ICPIC 87

THE PRODUCTION PERFORMANCE & POTENTIAL OF POLYMERS IN CONCRETE

Editor: Dr Barry W. Staynes

BRIGHTON POLYTECHNIC

5th International Congress on Polymers in Concrete, Brighton, England

Relation between Creep and Performance of PC

Ju. HRISTOVA
Bulgarian Academy of Sciences, Sofia
R.A. BARES
Czechoslovak Academy of Science, Prague

SUMMARY

Creep (increase of material deformations under constant stress and environmental conditions in the course of time) has particular significance for bearing PC structures. It influences the value of long-term strength, the possibility of utilization in different service conditions, etc. Creep of PC depends on many factores, mainly: parameters of compositions, load history, kind of environment.

The paper deals with the influence of some composition parameters (e.g. chemical character of resin, filler/binder ratio, maximal diameter of filler grains) on PC creep. It analyses the effect both of the relative value and of the sign of stress as well as of loading history on the behaviour of the material.

From the results it follows that it is possible to attain creep compliance of PC similar to that of CC, if the resin, filler/binder ratio and granulometric composition are correctly selected.

INTRODUCTION

The knowledge of creep parameters is of great importance for structural polymer concrete (PC). Creep characteristics must be taken into account in the design and analysis of PC elements, structures and equipment.

Creep is an intrinsic property of many natural and artificial materials and manifests itself by the growth of deformation in the course of time under constant value of external effects (mechanical load, temperature, humidity of the environment, etc.).

From the practical point of view not only the absolute magnitude of creep deformations ε_c attained in the course of time but also the character of the process are of interest. We distinguish between:

1) fading or stabilized creep, when for a time $t \rightarrow \infty$ the deformation $\varepsilon_c \rightarrow \varepsilon_{c(\infty)}$ (= const), the speed of deformation $\dot{\varepsilon}_c \rightarrow 0$ and the creep curve have an asymptotic form;
2) steady or indifferent creep, when in the course of time the speed deformation $\dot{\varepsilon}_c$ = const and the crrep curve is linear;
3) increasing or unstable crrep, when both the deformation ε_c and the speed of deformation $\dot{\varepsilon}_c$ rise progressively and the process ends in destruction.

To obtain sufficiently reliable and durable PC elements they must be so designed that fading creep takes place under working conditions. On this account it is necessary to know the creep limit - i.e. the maximum stress at which the process assumes a fading character; this is the long-term strength of PC.

Creep magnitude and character can be changed by the application of suitable continuous or dispersed reinforcement (metal, glass, etc.).

The polymer component and the composition are responsible for PC creep which but exhibits some peculiarities. They are determined by the macro-dispersed (conglomerate, concrete-like) structure of the composite; thence follows the difference from conventional plastics. Therefore, according to its deformation behaviour, PC has an intermediate position between ordinary cement concrete (CC) and plastics.

PC creep depends on a variety of factors which may be generally divided into composition parameters, load conditions and environmental conditions. In the past years special attention has been given to PC creep study, reflected in the research results of many scientists from different countries.

The authors of the present paper have made an attempt to summarize to a certain extent the data accumulated up to now, using for this purpose their own experiments as well as publications of their colleagues.

The parameter used as the criterion for the assessment of PC creep in test results analysis is the creep compliance (specific creep, a measure of creep).

The creep compliance $J = \varepsilon_c/\sigma_o$ (ε_c is the creep deformation, σ_o the constant stress) in fact is the creep caused by a unit of stress and in the authors' opinion it is a very suitable characteristic for results comparison and for ascertainment of relationships in creep processes.

DISCUSSION OF EXPERIMENTAL RESULTS

Influence of the composition parameters on PC creep

The composition parameters under consideration are: type and chemical nature of the polymer binder, the filler/binder ratio F/B (in weight) and the maximum grain size of the filler d_{max}.

