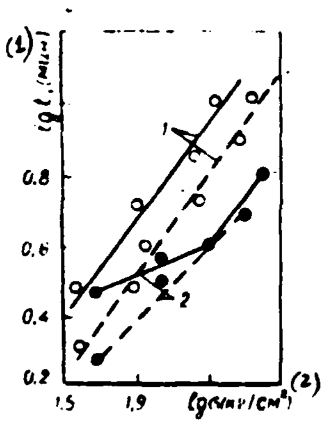

Fig. 3.

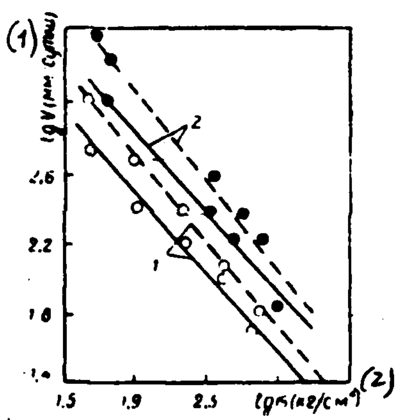

Fig. 4.

Fig. 3. Dependence of the rate of stationary creep strain on stress σ with static bending of P-12 (1) and STD (2) in air (dashed curves) and in model medium (solid lines). Key: (1) min; (2) kg/cm^2.

Fig. 4. Dependence of time of achievement of maximum of nonstationary creep strain on stress σ with static bending of P-12 (1) and STD (2) in air (dashed line) and in model medium (solid lines). Key: (1) mm/days; (2) kg/cm^2.

Thus for thermosoftening plastics with a high degree of crystallinity (P-12 and STD), the creep in the process of static bending at high stresses in air and in a physiological solution can be described by the following equation:

$$\varepsilon_n = \frac{\sigma}{E} + A\sigma^k + B\sigma^m(t - C\sigma^n). \qquad (6)$$

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