FORECAST OF POLYMER CONCRETE LONG-TIME BEHAVIOUR USING FINDLEY THEORY

R.BAREŠ
ÚTAM-ČSAV Vyšehradská 49, 128 49 Praha-2, Czechoslovakia
J.HRISTOVA
Lab.phys.-chem.mat.BAN, Bontcheva 1, 1113 Sofia, Bulgaria
Z.FIALA
ÚTAM-ČSAV Vyšehradská 49, 128 49 Praha-2, Czechoslovakia

ABSTRACT

For the safe utilization of polymer concrete it is necessary to know long-time behaviour of polymer concrete. In this contribution is screened the possibility to describe and forecast long-time creep and stress relaxation using Findley's model. The forecasting curves were obtained by the extrapolation of short time experimental values. The limits of extrapolation were determined by comparison forecasting values with results of long-time experiments. The full agreement of the forecasting and experimental results was proved conclusively in the region of linear deformation. PC is frequently utilized in higher temperature and/or humidity conditions. It was proved that the description and forecast of long-time behaviour of PC according to the Findley's model is possible even for different temperatures and/or water saturation. There are given the functional relations between parameters of Findley equation and quantity of the matrix in polymer concrete.

INTRODUCTION

Polymer concrete (PC) is a polymer based composite system with a concrete-like conglomerate structure. It possesses high mechanical characteristics, durability under aggressive media and abrasive conditions and good permittivity properties. PC possesses also a damping capacity better then that of granite and diabase and much better than that of cast iron and steel.

The behaviour of PC under long-term mechanical action is of basic importance for the durability and operation of building constructions, machines and equipment, containing PC elements.

The experimental data demonstrating PC behaviour under creep conditions prove that it displays the characteristics of a viscoelastic body.

Under constant stress PC exhibits deformation in the course of time (it creeps) but the deformations are considerably smaller than these of conventional plastics. Nevertheless, the action of the environmental medium factors to PC elements under mechanical loading intensity the deformation process, deformation may reach values hampering the normal operation and live-time of elements. The quantitative and qualitative experimental data for the long-term characteristics of PC alteration under the environmental medium action are indispensable. Different approaches and mathematical models can be applied for this purpose [1-5] to afford the prediction of the materials behaviour on the basis of experimental data.

The authors have made an attempt to apply Findley's theory for the description of the long-term behaviour of viscoelastic materials in the case of PC. According to Findley [6,7] the deformation e caused by the constant stress s is

$$e = e_0 . \sinh(s/s_0) + e_t . \sinh(s/s_t) . t^n, \qquad (1)$$

where e_0, e_t, s_0, s_t, and n are experimentally determined material constants.

PC under working conditions is subjected to loading in the linear range of deformation and this is the reason to analyse its linear viscoelastic behaviour. For the case under consideration it is possible to use transformed interrelations of the type

$$e = s/E_v \, , \qquad (2)$$

$$E_v = \frac{E_v \, . \, E_0}{E_t + E_0 \, . \, t^n}, \qquad (3)$$

where E_v is modulus of viscoelasticity, $E_0=s_0/e_0$, $E_t=s_t/e_t$ (if we suppose that $\sinh(s/s_0) \sim s/s_0$, $\sinh(s/s_t) \sim s/s_t$).

MATERIALS AND METHODS

PC is produced by a comparatively simple technology by mixing of thermoset oligomer (resin) and mineral (rock) fillers: microfillers with sizes up to 60um and aggregate with a size in the range of 0.15-20mm. The oligomer and the microfiller form the matrix of the composite material.

In the process of curing, which is usually realized at normal temperature and pressure by means of chemical substances, the oligomer is transformed into a highly cross-linked polymer. The surface of the filler and the aggregate exerts its influences on the processes of hardening and formation of cross-linked polymer and the composite and their properties as well. The quantity, size, form and spatial distribution of the mineral filler and its elastic properties also have an effect on the hardening and structure formation of the composite. This affords the opportunity to model PC properties in a desirable direction.

The present investigations have been carried out on PC, containing diabase or marble flour as a microfiller and diabase-quartz filler aggregates with a discontinues grading. Polyester polymer concrete has been obtained on the ,basis of oligoestermaleinates and the epoxy polymer concrete on the basis of dian epoxy oligomers. In order to stabilize the structure and properties of PC in the process of investigation the hardened material was thermally treated at $T=T_g+10^oC$ (T_g is the glass transition temperature).

