BUILDING MATERIALS AND PRODUCTS

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ACCELERATED METHOD OF PREDICTING CYCLIC DURABILITY OF POLYMER COMPOSITE MATERIALS

Statement of the problem. A widespread use of polymer composite materials is currently constrained by the complexity of predicting the deformability and strength characteristics under cyclic loading, as well as due to insufficient knowledge of the behavior of polymer composites under such kinds of loading. There is rather limited theoretical and experimental data on the stress-strain state of polymer composites with prolonged loading. These led to the need for a careful consideration of these issues.

Results. The limits of endurance of polymer composites were experimentally determined using the accelerated method based on the study of the internal friction coefficient. It was found that the long-term effect of cyclic loading leads to a change in the structure of polymer composites due to local self-heating in the tops of growing submicrocracks. This causes a change of flexible and resistant properties of the composite material, which causes a fatigue energy to manifest itself.

Conclusions. The proposed method enables the evaluation of the endurance limit of the composite in any database testing and whereby a cycle life of the composite polymer material. The proposed method can be used to characterize the stress-strain state of composite materials under cyclic loading types based on different polymeric binders.

Keywords: polymer composite, cyclic durability, endurance limit.

Introduction

The development and application of modern corrosion-proof effective building materials and products cuts down the operating costs of buildings and structures as well as it is one of the top priorities addressed by industrialization. Among these materials are polymer compositional materials of various composition. Applications of polymer composite materials are restrained by complexities involved in predicting deformation strength characteristics under cyclic loads as well as inadequate amount of study investigating the behavior of polymer composites under this kind of loads.

Theoretical and experimental data on the assessment of stress-strain state of polymer composites under long-term loads is limited. Therefore for artificial building conglomerates, particular considerations should be made on the above issues.

1. Interior friction in viscoelastic bodies

Operational loads are an important factor for the durability of polymer composite structures. Under this kind of loads materials in the long term experiences fatigue microcracking which inadvertently leads to failure. The major cause of microcracking is breakage of bonds. This is due to compressive and tensile deformations in the material.

In case strains in a certain area of dislocations are over the yield strength of a composite, microcracking occurs [1].

A long-term effect of cyclic loads leads to change in the structure of polymer composites due to local self-heating at the tops of growing submiscrocracks. This causes changes in elastic heat resistant properties of composites resulting in fatigue energy. Joint cyclic effect of force as well as own strains leads to an excessive total effect of certain types of stresses.

Oscillations of viscoelastic bodies are dampening due the conversion of kinetic energy of their particles into the thermal energy. Mechanisms of this conversion vary. In physics they are universally referred to as “internal friction”. Measuring the internal friction is of particular interest since it is central to its dampening properties.

There are different ways to study the internal friction. For instance, internal friction is determined by the amount of energy dispersed in a unit of volume in a unit of time

$$\omega = \sigma \cdot \varepsilon', \quad (1)$$

where σ is the stress in the material during a single-axis deformation; ε' is a deformation rate.

Internal friction is commonly defined as the energy ratio in a sample which is dispersed over one period to that of amplitude deformation and strain.

The ratio of damped oscillations is written as

$$\psi = -\int_{t}^{t+T} \frac{dW}{W}\,. \tag{2}$$

Assuming that W is proportional to the square of the deformation amplitude $\varepsilon_0^2(t)$, $\varepsilon_0(t)$, surrounding the curve of damping oscillations, (2) indicates that

$$\psi = -2\int_{t}^{t+T} \frac{d\varepsilon_0(t)}{\varepsilon_0(t)} = 2\ln\frac{\varepsilon_n}{\varepsilon_{n+1}} = 2\delta\,, \tag{3}$$

where $\delta = \ln\frac{\varepsilon_n}{\varepsilon_{n+1}}$ is a logarithmic decrement of oscillations [2].

Therefore determining the internal friction of the material comes down to determining its decrement of damping of oscillations. During changes taking place in the internal friction energy dispersion has to be considered which is due to the energy conversion as well as its dispersion over heterogeneous elements of the structure. Stresses are dramatically lower if the size of these elements is comparable to the wavelength. Large internal frictions cause a logarithmic decrement to cease to be a precise characteristics of internal friction and has no sense whatsoever in aperiodical oscillations of the particles of the material [2, 3].

