

Influence of Feedback in the Structure of Carbon Plastics on their Properties

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ABSTRACT: The results in the present article allow to find a structural sense of feedback effect in carbon plastics based on phenylone and demonstrated its influence on the strength of these materials. The decrease of feedback parameter can be a result of a substantial increase of carbon plastics macroscopic strength. The control of the value of this pa-

rameter is possible by the change of fibers orientation factor, which is the controlling parameter for interfacial regions. © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 100: 2817–2820, 2006

Key words: composites; short fibers; interfaces; structure; mechanical properties

INTRODUCTION

As shown previously,¹ carbon plastics structure, which is produced with the help of the method of components preliminary blending in rotating electromagnetic field, is a synergetical system. This is expressed in its main characteristic behavior as a function of blending duration t : at small t ($t \leq 120$ s) a periodical (ordered) behavior close to sinusoidal with twofold period is observed, and then the transition to chaotic behavior is realized.¹ As it is known from earlier studies,² one of the main features of synergetical systems is the existence of feedback in them. Structural sense of feedback for the studied carbon plastics is expressed by simple relationship¹:

$$\varphi_{cl} = 0.74 - \varphi_{int} \quad (1)$$

where φ_{cl} and φ_{int} are the relative fractions of local order regions (clusters) and interfacial regions, respectively, i.e., denselypacked regions of structure.

It should be pointed out, that the constant 0.74 in eq (1) is equal to maximally possible relative fraction of denselypacked regions of composite, according to the conception of thermal cluster.³

Therefore, the physical sense of feedback effect in the studied carbon plastics is very simple: the increase in φ_{int} results in a decrease in φ_{cl} and *vice versa*. Therefore, the purpose of the present study is to find the degree of influence of feedback in structure of carbon

plastics based on phenylone on their mechanical characteristics, particularly, on fracture stress (strength).

EXPERIMENTAL

An aromatic polyamide, phenylone,⁴ is used as the polymer matrix and carbon fibers (CF) with diameter 7–9 mm and length 3 μm is used as filler. The composite is produced by “dry” method, which includes blending of components in a rotating electromagnetic field. In this method, powdery polymer, CF, and non-equiaxial ferromagnetic particles with length 40 mm were placed in the reactor. Then the reactor was placed in the end window of the generator of the electromagnetic apparatus. Through the action of rotating electromagnetic field, ferromagnetic particles begin to rotate, colliding between themselves, which results in equipartition (chaotic) distribution of CF in polymer matrix. As a result of this collision, particles are wear down and the worn out products get to composite. For removing ferromagnetic particles after blending, two methods are used: magnetic and mechanical separation.⁵

Specimens for studying the mechanical properties are prepared by the method of hot pressing at a temperature of 603 K and a pressure of 55 MPa. The compression testing is made on the machine FP –100 at a temperature of 293 K and a strain rate of 10^{-3} s^{-1} .

The thermal properties were determined on differential scanning calorimeter of model UT-C-400 at a heating rate of 10 K/min.

RESULTS AND DISCUSSION

At first, we give the brief description of the method of calculating parameters φ_{cl} and φ_{int} in eq. (1), which

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will be necessary for the next estimations. The value of fractal (Hausdorff) dimension d_f of carbon plastics structure is determined from equation⁶:

$$d_f = 2(1 + \nu) \quad (2)$$

where ν is the Poisson's ratio, the value of which can be calculated with the help of mechanical testing results with the usage of relationship⁷:

$$\frac{\sigma_Y}{E} = \frac{1 - 2\nu}{6(1 + \nu)} \quad (3)$$

where σ_Y is the yield stress and E is the elasticity modulus.