The PC structure as a composite of 3th type (with continuous porosity) is shown on Fig. 1-a,b,c [8].

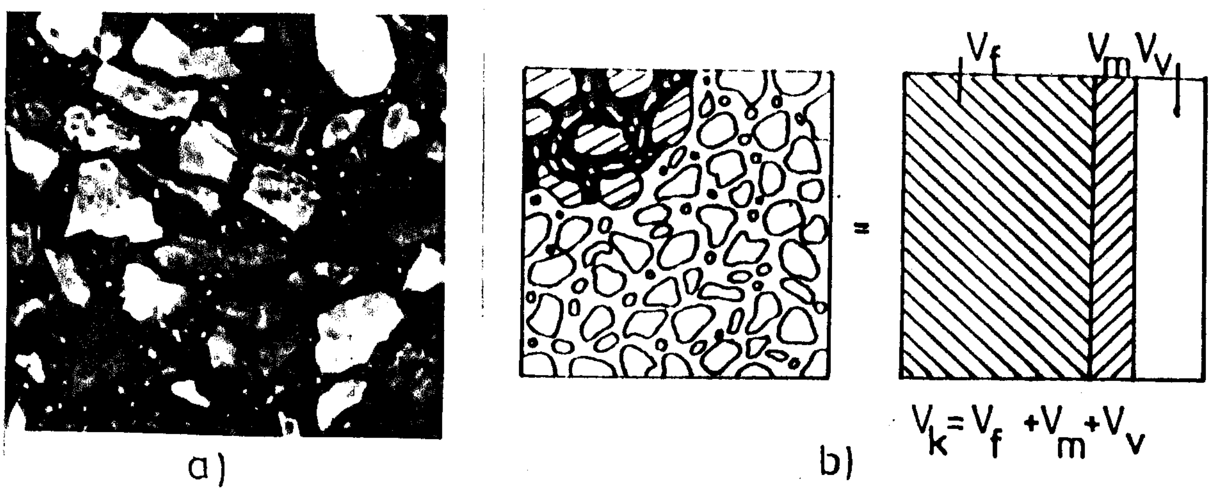

Figure 1. Real structure of polymer concrete (a) and its schematic pattern according to general theory of composites [8] (b)

The creep and stress relaxation experiments were performed under compressive loading in the linear range of deformation. The influence of temperature has been investigated under isothermal conditions at $T=20^o$-60^oC, which are in the range of the glass-form stage of the highly cross-linked polymer and correspond to the working conditions of the constructional PC. The influence of the liquid surrounding medium (water) has been investigated at a constant quantity of the absorbed liquid (constant water content w) in the volume of PC during the creep and stress relaxation experiments. The samples were preliminary water-soaked, their surface being sealed in order to achieve a near constant water content.

The obtained experimental results have been computed on PDP-11/44 using special programme.

RESULTS AND DISCUSSION

Findley's model application for PC

The analysis of the obtained test results showed that Findley's theory is applicable for the description and forecast of creep and stress relaxation of PC when the stress and strain values fall within the linear range.

This has been illustrated on Fig.2 and 3, where the curves obtained according equations (2) and (3) are compared with control experimental results. It is obvious that in both cases the coincidence is quite satisfactory.

It was discovered that the forecast of creep using Findley's theory is possible from one-day experiment data only while for the forecast of stress relaxation are 25-days experimental data necessary.

It was established that Findley's model is applicable for PC in certain limits. It is suitable for creep description and/or forecast up to the moment when the creep process has stabilized, i.e. for the description of the so called steady or indifferent creep.