The paper [4] introduces a method for determining a fatigue strength of a polymer concrete based on change in internal friction of the sample followed by a larger level of stress. Using the coefficient of internal friction the outset of structure changes in the material and absolute endurance limit can be observed causing no complete failure of the sample. The experimental research indicates that a level of internal friction of polymer samples in cyclic stresses which is lower than absolute endurance limit does not change. As an absolute endurance level increases, so does an absorption level therefore there are no more changes taking place till a failure occurs.

2. Study of cyclic durability using the internal friction coefficient

During cyclic deformation of a solid body there is dependence between the deformations: it is not identical for loads and loading. This is indicative of non-elastic deformation of materials. As a result, some mechanical energy of oscillations is irreversibly converted into heat and is finally dispersed. To put it differently, some of potential energy of the system is absorbed by the material, which is called its absorbing property. Absorption of mechanical energy inside the material is due to elastic as well as non-elastic deformations. During cyclic deformation this manifests itself as a hysteresis loop.

In order to determine an endurance limit of a polymer concrete, there is now a method in place which is similar to fatigue tests of metal samples. It is based on recording changes in internal friction in the samples being tested while stresses are slowly on the rise. Cyclic stresses cause irreversible changes in a composite which manifest themselves in changes occurring in the internal friction coefficient.

Thus knowing the internal friction coefficient, we can mark the outset of structural changes taking place in the material and observe the initial endurance limit without causing failure of the sample. It was earlier found that during cyclic stresses lower than an endurance limit a level of internal friction remains almost unchanged [4].

In order to obtain credible results while testing a series of 15 or 20 samples, it is necessary that no less than $2 \cdot 10^6$ test cycles are performed. As an endurance limit increases, there is initially a rise in the absorption coefficient with almost no change till there is failure taking place. Internal friction is stabilized if there are as many as $2 \cdot 10^6$ cycles which is 2—3 % of the total research base. About 40 thousand cycles before failure there is a rapid rise of the absorption coefficient which is caused by the disruption to the continuity of the material [2, 4].

Samples of 40×40×160mm were used for the experiment. First, the absorption coefficient at the stress of $0.25R_b$ was determined using a static hysteresis loop. Then the stress was kept stable regardless on the level of loading stress of the sample. A maximum stress of a cycle was frequently growing strating from the stress considerably smaller than the endurance limit. A number of cycles of changeable loading for each stage remained identical and was $N = 100\,000$ cycles.

Finally, the absorption coefficient was determined after the load was applied. Therefore endurance limits of composites were determined based on ПН-609-21М, ФАМ, ФАЭИС-30 (Fig. 1, 2).

The horizontal area in the diagrams corresponds to the levels of stress at which the coefficient of internal friction remains almost unchanged when it reaches

