

Creep of Polyester Resin Filled with Minerals

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ABSTRACT: An attempt of application of a structural approach in evaluation of viscoelastic properties of two polyester based concretes and their matrices—polymer resin filled with minerals at various filler volume content—was undertaken. It was found that the approach can be used in evaluation of the creep compliance curves of the composites under compression either in conditionally initial state or after aging. The results of calculation by Kerner's model and the generalized Christensen's model are in close agreement. They gave good description of the experiment. The higher calculated values of the elastic moduli of the composites than the experimental values were obtained. A better description is obtained using Kerner's model of composite consisting of the resin (matrix) and filler (small- and large-dimensional particles). The application of the structural approach for description of elastic and viscoelastic properties of the composites made it possible to evaluate interphase properties and content and porosity of the composites and their changes during creep. © 2000 John Wiley & Sons, Inc. *J Appl Polym Sci* 77: 45–52, 2000

Key words: polymer concrete; creep; structural approach; interphase

INTRODUCTION

A polymer concrete (PC) material based on thermoset resin (polyester, epoxy, phenol, etc.) with mineral flour (diabase, marble, quartz, etc.) or cement, filled with diabase, granite, marble, or other rock grains (aggregates)¹ has a special place in class of filled composites. Its high mechanical parameters, corrosion and abrasion resistance, dielectric properties, high damping capacity, etc., allow finding the scope of reasonable applications of PC in replacement of metals and other conventional materials in construction, machine building, electrical engineering, chemical industry, metallurgy, ore mining, etc., in cases when they are not sufficiently effective.

PC is composite in composite, and its simulation should be based on consideration of two structural levels. The small size of filler particles (to 60–80 μm) is a peculiarity of the first level. At low filler concentrations the particles serve as centers of generation of the polymer structure. For example, the oriented and more stressed polymer structure was found² around the quartz particles embedded in the polyester resin at a filler volume content of about 10%. Such interphase has a size larger than the filler grain, and attains 50–80 μm . As the size of filler particle increases, the size of the interphase decreases. As the filler concentration in composite increases the interaction between the particles increases and influences the interphase formation. Due to increased heterogeneity of composites at high filler concentrations, the formation of the pores in the structure also takes place. A peculiarity of the second structural level in PC is the high content of the large dimensional filler particles. The polymer

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binder in PC is distributed in thin strata, and its structure differs from the structure of the polymer binder in a bulk.

The mechanical properties of PC depend on the properties of resin and filler, filler concentration, dispersion of filler particles, and state of resin-filler interface. To construct the PC with a combination of useful mechanical properties an investigation of the structure should be performed. The structural method of attack in the assessment of mechanical properties of filled polymers is dictated by the necessity of evaluation of the composite properties on the properties of structural components and their contents; indirect estimation of the properties of one composite component on the properties of the composite and another (others) component(s); and simulation of composite structure (properties and extension of interphase, fillers aggregates, and others). As of now, an applicability of a structural approach for evaluation of composite deformational characteristics, in particular characteristics of elasticity, is better understood than of the strength characteristics. Studies on applicability of the structural approach for evaluation of composite viscoelastic properties, are still few in number, whereas the investigation of viscoelastic properties of a composite using the structural approach has been a problem of main interest. The solution of this problem should enable evaluation of the long-term deformability of a composite, accounting for the changes of the properties of the components, so as to attack the problem of durability prediction.

No previous investigation on the use of a structural approach in evaluation of the viscoelastic properties of PC has been made. Here, we attempt to evaluate the viscoelastic properties of PC from the properties of its structural components.

MATERIALS AND TESTS

We examined two PCs based on low-molecular polyester oligomer (polyester resin Vinalkid 550 P) filled with diabase flour (matrix R+DF) and marble flour (matrix R+MF) (flour volume concentration was $28.0 \pm 0.8\%$, size distribution of the flour particles was 1–60 μm). The large dimensional inclusions (aggregates to 10 mm) were of the same nature: diabase in the first case (PC-3) and marble in the second case (PC-5). The resin volume content was $22.3 \pm 0.8\%$ in PC-3

and $26.0 \pm 0.8\%$ in PC-5. Also, hardened polyester resin in block has been investigated.