Different synthetic resins are employed as binders in PC (oligomers, oligomer solutions in reactive monomers, monomers, etc.). The most wide-spread binders are the epoxy, unsaturated polyester and furan resins, as well as their modifications.

Fig. 1 shows the compliance curves for fine-grained PC, obtained on the basis of different resins. Fig. 2 presents the compliance curves for PC, containing coarser aggregate fractions.

The analysis of test results from the above-mentioned figures does not prove any dependence of creep on the type of resin.

However, it is evident that the fine-grained PCs (Fig. 1) have greater compliance J that those containing aggregates with grain sizes above 5 mm (Fig.2), the resin binder being the same in both cases. Most probably it is due to different granulometry and specific surface of the filler. Nevertheless, is has been also observed that PCs based on different brands of the given type of resin (e.g. unsaturated polyester) at a nearly equal F/B ratio exhibit various magnitudes and character of compliance (Fig. 1, lines 3 and 6, Fig. 2, lines 2 and 4). This can be explained by the different initial products used in the synthesis and

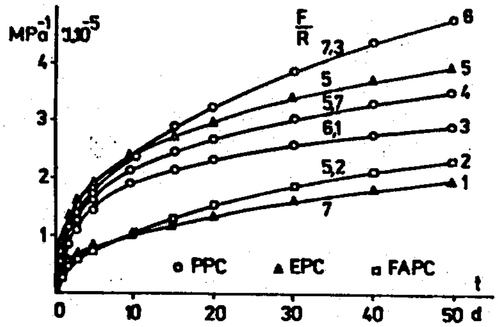

Fig. 1 Compliance curves of fine grained PC ($d_{max} < 5$ mm) under compressive load
Epoxy PC (EPC) - 1 [1], 5 [4] ;
Furan PC (FAPC) - 2 [2]
Polyester PC (PPC) - [Authors],4[3],6[5].

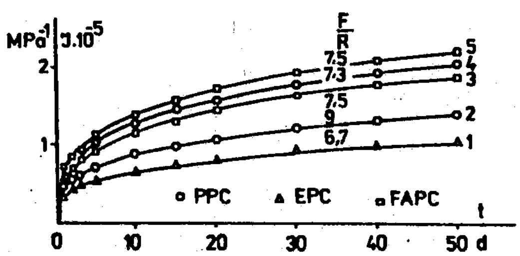

Fig. 2 Compliance curves of PC with coarse aggregates ($d_{max} > 5$ mm) under compressive load
EPC - 1 [6], PPC - 2 [3] , 4 [3]
FAPC - 3 [2], 5 [2]

but on the chemical nature of every particular brand of resin.

The curves on Fig. 3, showing the relation J = f (F/B), give an idea of the influence of the F/B ratio on the PC creep. This is pronouncedly noticeable at values of the ratio F/B < 5, beyond which the influence becomes negligible. It may be assumed that in the case of F/B ≥ 5 a second type macrodispersed structure [7] is formed in PC, which corresponds to the minimum display of creep phenomena. The location of this boundary on the F/B axis, nevertheless , depends, once again, on the general filler properties as well as on induced, moulding energy.

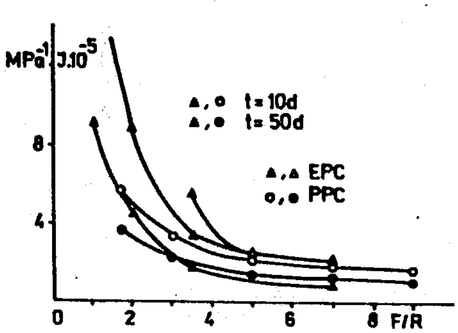

Fig. 3 Influence of the ration F/B (by mass) on the compliance of EPC 4 and PPC authors

Influence of load conditions on PC creep

The relative value of the permanent stress $\bar{\sigma} = \sigma_o / \sigma_R$ i.e. the ratio of the stress σ_o under the working load to the short-term strength of the material σ_R , is substatially important for the creep behaviour of PC. According to the magnitude of $\bar{\sigma}$ the values and shape of the compliance curves may differ considerably, i.e. under different stress one and the same PC manifests essentially diverse creep.