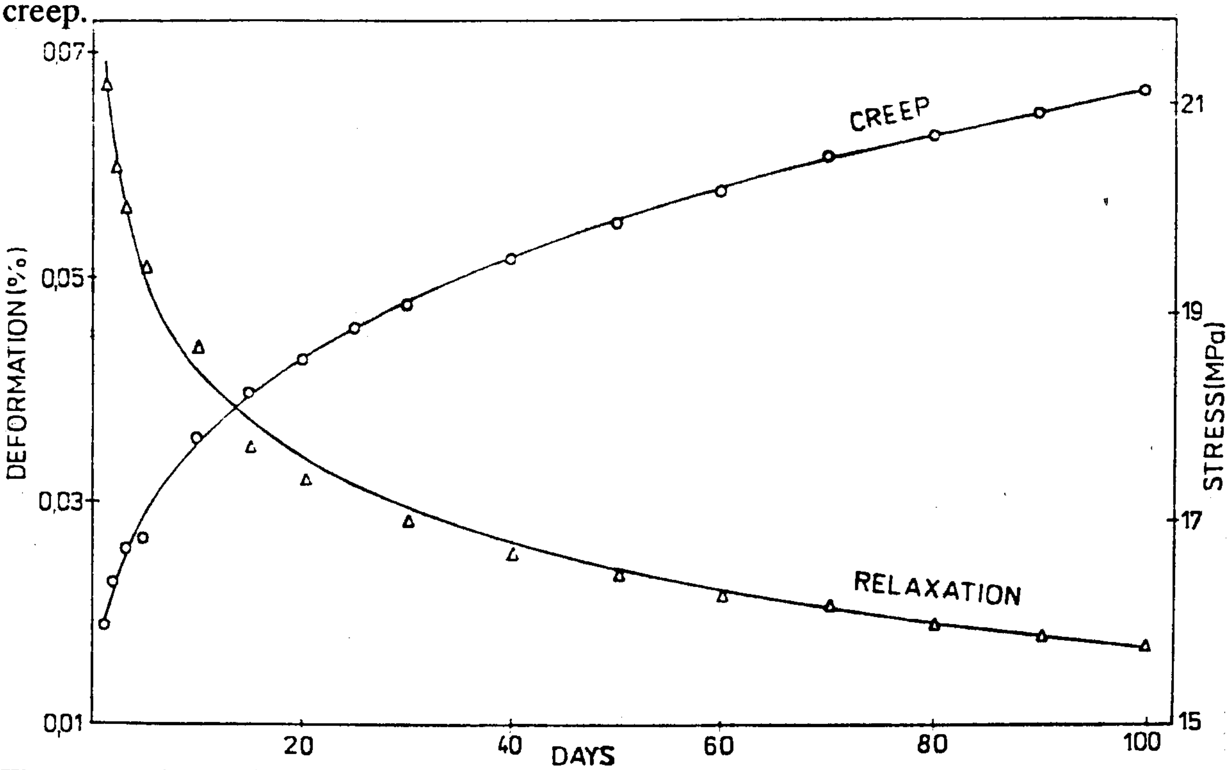

Figure 2. Theoretical curves according to the Findley's model and experimental values (o,)