The materials were cured at room temperature by means of cyclohexanonehydroperoxide and cobalt naphthenate. After hardening the samples were subjected to heat treatment (6 h at temperature 60°C). Creep deformation in compression in linear viscoelastic region was measured on two opposite sides of the prismatic specimen ($4 \times 4 \times 12$ cm) using mechanical recorders of 1 μm accuracy on the 30-mm base. Creep tests were conducted at room temperature ($20 \pm 1^\circ\text{C}$). The test method has been described in ref. 3.

Two structural levels in PC were examined: (1) matrix R+DF or R+MR; (2) polymer concrete PC-3 or PC-5.

Hardened polyester resin in a block, R+DF matrix and PC-3 were studied in conditionally initial (as-received) state and after long-term (12–13 years) aging at room conditions (temperature $20 \pm 1^\circ\text{C}$ and humidity $60 \pm 5\%$).

THEORY

The effect of filler concentration on the mechanical properties of composites was widely studied and mathematical models have been elaborated. A group of models, which considers a spherical inclusion with the matrix layer around it in a media with unknown effective characteristics, is well known. Seen from the particle, there are effectively three phases: the particle; its "own" concentric matrix material (the continuous phase); and the remaining material. This remaining material is assumed to be homogeneous and to have the properties of the "average" composite. The radius of the shell of the matrix material (b) is thus found under the condition that the concentration (c) of the inclusions satisfied the relation

$$\left(\frac{a}{b}\right)^3 = c,$$

where a is the radius of the spherical inclusion. The effective bulk K and shear G moduli are calculated from the continuity conditions at the interfaces, assuming that bulk and shear moduli of the inclusions and the matrix are known. In such a way the simple formulas for composite with low filler concentration are derived from ref. 4:

$$K = K_m + c \frac{K_f - K_m}{1 + (1 - c) \frac{K_f - K_m}{K_m + \frac{4}{3} G_m}}, \quad (1)$$

$$G = G_m + c \frac{G_f - G_m}{1 + (1 - c)(G_f - G_m) \frac{6(K_m + 2G_m)}{5G_m(3K_m + 4G_m)}}, \quad (2)$$

where K_m , G_m , and ν_m , K_f , G_f , and ν_f are the bulk, shear moduli, and the Poisson's ratio of the matrix and filler, correspondingly.

In Christensen's theory,⁵ the concentric spheres, with the particles in their centers, are assumed to fill the whole space. Christensen's theory was extended in ref. 6 to more than one type of spherical inclusion bearing an index j . The total concentration of inclusions is

$$\sum_j c_j = c$$

The bulk modulus of the composite is expressed by following:

$$\frac{K_m}{K} = 1 + (1 + r) \sum_j c_j \frac{K_m - K_j}{r(1 - c)K_m + (1 + rc)K_j}, \quad (3)$$

where

$$r = \frac{4G_m}{3K_m} = \frac{2(1 - 2\nu_m)}{1 + \nu_m},$$

K_j ($j = 1, 2, \dots, N$) is the bulk modulus of j th filler.

Note that K depends on the shear modulus of the matrix (through r), but not on the shear moduli G_j ($j = 1, 2, \dots, N$) of the inclusions. If only one type of inclusion is considered, eq. (3) reduces to eq. (1). Shear modulus of the composite is determined from the following relation

$$\sum_j c_j \frac{(q_c + g + p_j) \left(q_c - h - \frac{q_j}{c} \right) + 6f^2}{(q_c + g + p_j) \left[\frac{8 - 10\nu}{3} + (1 - \nu) \left(h + \frac{q_j}{c} \right) \right] - 6f[f(1 - \nu) - 1]} = 0, \quad (4)$$

where is the Poisson ratio of composite.