Test results analysis had proved that up to a certain limit of $\bar{\sigma}$ the compliance J and the other viscoelastic characteristics of PC (those dependant on time) are not influcences by the value of the applied constant stress. They are to a certain extent characteristic parameters of the material and therefore very suitable for the comparison of different PC creep behaviour.

The maximum $\bar{\sigma}$ at which the viscoelastic characteristics do not depend on the value of σ_o determines the limit of the linear range $\bar{\sigma}_l$ [8] . The values of $\bar{\sigma}_l$ for the particular PC are different and depend predominantly on the formed macrosidpersed structure.

Fig. 4 (a, b, c) presents the curves J (t) for three PC under compressive load in and out of the linear range. It is evident that the limit of the linear range of creep is different for the three kinds of material but it does not depend on the brand of the resin. For compressive stresses $\sigma_o / \sigma_R < \bar{\sigma}_l$ the values of the compliance J are located on one and the same curve (line 1), which characterizes creep of the linear range and is sufficient for creep description of viscoelasticity.

The limit of linear range for compressive loading generally does not coincide with that for tensile loading. For a number of PC, however, it has been experimentally established that the compliance curves J (t) obtained under compressive and tensile loads and falling into the linear range of creep for compression and tension respectively, are very close and may be assumed to be identical in a definite time interval. On the other hand, the curves J (t) for tensile stresses higher that the limit of linear range are entirely different in character

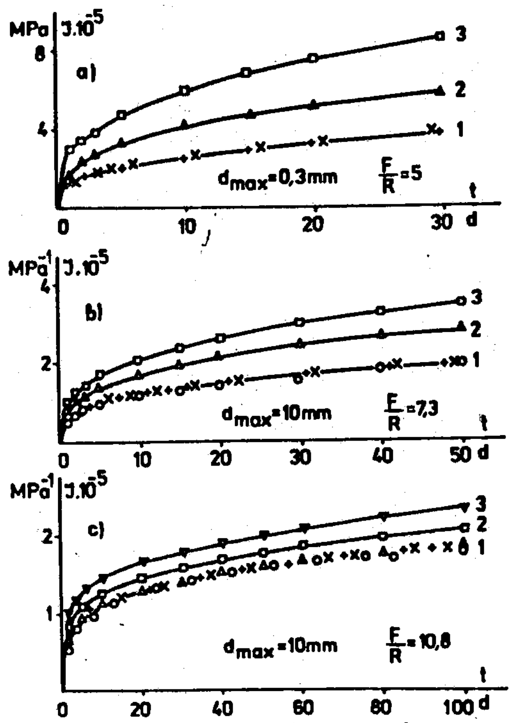

Fig. 4 Compliance curves J (t) of EPC [4] (a), FAPC [2] (b) and PPC [authors] (c) for compressive load at a level of constant stress $\bar{\sigma}$ = 0,1 (o);0,2 (+);0,3 (x);0,4 (Δ); 0,5 (□);0,6 (▼)

(Fig. 5, lines 2, 3, 4) from those for compressive stresses beyond the linear range (Fig. 4a, lines 2, 3). Under the action of tensile stresses $\sigma_0/\sigma_R < \bar{\sigma}_t$ PC exhibits steady creep and in many cases after a shorter or longer period of time the process ends in destruction (Fig. 5, lines 3, 4). This is one of the reasons which demands the reinforcement of PC structures subjected to tension or flexure. The magnitude of $\bar{\sigma}$ affects also the recovery of creep deformations (Fig. 6 [9]).

