

Investigations on the Behaviour of Highly Orientated Polycapromide under Static Tensile Conditions

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The investigations of the deformation properties of chemical fibres are very pressing and have an important significance for the creation of the bases of a science, for purposeful regulation and improvement of the technological process of their production.

Many questions, connected with the general regularities of their behaviour in a strained state are insufficiently investigated. As for the highly orientated polycapromide (HOPCA) such are, e. g. the establishment of simple and universal description of the relaxation processes in a wide range of deformations, investigation of the effect of the temperature on the intensity of the passing relaxation processes, etc. (1). On the other hand, these questions are of great importance as they are connected directly with the prognostication of the fibres' properties during exploitation and processing (2).

That is why of certain scientific and applied interest are the investigations on the behaviour of chemical fibres under static tensile stress. The object of the present work is the studying of the relaxation of the stress in HOPCA during a constant deformation at tensile loading in order to establish the possibilities for prognostication of its behaviour in similar conditions.

Methodical Part

The experiments are carried out with samples from the regular production of Plant "Vidlon", Vidin. Four types of HOPCA (cord rayon) are investigated, whose physico-mechanical properties are given in Table I.

The samples are investigated on the "Relaxomer RP", whose description is given in details in (3), and the way of its exploitation — in (4).

The samples are with an initial length $l_0=100$ mm. For all experiments the deformation is 5% from the initial length. The rate of setting the deformation is $V=80$ mm/sec., which has been achieved by means of electromagnet (3).

The dependence $\sigma=f(t)$, when $\epsilon_0=\text{const.}$, where σ is the stress, in CN/tex, which the sample gets in every moment, is experimentally taken down.

The investigations have been carried out in the range of temperature from about 20°C up to 175°C and in the range of time from 0 up to 3300 sec.

The processing of the results was carried out by a specially developed programme for an electronic computer, whose algorithm was given in our previous work (5). With the purpose of the nearest approximation the present investigations to the practice's needs, the tensile stress σ , and respectively the current modulus of elasticity $E = \frac{\sigma}{\epsilon_0}$ are given in cN/tex.

Experimental Results and Discussion

The experimental dependences $\sigma = f(t)$, obtained at $\epsilon_0 = \text{const.}$ and at different temperatures are given in Fig. 1. The character of the dependences for all samples is one and the same. It can be noticed from the plot and abrupt decrease of the stress during the first 600-700 s and an inconsiderable change after 2000-3000 s. The registration of the value in the first 1-2 s depends on the swiftness of the action of the recorder, and this is necessary because an elastic deformation develops meanwhile.

These facts make it necessary to look for an analytical kind of the dependence and by approximation to obtain the values of σ for the initial moment when because of the above-mentioned reasons the experimental values cannot be read.

As a mathematical model for the relaxation processes, taking place in the Bulgarian HOPCA fibres, the dependence known as an Equation of Kolraush (6) is used:

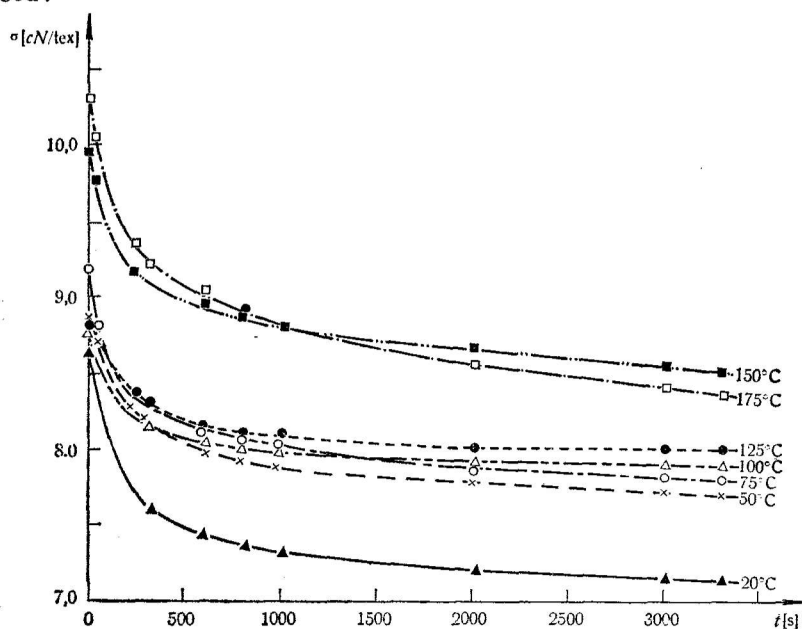


Fig. 1. Experimental dependence of the function $a=f(t)$ for the sample 4

$$\sigma(t) = E_{\infty}\epsilon_0 + \Delta E_0\epsilon_0 e^{-at^k},$$

where E_{∞} — equilibrium modulus of elasticity
 ΔE_0 — relaxation part of the modulus of elasticity
 a and k — relaxation constants.

Table 1

No	Number of single fibres	Linear density, tex*	P , kg	ϵ , %	R , cN/tex
1	1×280	194,93	13,36	16,80	67,23
2	1×140	94,97	6,08	16,60	62,80
3	2×140	200,80	13,12	16,08	64,00
4	2×2×140	403,23	25,16	24,64	61,21

* tex — weight measure of fibres thickness.

Table 2

Time, s	1	15	222	300	600	800	1000	2000	3000	2300
E_i , exper. cN/tex	190,30	186,7	173,3	171,0	169,4	169,3	167,4	164,8	164,8	163,2
ΔE_i , calc. cN/tex	190,1	186,5	174,7	172,9	168,9	167,5	166,4	164,2	164,2	163,3
ΔE_i , cN/tex	-0,21	-0,22	1,46	1,95	-0,46	1,84	0,96	-0,63	-0,63	0,35
δ , %	-0,11	-0,12	0,83	1,13	-0,27	-1,0	0,57	-0,38	-0,38	0,21

Table 3

Sample	E_∞ , cN/tex	ΔE_0 cN/tex	E_0 , cN/tex	a	k	τ , s
1	260,24	24,12	284,36	0,0544	0,4982	345,3
2	162,91	28,35	191,25	0,0385	0,5775	281,8
3	154,38	33,87	188,25	0,0976	0,4099	291,9
4	141,51	38,79	180,30	0,1515	0,3707	162,0

Our previous investigations (7) showed that by this equation for HOPCA is possible the function $\sigma=f(t)$ to be approximated with a sufficient accuracy for times shorter than the swiftness of the action of the recorder as well as for times longer than the time of the experiment.

The results obtained from the processing and their comparison with the experimental data for sample 2 at a temperature of 20°C can be observed in Table 2. The results for the rest of the samples and temperatures are analogous.

As it can be seen from the table the relative error is not higher than 1%. Hence in that case we may conclude that the mathematical model sufficiently well describes the experimental dependences obtained for all models and temperatures investigated. This made it possible to use the model as a base of the calculations during the next processing.

The constants E_∞ , E_0 , a , k and $\tau = \frac{1}{a^{1/k}}$ from the equation of Kolraush were determined. Their values for a temperature of 20°C are given in Table 3.

The samples 2, 3, 4 are from successive stages of the production of PCA cord rayon and a comparison between them may be made in order to trace out the effect of the mechanical processing.

In relation to the modulus of elasticity a tendency of decreasing of the values for each next stage of the processing is observed. On the other hand,

the difference between the initial and the final modulus of elasticity increases. It may be concluded that the part of the plastic deformation in the total one increases

For a and K definite tendency of increasing is noticed in the following stages of processing.