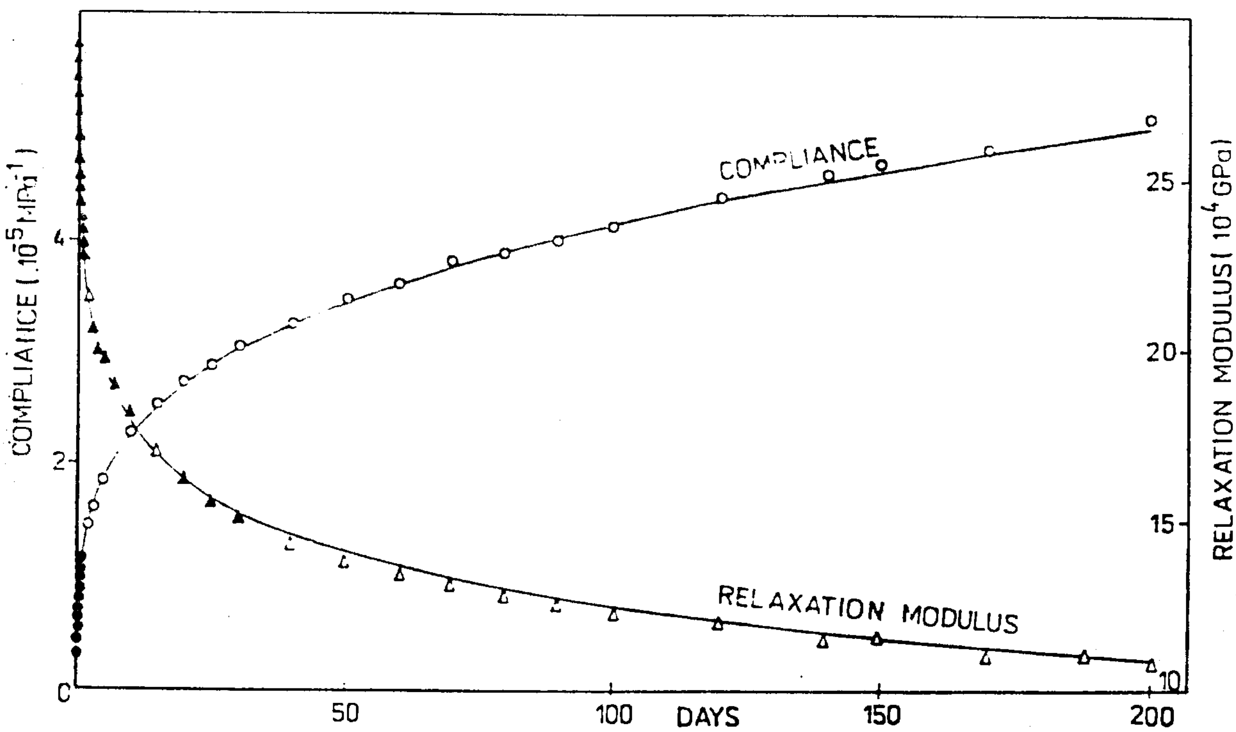

Figure 3. Forecasting curves after short-time investigation according to the Findley's model and experimental values {(o,) - short-time experiments, (o,) - long-time check experiments }

The period of time necessary for the rate of creep to become zero depends on several factors: the type and brand of polymer or its chemical content and composition and the presence of chemical additives for different purposes (plastifiers, solvents etc.). The magnitude and sign of the applied stress, the environmental conditions, etc. are also factors that exert substantial influence.

Our results showed that under laboratory conditions with ambient temperature $T=20^{o}\pm1^{o}C$ and relative humidity $w=60\%\pm5\%$ at equal degrees of compressive loading polyester PC exhibits a low rate of creep after a considerably long period of time compared with epoxy PC. Fig.4 displays that for polyester PC, loaded with a constant stress which is only 10% of the compressive strength, this period is 1950 days (5.34 years).

When the deformation process of PC has a stabilised character the creep curves obtained after Findley's model are situated above the experimental ones (Fig.4). Consequently, for the longer periods when creep begins to be stabilised, the creep values accordingly to Findley's theory are higher than the real ones, which is for the benefit of security. On the other hand the difference between the real (measured) and the theoretical (predicted) values is negligible and it becomes clear that if the predicted long-term characteristics are used for the design, the cost of the constructions elements will increase insignificantly.