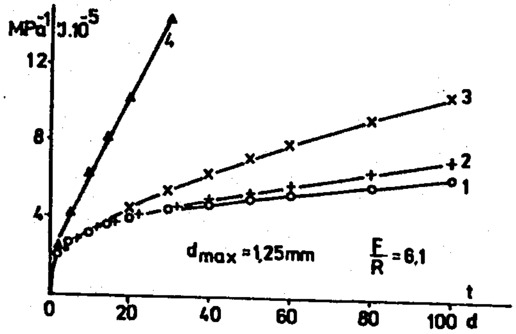

Fig. 5 Compliance curves J(t) for fine-grained PC under tensile load for a constant stress level $\bar{\sigma}$ = 0,1 (o);0,2 (+);0,3 (x), 0,4 (▲)

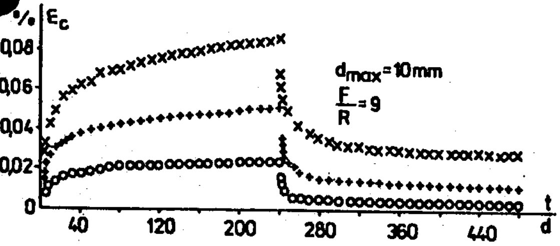

Fig. 6 Creep deformation curves ε_c (t) and recovery of deformations after unloading for constant compressive stress level $\bar{\sigma}$ = 0,1 (o);0,2 (+); 0,3 (x)

The load level at which PC exhibits fading creep is assumed to be the creep limit $\bar{\sigma}_{tc}$. It is employed for the determination of the long-term strength - a computation characteristic in the design of PC structures. On this account the determination of $\bar{\sigma}_{tc}$ is an important task demanding long-term experiments as well as adequate precise and sensitive methods for measurement of deformations in the discrete periods of time. Fot these reasons some of the data available in literature for $\bar{\sigma}_{tc}$ are controversial.

As it has been established in the authors' investigations (Fig. 7) the time required to reach fading creep varies - the higher the level of constant stress, the longer the time interval. As far as the limit $\bar{\sigma}_{tc}$ is the maximum stress, at which creep acquires a fading character, it is obvious that also long-term experimental investigations are necessary for its determination.

Both the creep limit and the long-term strength of PC may be forecast by means of the so-called " structural" diagrams [2 , 10].

Nevertheless, the long-term experiment is a source of important information on the deformation behaviour of PC and its significance must not be underestimated, since a great deal of the response of the material to external effects is closely connected with their duration. In this connection the dependence of the deformations recovery after unloading on the duration of the preceding creep should be mentioned (Fig. 8 [9]).

The isochronous diagrams showing the relationship between stress and deformation under creep conditions also depend on the time t, when the deformations reading has been made. The diagrams are the more curved, the more remote is the time of the read-

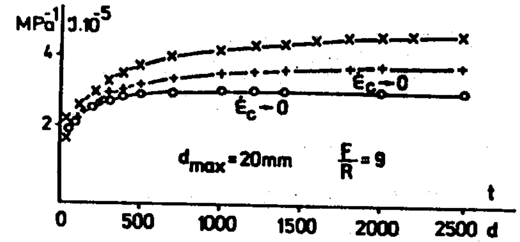

Fig. 7 Compliance curves J(t) for PC under compressive load for constant stress level $\bar{\sigma}$ = 0,1 (o); 0,2 (+);0,3 (x)

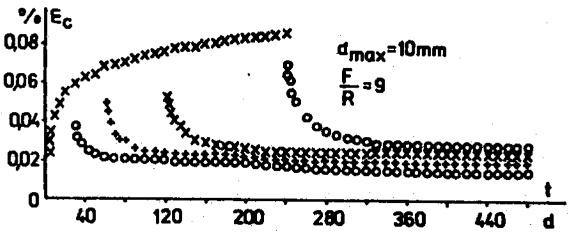

Fig. 8 Creep deformation curves ε_c(t) and recovery of deformations after unloading for constant compressive stress level $\bar{\sigma}$ = 0,3 and duration of its application 30 (o), 60 (+), 120 (x), 240 (o) days.