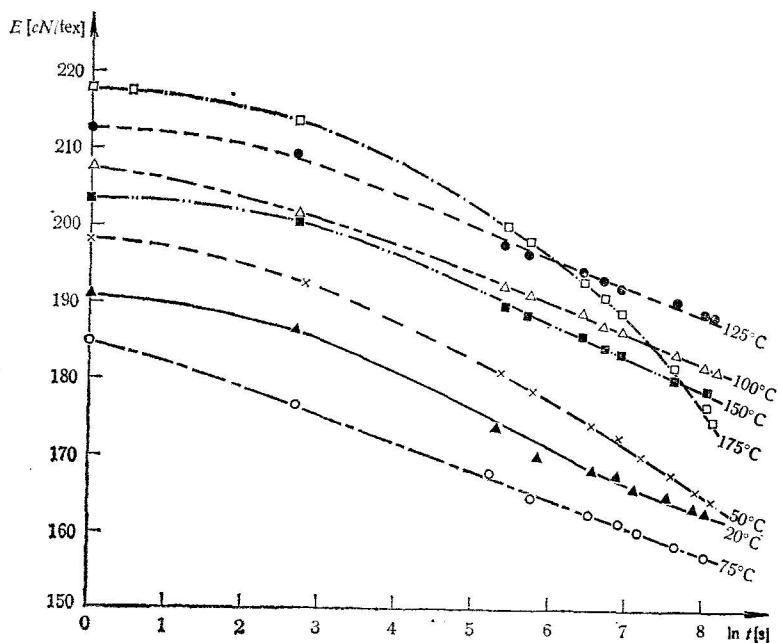


Fig. 2. Experimental dependence of the function $E=f(\ln t)$ or the sample 2

Table 4

Sample	1	2	3
C_1	21,0	17,1	13,1
C_2	226,5	210,6	125,6

Table 5

τ , °C	20	50	75	100	125	150	175
1	345,3	207,9	324,6	603,4	198,9	379,9	601,2
2	281,8	548,4	—	303,0	287,0	387,8	834,8
3	291,9	290,6	218,9	261,9	272,3	350,2	651,3
4	161,9	340,0	324,0	318,7	205,1	428,5	3297,2

For the constant τ which depends directly on a and K ($\tau = \frac{1}{a^{1/k}}$) cannot be noticed a definite dependence on the processing conditions. The result obtained can be explained by the compensation effect between the a and K constants. This shows that the experimental data for τ must be discussed with a certain

reserve. Therefore, in order to be connected with the term time of relaxation additional independent investigations are necessary.

The experimental time dependences obtained at different temperatures show a tendency to increasing of the modulus of elasticity with the increase of the