Here, the following designations are used:

$$\begin{aligned} q_j &= \frac{5G_m}{G_j - G_m}; & q_c &= \frac{5G_m}{G - G_m}; \\ p_j &= \frac{4c^{7/3}(7 - 10\nu_j)q_j}{7 + 5\nu_j + 7(1 - \nu_j)q_j}; & f &= \frac{1 - c^{2/3}}{1 - \nu_m}; \\ g &= \frac{4 \left(1 - \frac{10\nu_m}{7} \right) (1 - c^{7/3})}{1 - \nu_m}; \\ h &= \frac{(8 - 10\nu_m) \left(\frac{1}{c} - 1 \right)}{3(1 - \nu_m)} \end{aligned}$$

Composite compliance in compression (tension) is

$$I = \frac{1}{3G} + \frac{1}{9K}.$$

It is to be stressed that the above-mentioned theories are linear, i.e., they hold only for small applied pressures or small applied shear forces. Hence, by applying shear, the spherical shape of inclusions should not be distorted. Although, in theory, a specific geometry of inclusion is used, the formulas are elegant and handy to use when comparison with experiments is made.

An extension of the above-mentioned models may be one with an additional concentric sphere of radius a_i , $a \leq a_i < b$. The layer within the inner a and outer a_i radii simulates an interphase. Its stiffness can be chosen to be proportional to the corresponding one of the matrix,⁷ $K_i = \beta K_m$ and $G_i = \beta G_m$. The approach was applied for simulation of filler-matrix adhesion interaction. Note that in such a case the equality of Poisson's ratio of interphase and matrix was proposed. More significant is a problem on the evaluation of changes of interphase properties and extension using known properties of composites with different filler concentrations, and of the matrix and of the filler. Such problems in elastic region were solved for marble/epoxy⁸ and cement/polyester⁹ systems. It was supposed that the interphase characteristics of elasticity are the same for all the filler concentrations, but extent of the interphase changes with changes of filler concentration. The simulation showed that the interphase stiffness can be higher (for epoxy resin filled with marble flour) or lower (for polyester resin filled with cement) than the stiffness of the matrix. The interphase thickness for both composites under consid-

eration decreases as the filler volume content and interphase surface area increase. The results of evaluation of the interphase extent in epoxy resin filled with marble flour qualitatively correspond to the results of the experiments on viscosimetry.

All the above eqs. (1)–(4) can be extended to viscoelastic systems by considering all K s and G s or the corresponding compliances as time-dependent functions. By going to compliances, eqs. (1)–(2) can be rewritten as the following:

$$\frac{1}{\bar{K}} = \frac{1}{K_m} \cdot \frac{\frac{K_f}{K_m}(1 + \nu_m)(1 - c) + 2(1 - 2\nu_m) + c(1 + \nu_m)}{\frac{K_f}{K_m}(1 + \nu_m + 2c(1 - 2\nu_m)) + (1 - c)(1 - 2\nu_m)}, \quad (5)$$

$$\frac{1}{\bar{G}} = \frac{1}{G_m} \cdot \frac{\frac{G_f}{G_m} 2(4 - 5\nu_m)(1 - c) + 7 - 5\nu_m + 2(4 - 5\nu_m)c}{\frac{G_f}{G_m}(c(7 - 5\nu_m) + 2(4 - 5\nu_m)) + (1 - c)(7 - 5\nu_m)}. \quad (6)$$