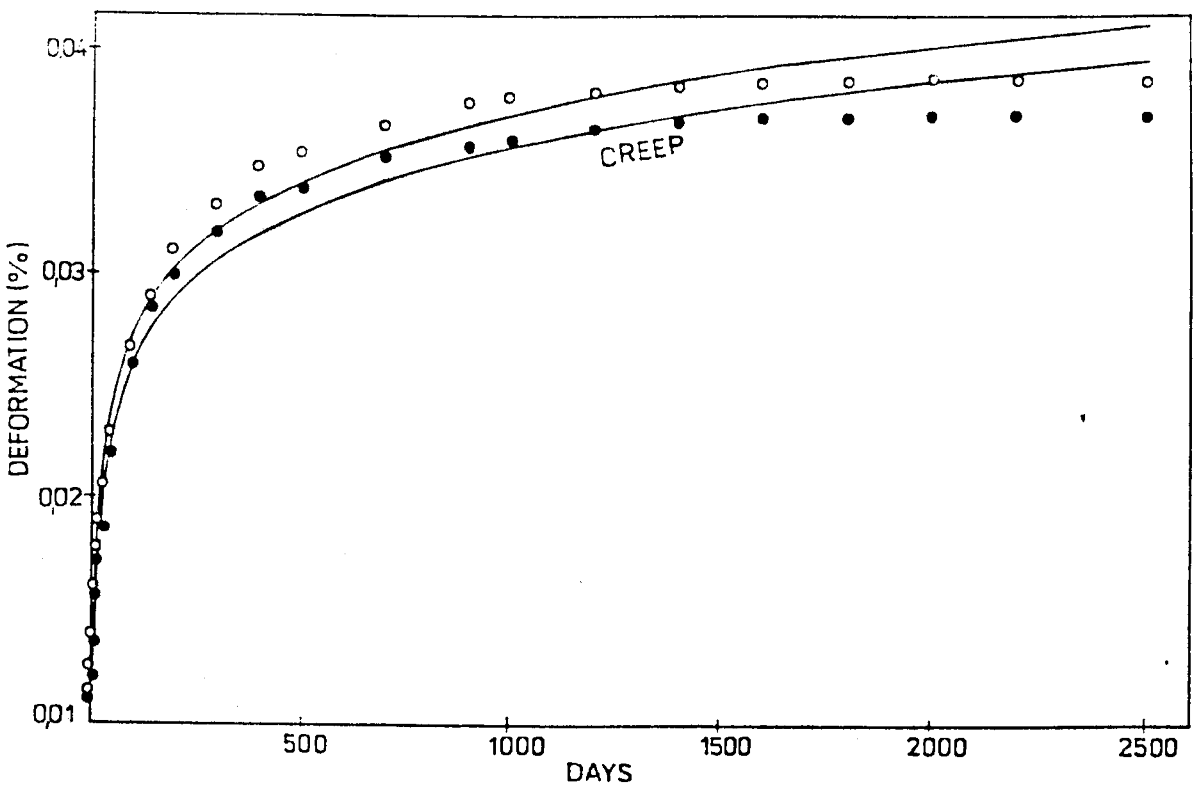

Figure 4. Theoretical curves according to the Findley's theory for polyester PC with stabilized creep and experimental values

The investigations have proved also that Findley's model is applicable for creep and stress relaxation descriptions in the cases when PC is subjected to isothermal conditions ($T<T_g$) and when liquid from the surrounding medium has penetrated into its volume as a consequence of an adsorption-diffusion processes. The results showed that even in this case the theoretical curves describe accurately enough PC behaviour in the periods when the material exhibits indifferent creep [9]. Conclusions, analytical to those under room conditions, are operative also for extreme environment.

Influence of some factors on parameter values in Findley's model

It is interesting to point out that a monotonic alteration of the values of the parameters in the transformed Findley interrelations was established as a function of some factors.

It was established for instance that the parameters vary in conformity with the quantity v_m of the matrix in PC. This has been demonstrated on Fig.5, where the parameters for the relaxation modulus are presented as a function of the volumetric content of the matrix v_m.

Similar relationships were established also between the parameters and the temperature T (Fig.6) and the water content in PC volume (Fig.7). It was found that it is possible to approximate the obtained graphical relationship for the influence of thefactors v_m, T and w on the parameters in Findley's model with this analytical expressions:

$$1/E_0 = a_1 \cdot x^2 + b_1 \cdot x + c_1 \qquad (4)$$

$$1/E_t = a_2 \cdot x^2 + b_2 \cdot x + c_2 \qquad (5)$$

$$n = a_3 \cdot x^2 + b_3 \cdot x + c_3 \qquad (6)$$

where a_i, b_i, c_i are coefficients, x corresponding factors v_m, T, w .The values of coefficients a_i, b_i, c_i found from the relationships of the Figures 5 to 7 are given in Table 1.

TABLE 1.
The values of coefficients in equations (4)-(6) for different factors

factors :	V_m	T	w
a_1	$8,30.10^{-2}$	$3,44.10^{-5}$	$1,71.10^{-2}$
b_1	$-2,54.10^{-2}$	$-1,25.10^{-3}$	$1,02.10^{-2}$
c_1	$2,04.10^{-5}$	$3,31.10^{-2}$	$2,12.10^{-2}$
a_2	$1,28.10^{-2}$	$2,39.10^{-6}$	$-1,60.10^{-6}$
b_2	$1,35.10^{-4}$	$-3,28.10^{-4}$	$-3,51.10^{-3}$
c_2	$5,39.10^{-3}$	$1,11.10^{-2}$	$5,45.10^{-3}$
a_3	$2,20.10^{-2}$	$4,57.10^{-4}$	$8,45.10^{-2}$
b_3	$9,80.10^{-2}$	$-2,26.10^{-2}$	$8,75.10^{-2}$
c_3	$7,06.10^{-2}$	$3,98.10^{-1}$	$1,08.10^{-1}$

This results provide reliable prediction of these parametric values.