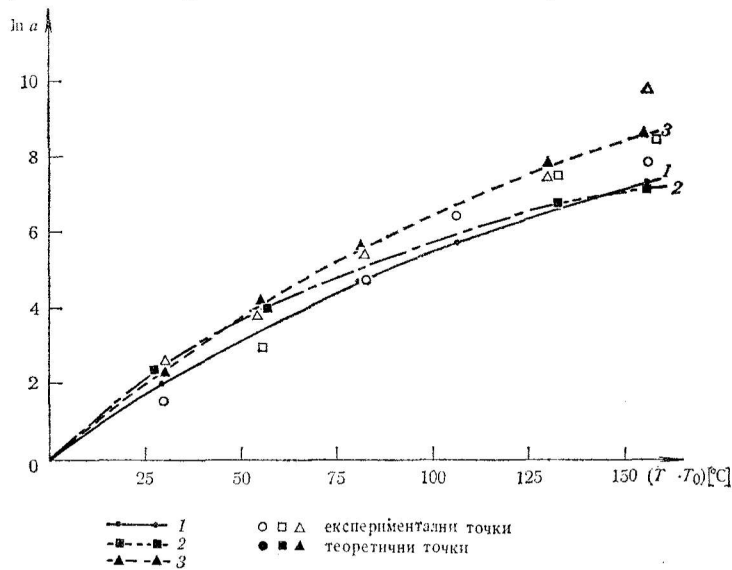


Fig. 3. Temperature dependence of the function $\ln a_T = f(T - T_0)$

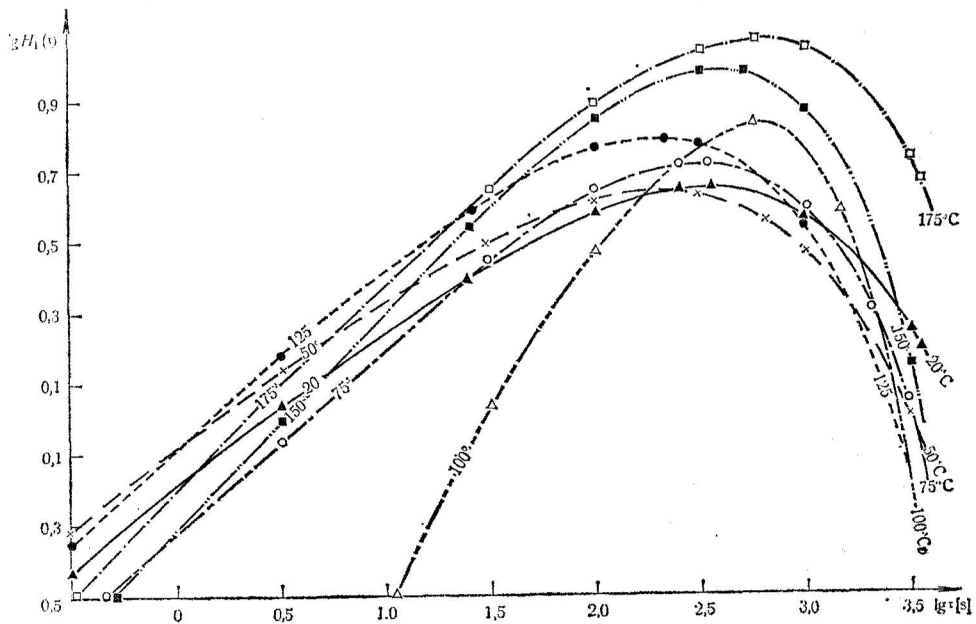


Fig. 4. Time relaxations spectrum for the sample 1

temperature. It is logical to look for some relation between the changes of both parameters and on its base the effect of the first parameter, to be prognostigated knowing the dependence of changing the modulus from the second parameter.

Different methods for prognostication of the effect of different parameters, knowing the dependences for one of them, are well known. One of them is, e. g., the Principle of Temperature-Time Superposition (TTS), based on the relationship:

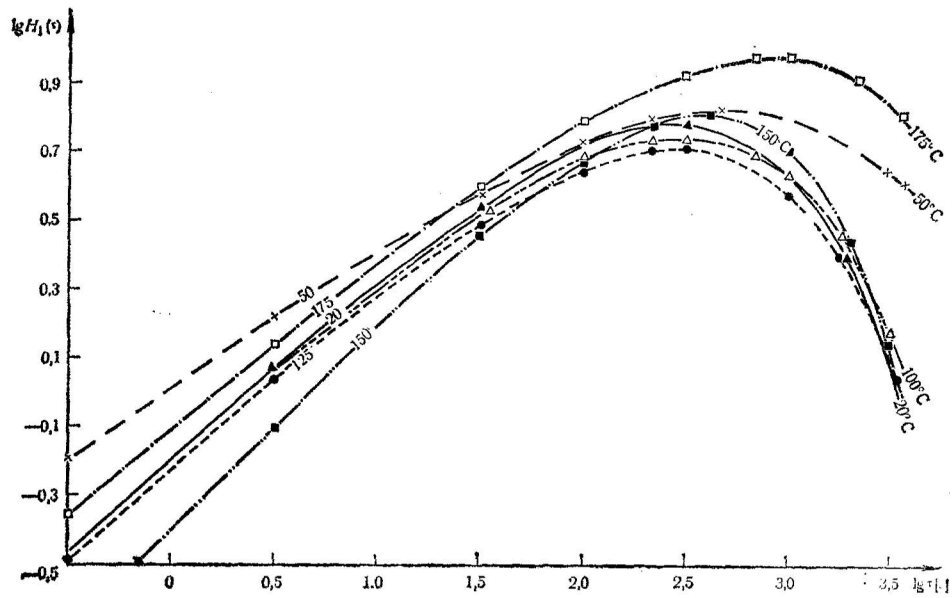


Fig. 5. Time relaxations spectrum for the sample 2

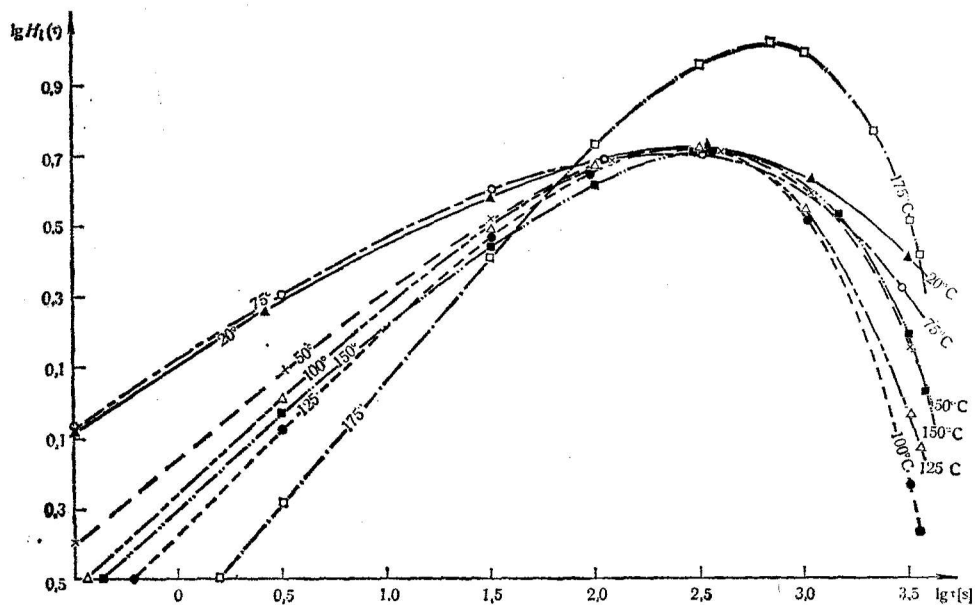


Fig. 6. Time relaxations spectrum for the sample 3

$$E_{sT}(a_T \cdot t) = E_{sT}(t),$$

where E_{sT} — modulus of elasticity at temperature T

E_{CT_0} — modulus of elasticity at random characteristic temperature T_0
 a_T — coefficient of reduction.

The coefficient a_T when plotting generalized curves according to Tobolski et al. (8) is calculated by the formula of Williams, Landel and Ferry (9):