$$0,29\frac{\sigma_{\max}}{R_b} \quad \text{for ПН-609-21М;}$$

$$0,27\frac{\sigma_{\max}}{R_b} \quad \text{for ФАМ;}$$

$$0,35\frac{\sigma_{\max}}{R_b} \quad \text{for ФАЭИС-30.}$$

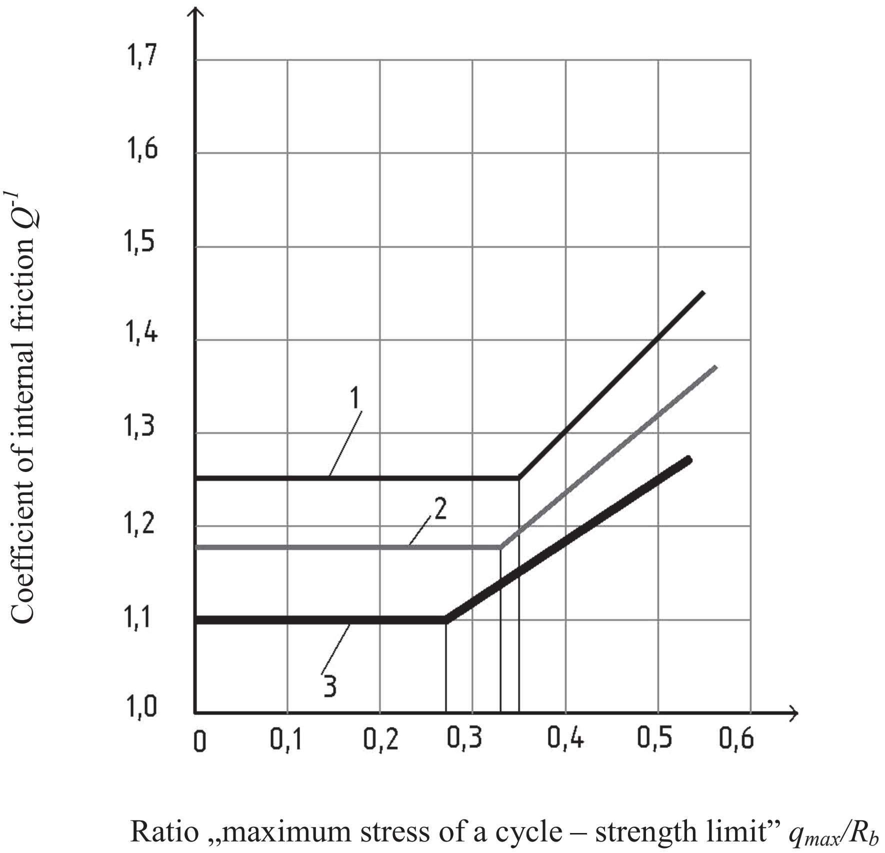

Fig. 1. Dependency graphs $\sigma_{\max} / R_b = f(Q^{-1})$ for polymer concrete ПН-609-21М: 1 at ρ = 0.6; 2 at ρ = 0.3; 3 at ρ = 0.1

The absorption coefficient further keeps increasing and is depicted in the graph as a break. This level corresponds to the endurance limit of polymer composites of the examined compositions. For the assessment and comparison of the endurance limits determined based on the standard methods. The results are identified in Table 1, 2. The comparison of the endurance limits obtained traditionally shows that the last one is 10—17 % higher. A small number of $N = 2 \cdot 10^6$ cycles obtained in traditional fatigue tests explains that. According to theory of O. Ya. Berg [5], in order to identify structural changes occurring in the material, endurance limit should be equal or lower than a level of cracking. The obtained experimental results are in good agreement with the assumption.