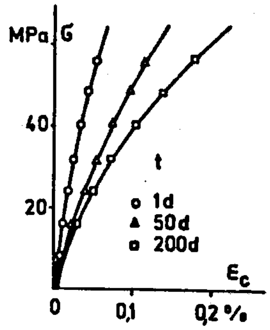

Fig. 9

Isochronous diagrams σ - ε_c for PC with F/B = 10,8 and d_{max} = 10 mm at different times t after initial load application

In order to bestow full consideration upon the problem and to obtain a right idea of the real place of PC between the other structural materials, the compliance curves J(t) have been compared (Fig. 10), both for conventional cement concrete (CC) (line 1), which is the basic material of contemporary building, and for some compositions of PC (lines 2, 3).

From the results it follows that it is possbile to attain similar creep compliance of polymer concrete and ordinary cement concrete if the ingredients and the structure of PC composition are correctly selected.

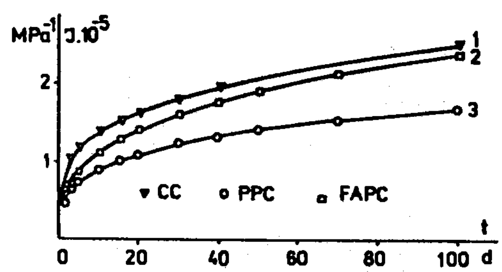

Fig. 10 Compliance curves J(t) for ordinary CC (1) [11,] FAPC (2) [2] and PPC (3) [authors] under compressive load for constant stress level $\bar{\sigma}$ = 0,3

REFERENCES

1 Hugenschmidt, F., Epoxy adhesives for concrete and steel. In: Proc.First Int. Congress on Polymer Concretes, London, The Concrete Society, 1975, pp 195-209

2 Stalepolimerbetonnyje strojitelnyje konstrukcii. Pod redakcijej S. Davydova i A.M. Ivanova, Moskva, Izd.lit.po strojitelstvu, 1972, s.69-79 (in Russian)

3 Okada, K., Koyanagi,W, Yonezawa,T., Thermodependent properties of polyester resin concrete. In: Prof.First Int. Congress on Polymer Concretes, London, The Concrete Society, 1975, pp.210-215

4 Ayyar,R.S., Desphande,S,N,, Creep studies on polymer mortars. In: Proc. Third Int. Congress on Polymers in Concrete, Koriyama, 1981, pp 504-523

5 Ivanov,a.m., Beljajev,V.E., Grosev,E.E., Soprotivljajemost poliefirnovo polimerbetona osevomu rastazeniju i szatiju. In: Issledovanije strojitelnych konstrukcij s primenenijem polimernych materialov. Vyp. 1, Voronez, Izdat.Voronezskogo un-ta, 1973, s.3-8 (in Russian)

6 Potapov,J.B., Celjajev,V.P., Svidko,J.I. Vlijanije prodolzitelnosti dejstvija postojannoj nagruzki na epoxidnyj polimerbeton. In: Issledovanije strojitelnych konstrukcij s primenenijem polimernych materialov. Vyp.2,Voronez, Izdat.Voronez. skogo un-ta, 1975,s.10-19 (in Russian)

8 Christova,j., Popova,M. Izsledvane na linejnata oblast na viskoznoelasticno povedenie na polimerbatona. Techniceska mysl, 1975,No.3, s.75-78 (in Bulgarian)

9 Christova,j.,Vzvrtscane na deformacijata na polimerbetona sled plzene. Fiziko-chimiceska mechanika, Sofia, BAN, 1980, No.6, s.65-72 (in Bulgarian)

10 Ivanov,A.M., Potapov,J.B., Strukturnaja diagramma furfurolacetonovogo plastbetona pri szatii. Mechanika polimerov, 1968, No. 3, s.451-461 (in Russian)