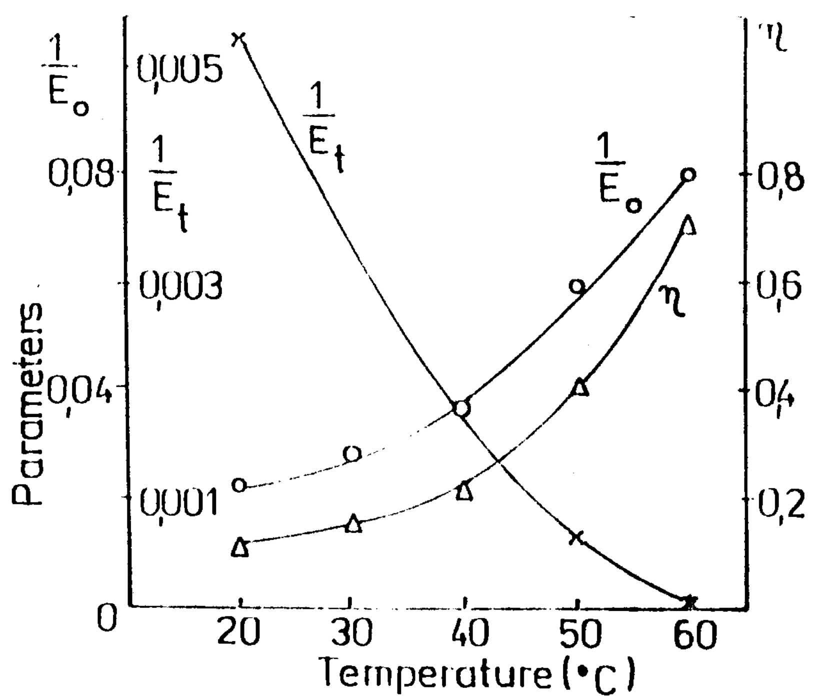

Figure 5. Relationship of the parameters in the Findley's model on volumetric quantity of matrix in PC

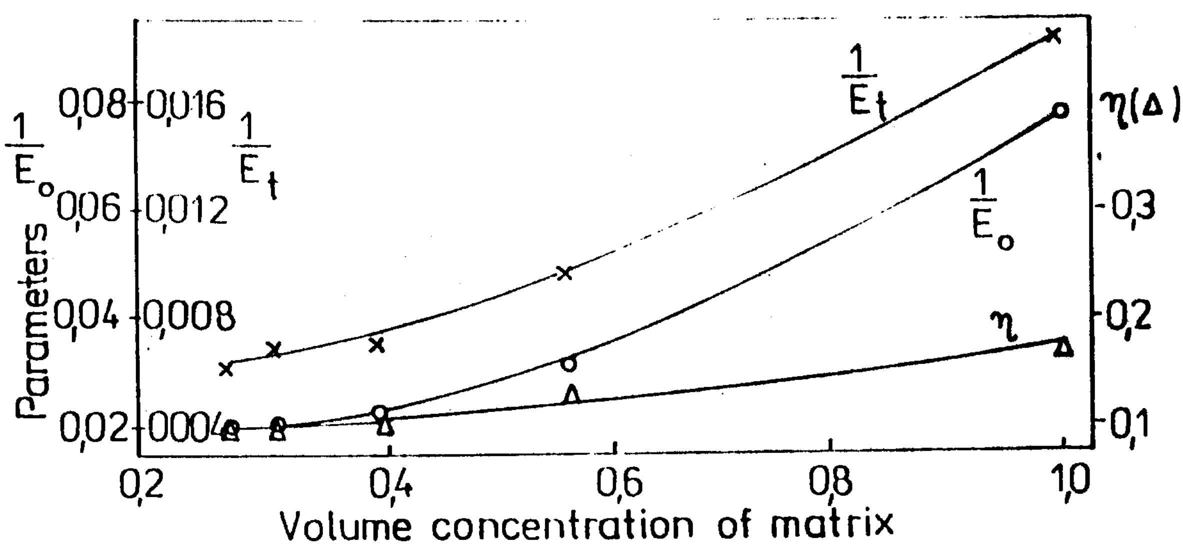

Figure 6. The relationship of the parameters in the Findley's model on surrounding temperature for polyester PC