If only one type of inclusion is considered, eq. (3) reduces to eq. (5), but eq. (4) reduces to the following one:

$$\frac{1}{\bar{G}} = \frac{1}{G_m} \cdot \frac{1}{1 - \frac{5}{2} \cdot \frac{B \pm \sqrt{B^2 - 4AC}}{2A}}, \quad (7)$$

where

$$A = 6f^2 p^* q^* - (gp^* + 1) \left(\frac{1}{c} + hq^* \right),$$

$$B = (g - h)p^* q^* + q^* - \frac{p^*}{c}, \quad C = p^* q^*, \quad (7a)$$

with f , g , and h are as defined above [see eq. (4)], and

$$q^* = \frac{1}{5} \left(\frac{G_f}{G_m} - 1 \right); \quad p^* = \frac{1}{p_j}. \quad (7b)$$

If the stiffness of filler is much greater than of matrix

$$\frac{K_m}{K_f} \ll 1, \quad \frac{G_m}{G_f} \ll 1,$$

eqs. (5)–(7) are simplified

$$\frac{1}{\bar{K}} = \frac{1}{K_m} \cdot \frac{(1 - c)(1 + \nu_m)}{1 + \nu_m + 2(1 - 2\nu_m)}, \quad (8)$$

$$\frac{1}{\bar{G}} = \frac{1}{G_m} \cdot \frac{2(1 - c)(4 - 5\nu_m)}{2(4 - 5\nu_m) + c(7 - 5\nu_m)}, \quad (9)$$

$$\frac{1}{\bar{G}} = \frac{1}{G_m} \cdot \frac{1}{1 + \frac{0.5(h - g)}{\pm \sqrt{0.25(h - g)^2 + gh - 6f^2}}}. \quad (10)$$

To calculate the viscoelastic compliance of the composite, the principle of correspondence between elastic and viscoelastic problems can be used. The simplest method of inversion of the Laplace transform is a so-called direct method:¹⁰

$$I(t) \approx p \cdot I(p)|_{p=1/2t}, \quad (11)$$

where $I(p)$ is a function image in Laplace transformation space, $I(t)$ is a function original.

In calculation of elastic and viscoelastic characteristics of the composites we assumed the following: (a) for a diabase filler $E_f = 88$ GPa, $\nu_f = 0.26$;⁹ (b) for a polyester resin in a conditionally initial (as-received) state $E_m = 5.6 \pm 0.2$ GPa, $\nu_m = 0.38 \pm 0.002$, and after aging, $E_m = 6.8 \pm 0.2$ GPa, $\nu_m = 0.38 \pm 0.002$ (experimental data); (c) the stiffness of the marble is much higher than of the polyester resin and the R+MF matrix; (d) Poisson's ratio of the matrix (resin, R+DF and R+MF matrices) during creep is constant—it is defined by the moduli

$$\nu_m = \frac{3K_m - 2G_m}{2(3K_m + G_m)}.$$

RESULTS AND DISCUSSION

Elastic Moduli

The characteristics of elasticity of the composites calculated by the scheme resin \rightarrow matrix \rightarrow PC and the experimental data are shown in Table I.

Table I The Characteristics of Elasticity of the Composites: Calculated^a (Numerator) and Experimental (Denominator) Values

Composite	Filler Volume Content, c	Elastic Modulus, E , GPa	Poisson's Ratio, ν
R + DF	0.280 ± 0.08	9.5 (9.2) 11.0 \pm 1.0	0.35 (0.36) 0.32
R + DF, after aging	0.280 ± 0.08	11.6 (11.3) 12.2 \pm 0.5	0.35 (0.34) 0.31
R + MF	0.280 ± 0.08	10.4 (9.9) 9.8 \pm 1.2	0.35 (0.36) 0.27
PC-3	0.697 ± 0.08	35.9 (33.7) 27.5	0.26 (0.30) 0.24
PC-3, after aging	0.697 ± 0.08	40.4 (39.7) 35	0.24 (0.27) 0.22
PC-5	0.632 ± 0.08	57.5 (45.2) 30	0.26 (0.31) 0.26

^a Calculated with generalized Christensen's [eqs. (3)–(4)] and Kerner's [eqs. (1)–(2)] (in parenthesis) models.