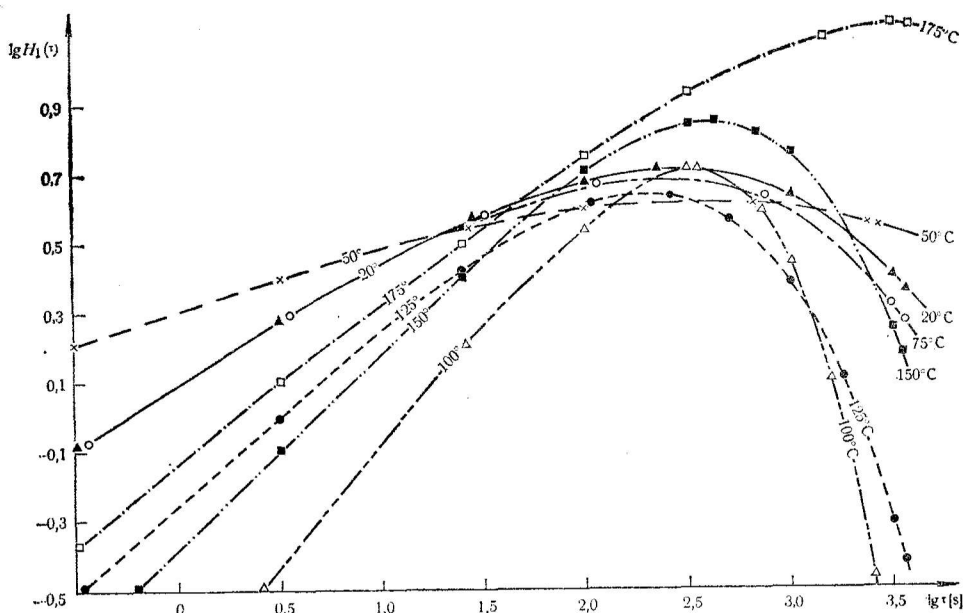


Fig. 7. Time relaxations spectrum for the sample 4

$$\ln a_T = \frac{C_1(T-T_0)}{C_2 + (T-T_0)}$$

That is why at first the experimental values of “ a_T ” must be found. For this purpose from the experimental dependences of the modulus of elasticity in the temperature range of 20° up to 175°C, shown in a semilogarithmic mode (Fig. 2), the average value of $\Delta \ln t$ between two neighbouring curves at one and the same value of E is determined. Furthermore when increasing the interval $(T-T_0)$ these values are summarized and $a_T = f(T-T_0)$ is obtained.

The values of the coefficients C_1 and C_2 calculated by the least squares method are given in Table 4.

By the temperature dependences for “ a_T ” thus obtained and shown in Fig. 3 the generalized curves of TTS can be plotted. In our case this is impossible. Instead of ramp function for the generalized curve, as must be expected, a decreasing one is obtained. This is due to the fact that the change of the temperature is a ramp function.

The increase of the modulus of elasticity with the increase of the temperature up to 125°C is due probably to the fact that the deformation is set before the overheating of the sample and at the experimental temperature processes of thermal shrinkage take place.

Another possibility for processing of the experimental results obtained for prognostication of the behaviour of HOPCA investigated is the drawing up of the spectra of relaxation times for different temperatures of investigation.

The spectra, shown in Fig. 4, 5, 6, 7 are drawn up in their first approximation by the formulae of Schwarzl and Stavermann (10):

$$H_1(\tau) = - \left. \frac{dE(t)}{d \ln t} \right|_{t=\tau}$$

It is seen from the spectra that the increase of temperature leads to deformation of the spectrum, i. e. a grouping of the relaxation times around the maximum of the spectrum is obtained. By comparison of the values of the constant τ from the equation of Kolraush and from the spectra an interesting fact is established: a coincidence of the values of the maxima with the values of τ (Fig. 4, 5, 6, 7 and Table 5). Therefore, τ may be considered as an average time of relaxation and according to it to judge for the position of the maximum in the spectrum of the relaxation times at a definite temperature. This result has an important practical value as it shows that an information for the position of the maximum of the relaxation times can be obtained right at the processing of the primary experimental results by means of the equation of Kolraush. All the same for the distribution of the different relaxation times in the development of the total process of relaxation of the stress may be judged only after the drawing of the spectral dependences.

The mode of the spectra for the experiments, carried out at different temperatures, explains why it is not possible to apply TTS. Actually as it is seen from them that with the increase of the temperature a deformation of the spectral dependences is obtained as the position of the maximum is changed a little. Shifting to the lesser times is not observed, as it is observed for some elastomers (10). The last is probably the result of a more complex nature of the relaxation phenomena in the orientated polymer materials which makes it necessary to work out new approaches for their description.

Conclusion

The relaxation of the stress in HOPCA "Vidlon" under static tensile loading is investigated. It is shown that the increase of the temperature leads to the increase of the current modulus of elasticity which makes it impossible to use TTS for prognostication of the behaviour of HOPCA. This unexpected result is explained with the metastability of the structure which is shown as an additional shrinkage of the sample investigated during the experiment.

The processing of the results obtained by means of the equation of Kolraush makes it possible to obtain an information for the position of the maximum of the spectrum of the relaxation times.

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