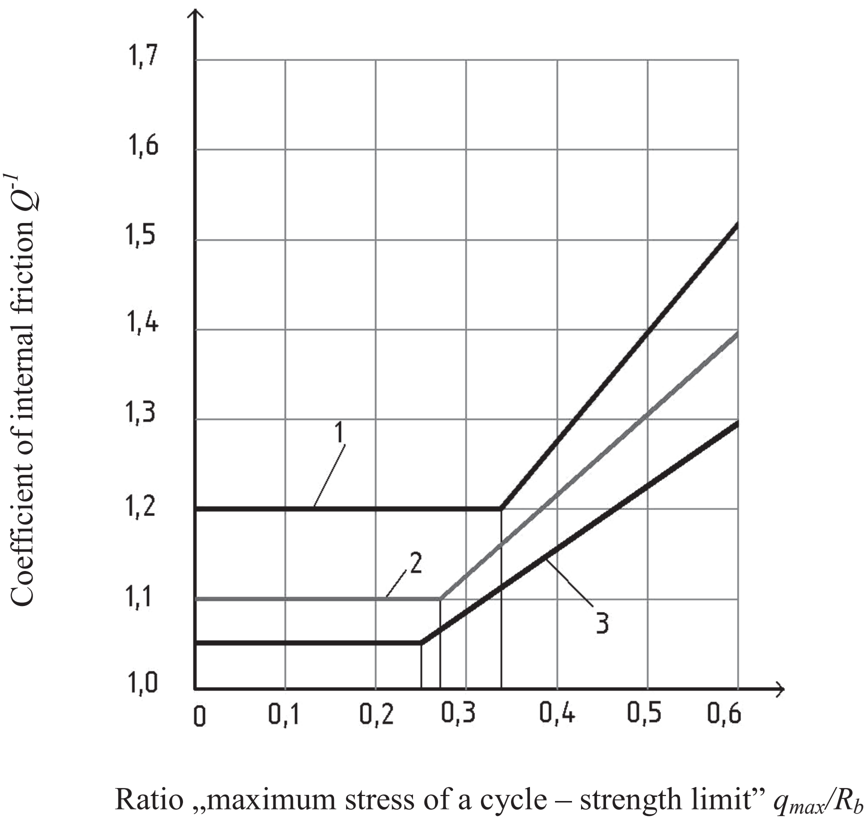

Fig. 2. Dependency graphs $\sigma_{max} / R_b = f(Q^{-1})$ at ρ = 0.1 for polymer concretes: 1 is ФАЭИС-30; 2 is ПН-609-21М; 3 is ФАМ

Table 1

Cyclic durability calculated using a traditional and accelerated methods for composites based on ПН-609-21М

Asymmetry coefficient of the cycle, ρ	Endurance equations	Endurance coefficient, $K_{b, pul}$		$\frac{K^{Tp}_{b,pul}-K^{Y}_{b,pul}}{K^{Tp}_{b,pul}}\cdot 100\%$
		traditional method	accelerated method	
0.6	$R_{b, pul}$ = 90.961-8.699 lgN	0.43	0.38	11.6 %
0.3	$R_{b, pul}$ = 100.289-10.714 lgN	0.39	0.33	15.3 %
0.1	$R_{b, pul}$ = 106.488-12.207 lgN	0.35	0.29	17.1 %

Table 2

Cyclic durability of polymer composites determined traditionally

Type of polymer composites	Asymmetry coefficient of the cycle ρ	Endurance coefficient $K_{b, pul}$
Polymer concrete ФАЭИС-30	0.1	0.35
Polymer concrete ПН-609-21Н	0.1	0.29
Polymer concrete ФАМ	0.1	0.27

Conclusions

1. The suggested method is proposed for determining the endurance limits of polymer composites using the accelerated method based on the study of the coefficient of internal friction and allowing the determination of endurance limits of materials for any research base.

2. The experimental research indicated endurance coefficients $K_{b,\ pul}$ for cyclic stresses for polymer composites based on furan, furan epoxide and polyethylene resins, their cyclic durability was also assessed.

3. The suggested method can be used to estimate the characteristics of stress-strain state of composites in different types of loading based on other polymer adhesives.

References

1. **Bondarev, B. A.** E'ksperimental'nye issledovaniya ciklicheskoj dolgovechnosti polimernyx kompozicionnyx materialov / B. A. Bondarev, P. V. Borkov, P. V. Komarov, A. B. Bondarev // Sovremennye problemy nauki i obrazovaniya. — 2012. — № 6. — (www. science-education. ru/106-7974). — (14.03.2013).

2. **Postnikov, V. S.** Vnutrennee trenie v metallax / V. S. Postnikov. — M.: Mashinostroenie, 1974. — 350 s.

3. **Rabotnov, Yu. N.** Mexanika deformiruemogo tverdogo tela / Yu. N. Rabotnov. — M.: Nauka, 1988. — 712 s.

4. **Mednov, A. E.** Opredelenie ustalostnoj prochnosti polimerbetona uskorennym metodom / A. E. Mednov // Issledovaniya stroitel'nyx konstrukcij s primeneniem polimernyx materialov. — Voronezh: VorPI. — 1987. — S. 98 — 100.

5. **Berg, O. Ya.** Fizicheskie osnovy teorii prochnosti betona i zhelezobetona / O. Ya. Berg. — M.: Gosstrojizdat, 1962. — 98 s.

6. **Bondarev, A. B.** Soprotivlyaemost' polimerbetonnyx i stekloplastpolimerbetonnyx e'lementov konstrukcij dlitel'nym i ciklicheskim nagruzkam / A. B. Bondarev, P. V. Komarov, O. I. Lifincev // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arxitektura. — 2009. — № 1 (3). — S. 92—97.