A good correspondence between the calculated and experimental data was obtained for the matrices, and especially for the R+MF. Despite lower stiffness of the diabase than of the marble, the experimental value of the elastic modulus of the R+DF matrix is higher than that of the R+MF. This effect may be caused by active interaction on the polyester/diabase interface, which was not accounted for in the calculation. The discrepancy between the results of calculation and experiment is high in the case of polymer concretes, and especially in the case of PC-5. The use of Kerner's model [eqs. (1) and (2)] for PC-3 and PC-5 gave the values of error of 22.5 and 50.6%, correspondingly. The use of the generalized Christensen's model [eqs. (3) and (4)] gave a higher values of error.

We also attempted to calculate the elastic characteristics of composites PC-3 and PC-5 on the properties of the resin and filler (small- and large-dimensional particles) for total filler concentration $c = 0.778$ in case of PC-3 and $c = 0.741$ in case of PC-5. The results of calculation with eqs. (3) and (4) and eqs. (1) and (2) (values in parentheses) are the following: $E = 33.4$ (30.2) GPa, $\nu = 0.27$ (0.31)—for PC-3, and $E = 51.5$ (38.1) GPa, $\nu = 0.27$ (0.33)—for PC-5. Such an approach gave lower values of elastic modulus of the composites. They are nearer to the experimental data than the results of calculation by the scheme resin \rightarrow matrix \rightarrow PC (see Table I). The discrepancy between the calculated and experimental values of the elastic moduli of the composites may be caused by porosity whose effect was not accounted in the calculation.

Creep

An experimentally obtained long-term (200 days) creep compliance curve of hardened resin in a conditionally initial (as-received) state (Fig. 1) was approximated by the expression

$$I(t) - I_0 = \sum_{i=1}^n b_i (1 - \exp(-t/\tau_i)), \quad (12)$$

where the instantaneous compliance

$$I_0 = \frac{1}{E}.$$

The parameters τ_i , b_i ($i = 1 \dots n$)—retardation spectra (see Table II)—were determined by minimizing the objective function in form of root-

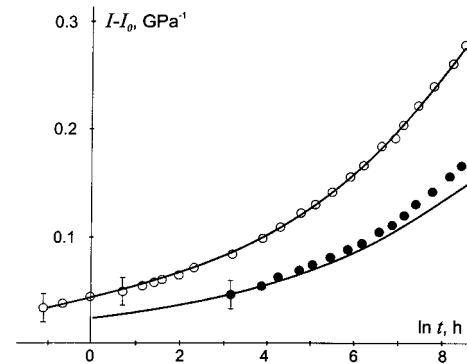


Figure 1 Creep compliance curves of hardened polyester resin in initial (as-received) state (○) and after long-term (13-year) aging (●); points—experiment, lines—approximation by eq. (12).

Table II The Retardation Spectra of the Materials

<i>i</i>	Resin		Matrix R + DF (R + MF)	
	τ_i, h	b_i, GPa^{-1}	τ_i, h	b_i, GPa^{-1}
1	0.994×10^{-2}	0.234×10^{-1}	0.198×10^{-1}	0.103×10^{-1}
2	0.619	0.190×10^{-1}	0.490	0.133×10^{-1}
3	0.957×10^1	0.352×10^{-1}	0.889×10^1	0.200×10^{-1}
4	0.142×10^3	0.614×10^{-1}	0.135×10^3	0.349×10^{-1}
5	0.230×10^4	0.158	0.229×10^4	0.910×10^{-1}
6	0.359×10^7	0.165×10^{-1}	0.135×10^7	0.103×10^{-1}

mean square (rms) deviation using the SIMPLEX algorithm.