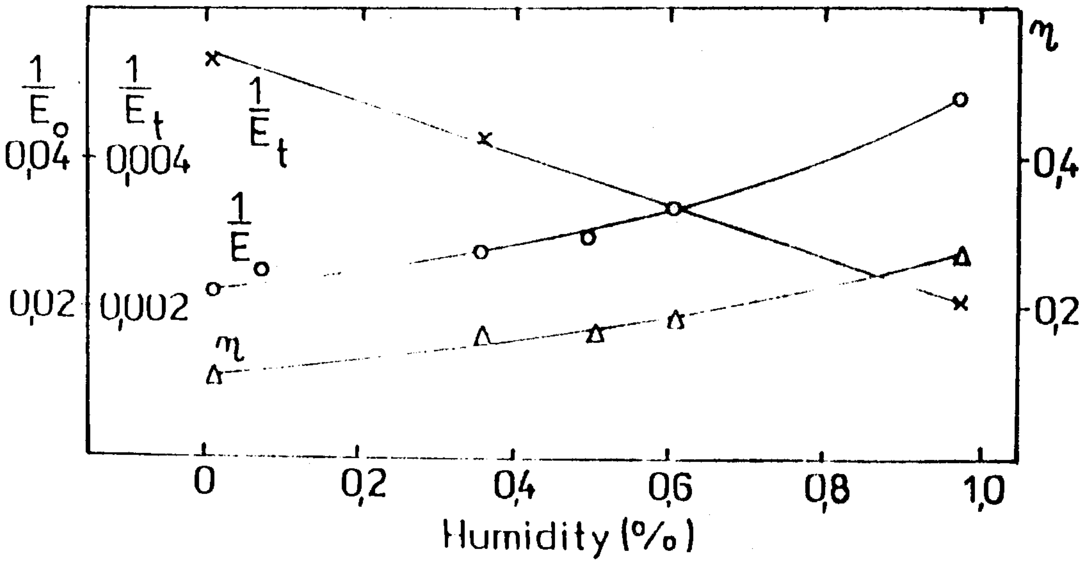

Figure 7. The relationship of the parameters in the Findley's volumetric water solution of PC

CONCLUSION

Findley's model is applicable for the description and the forecast of creep and stress relaxation of PC up to the moment when the processes has been stabilized, i.e. for the description of the steady or indifferent processes.

Findley's model is applicable also in the cases when PC is subjected to isothermal or humidity condition.

It was established that the parameters of the Findle y equation vary in conformity with the quantity v_m of the matrix in PC, the temperature τ and the water content w in PC volume.

REFERENCE

1. Bozhinov, G., Hristova, J. and Popova, M., Analytical Description of Creep Behaviour of Polyester Concrete. In Proc. Sec. Cont. Mech. Behaviour of Materials, Boston, 1976, pp. 408-417

2. Ayyar, R.S. and Deshpande S.N., Creep Studies on Polymer Mortars, In Proc. Third Int. Congress on Polymers in Concrete, Koriyama, 1981, pp.50-523

3. Hristova, J., On the Prognostication of the Rheological Properties of Polymer Composites by Means of the Analogy Method, In Proc. IX Int. Congress on Rheology, vol.3, Pergamon Press, 1984, pp. 409-416

4. Hristova, J. and Bareš,R.A., Forecasting of Polymer Concrete Thermo-Moisture Creep, In Science and Engineering of Composite Materials, 1989, No2, pp.69-74

5. Armeniades, C. and Dharmajan, N., A Constitutive Equation for Creep in Polymer Concrete, In Proc. 5th Int. Congress on Polymers in Concrete, Brighton, 1987, pp. 193-198

6. Findley, W.N., SPE Journal, 1960, 16, No1,2

7. Findley, W.N., Tracy, J.F., Polymer Engineering and Science, 1974, 14, No8

8. Bareš, R.A., General Theory of Composite Materials, In Proc. Int. Symposium on Composite Materials and Structures, Beijing, 1986, pp.1073-1082

9. Hristova, J. and Bareš, R.A., Relation between Creep and Performance of PC, In Proc. 5th Int. Congress on Polymers in Concrete, Brighton, 1987, pp.99-102