The calculated creep compliance curves of the R+DF and R+MF matrices merge into one. The result of calculation for the matrix (R+DF or R+MF) using the generalized Christensen's model [eqs. (5) and (7)] differs very little from the result of calculation using the Kerner's model [eqs. (5) and (6)] (Fig. 2, dashed and solid lines, correspondingly). The calculated creep compliance curve of matrix lies higher than the experimental one for R+DF and lower than for R+MF. Mainly, the initial point— instantaneous compliance—distinguishes the experimental data for the R+DF and R+MF matrices. The creep rates are already the same for both the matrices. Accounting for the dispersion of experimental values of instantaneous compliance (elastic modulus), one may conclude that the calculated creep

compliance curve closely matched the experimental for the R+MF matrix.

Long-term (for 12–13 years) aging of the hardened resin, the R+DF matrix, and the polymer concrete PC-3 under laboratory conditions has resulted in a reduction of creep compliance (see Figs. 1–3). The creep compliance curves of the materials after aging shifted along the logarithmic time axis in the direction to shorter times relatively to the initial material,¹¹ which corresponds to an increase of retardation times

$$\tau_i \rightarrow \tau_i / a_{ag} \quad (i = 1, 2, \dots, n), \quad a_{ag} < 1$$

in eq. (12). For polyester resin after long-term (13 years) aging under laboratory conditions $\ln a_{ag} = -2.7$ (see Fig. 1). With allowance for the change in the retardation spectrum due to aging, the maximum error of approximation of experimental creep compliance curve of the resin after aging in the form of rms is 8%. Using the corrected retardation spectrum of the resin after aging, the creep compliance curve of the R+DF matrix after aging was calculated (see curves 2 and 2' in Fig. 2).

As well as in case of resin, the calculated creep compliance curve of the matrix (R+DF or R+MF) was approximated by eq. (12). The obtained retardation spectrum (see Table II) was used in the calculation of the creep compliance curves of PC-3 and PC-5 [Fig. 3(a) and (b)]. The results of the calculation using the Kerner's model [eqs. (5) and (6)] and the generalized Christensen's model [eqs. (5) and (7)] (solid and dashed lines, correspondingly) differ mainly by the initial point— instantaneous compliance. The experimental creep compliance curves of PCs lie between that calculated by the two above-mentioned structural models. Despite the relatively high error in description of the creep compliance curve of the R+DF and R+MF matrices (curves 1, 1' in Fig. 2), the maximum deviation of the calcula-

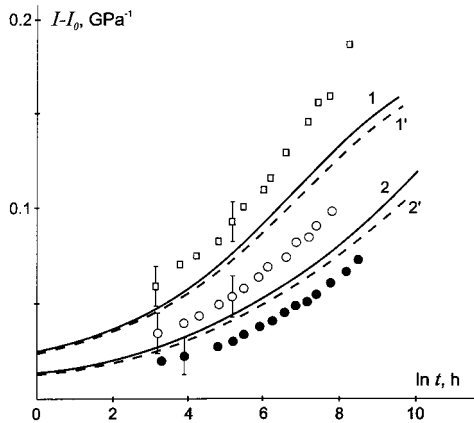


Figure 2 Creep compliance curves of matrices R+DF (○,●) and R+MF (□) in the conditionally initial (as-received) state (○,□) and after long-term (12-year) aging (●); experiment (points) and calculations on the properties of resin and filler by eqs. (5) and (6)—solid lines, and (5) and (7)—dashed lines.

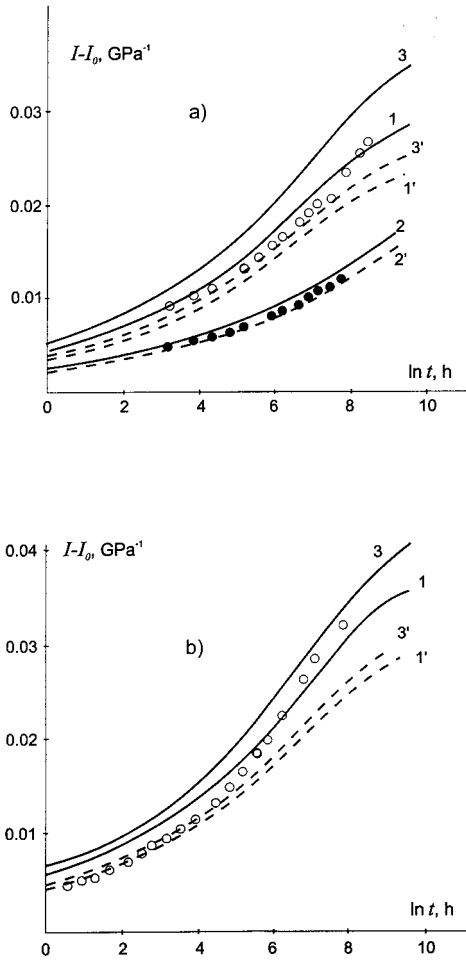


Figure 3 Creep compliance curves of PC-3 (a) and PC-5 (b) in initial (as received) state (○) and after long-term (13 years) ageing (●); experiment (points) and calculation by Eqs. (5), (6)—solid lines, and (5), (7)—dashed lines on the properties of matrix and filler (1, 1', 2, 2'), and resin and filler (3, 3').

tion from the experiment is no higher than 7% for PC-3 [see Fig. 3(a)] and 20% for PC-5 [see Fig. 3(b)], i.e., lies within the limits of experimental error. In the case of PC-3, the experimental and calculated creep compliance curves are parallel during almost all the time period of observation, so the creep rate in the experiment and calculation is the same. In the case of PC-5, the creep rate in the calculation begins to deviate from the experiment after $\ln t \geq 5$, $t \geq 148$ h. As the calculation was based on the long-term creep compliance curve of the hardened resin, the aging process of the polymer was implicitly accounted for. The calculation method was checked by the other composites: R+MF, R+DF, and PC-3 as received and after aging [see Figs. 2 and 3(a)]. Thus, the cause of the departure of the calculation from the experiment in the case of PC-5 may be due to some changes in the composite struc-

ture: interphase properties and content, porosity, etc.

Simulation of Changes in Structure of the Composites

An evaluation of interphase properties and content and porosity of the composites was carried out indirectly from known moduli of the composite, matrix and filler, and filler volume content using eq. (4). It was supposed that rigid filler particle of radius a , surrounded by interphase layer of thickness $a_i - a$, is embedded in the matrix (resin). The interphase volume content regarding to filler volume content is $V_i = (a_i/a)^3 - 1$. Another filler in the composite is a gas bubble (pore) with parameters $q_2 = -5$, $p_2 = 5c^{7/3}$, its volume content is c_2 .

The problem was solved with interphase elastic modulus E_i (or compliance I_i), Poisson's ratio ν_i and volume content V_i , and volume content of pores c_2 to be found by minimizing the objective function in the form of left part of eq. (4) using the SIMPLEX algorithm. The above-mentioned parameters of approximation, at an objective function value of about 10^{-9} , are shown in Table III.

For all the composites, the elastic modulus of the interphase is higher, while the Poisson's ratio is lower than that of the hardened resin. The largest interphase volume content has the R+DF matrix both in the conditionally initial state and after aging. The interphase volume content in the R+MF is 25 times smaller than in the R+DF. The value of V_i in PC-5 is smaller than in the corresponding matrix (R+MF). The interphase volume content in PC-3 after aging was increased about four times in regard to PC-3 in the conditionally initial state.

Most porous composites are PC-5, PC-3 in the conditionally initial state, and R+MF.

It was interesting to evaluate the changes in structure of the composites during their creep. The results [Fig. 4(a)–(f)] showed that the most stable structures are the R+DF in the conditionally initial state and PC-3 after aging. Their interphase volume content and volume content of pores are constant during all the time of observation. The decrease of the pore volume content from 2.9 to 2.4% was revealed in PC-3 in the conditionally initial state. The porosity of the R+DF after aging, the R+MF and PC-5 have a tendency to increase.

As for compliance of the interphase, it is constant during creep of all the composites excluding the R+DF, both in the conditionally initial state and after aging. The increase of the interphase compliance is not accompanied by any changes of the interphase Poisson's ratio.

Table III Approximated Values of Interphase Elastic Modulus E_i , Poisson's Ratio ν_i , and Volume Content V_i , and Porosity c_2 of the Composites

Composite	c_1	E_i , GPa	ν_i	V_i	c_2 , %
R + DF	0.280 ± 0.08	8.55	0.302	0.630	0.926
R + DF, after aging	0.280 ± 0.08	9.52	0.309	0.506	1.11
R + MF	0.280 ± 0.08	9.26	0.346	0.023	2.26
PC-3	0.778 ± 0.08	8.40	0.290	0.025	2.90
PC-3, after aging	0.778 ± 0.08	9.09	0.322	0.10	0.9
PC-5	0.741 ± 0.08	6.21	0.298	0.0062	4.42

CONCLUSIONS

Proceeding on the basis of the foregoing, we can state that:

1. The above-described structural approach can be used in the evaluation of the creep compliance curves of the composites under compression either in the conditionally initial

state or after aging. The results of the calculation by Kerner's model and the generalized Christensen's model are in close agreement. They gave good description of the experiment.

2. The higher calculated values of the elastic moduli of the composites than that of the experimental values were obtained. A better description is obtained using the Kerner's model of composite consisting of the resin (matrix) and filler (small- and large-dimensional particles).
3. An application of the structural approach for description of elastic and viscoelastic properties of the composites made possible evaluation of the interphase properties and content, and porosity of the composites and their changes during creep.

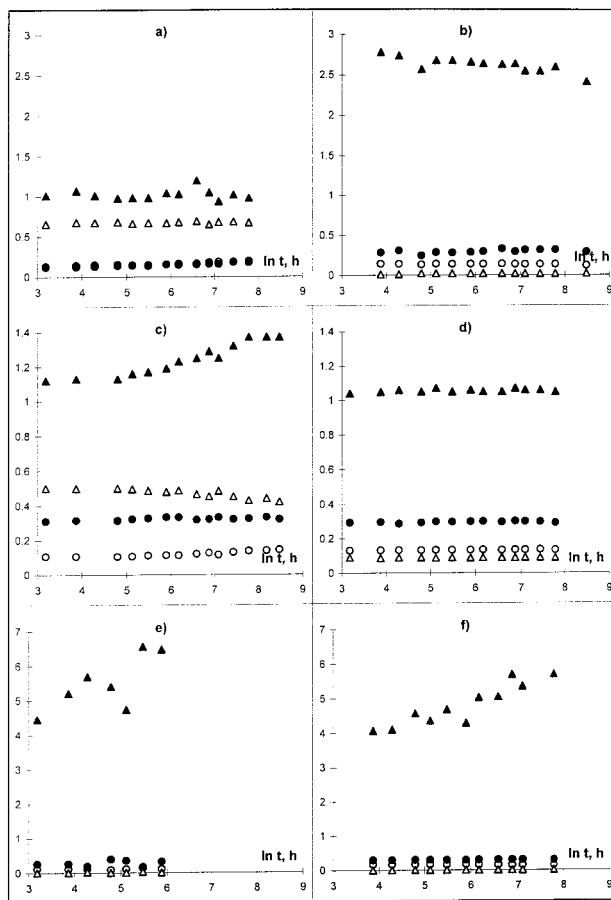


Figure 4 Calculated values of interphase compliance (○), Poisson's ratio (●), and volume content (△), and porosity (◆) of the composites: R+DF (a); PC-3 (b); R+DF after aging (c); PC-3 after aging (d); R+MF (e); and PC-5 (f).

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