Then the value φ_{cl} with the usage of equation⁸ is determined as follows:

$$d_f = 3 - 6 \left(\frac{\varphi_{cl}}{SC_\infty} \right)^{1/2} \quad (4)$$

In eq. (4), S is the cross-sectional area of a macromolecule and C_∞ is the characteristic ratio, which is an indicator of polymer chain statistical flexibility.⁹ For phenylone, $S = 17.6 \text{ \AA}^{210}$ and $C_\infty = 3$.¹¹

The value φ_{int} can be calculated according to the following equation¹²:

$$\varphi_{int} = 1 - \frac{\Delta C_p^c}{\Delta C_p^p} \quad (5)$$

where ΔC_p^c and ΔC_p^p are the values of heat capacity at constant pressure jump at glass transition temperature for composite and matrix polymer, respectively.

It was reported earlier¹³ that the controlling parameter at carbon plastics structure formation (exactly, their interfacial regions) is the fiber orientation factor η . Then the feedback parameter λ can be calculated according to the Puancaire equation²:

$$\eta_{n+1} = \lambda(1 - \eta_n)\eta_n \quad (6)$$

where indexes $n, n + 1, \dots$ are called sequential intervals of blending duration t of components in rotating electromagnetic field ($t_1 = 5 \text{ s}, t_2 = 10 \text{ s}, \dots$, and so on) and the values η are accepted according to the data given by Burya et al.¹³

In Figure 1, the dependence $\varphi_{cl}(\lambda)$, from which the φ_{cl} increase at amplification of feedback expressed followed by an increase in λ is presented. Such picture corresponds completely to relationship (7): the increase in λ results in "redistribution" of polymer material from interfacial regions in bulk polymer matrix and, as a consequence, to the increase of local order regions fraction in it. On the contrary, in most general terms, the change of feedback degree results in the

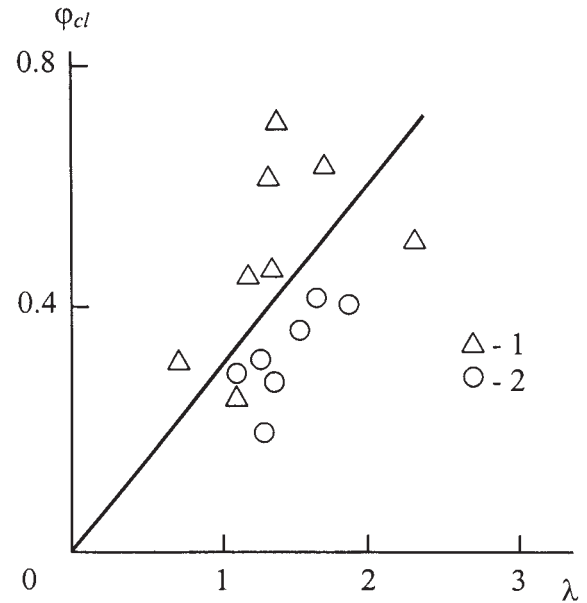


Figure 1 The dependence of clusters relative fraction φ_{cl} on feedback parameter λ . The specimens are prepared with the usage of magnetic (1) and mechanical (2) separation.

variation of polymer matrix structure. It is natural to expect that the above-mentioned structure change causes the variation of polymer matrix properties, particularly, its strength σ_f^m , which can be determined according to the equation¹⁴:

$$\sigma_f^m = 0.14 \left(\frac{\varphi_{cl}}{2N_A S l_0 C_\infty} \right)^{5/6} \text{ MPa} \quad (7)$$

where N_A is the Avogadro number and l_0 is the length of main chain skeletal bond (for phenylone $l_0 = 1.25 \text{ \AA}^{11}$).

From Figure 2, where the dependence $\sigma_f^m(\lambda)$ is presented, the change of feedback level is influenced substantially on bulk polymer matrix strength: the increase in λ from 0.67 up to 2.27, (i.e., approximately in three times) results in an increase in $\sigma_f^m \sim 2.7$ times, from 78 up to 218 MPa. Note the characteristic feature of linear correlation $\sigma_f^m(\lambda)$: it passes through the origin and it means that, in case of feedback absence, polymer matrix will have zero strength.

On the basis of the above-mentioned observations, it is necessary to propose that the "redistribution" of material from interfacial regions in bulk polymer matrix because of feedback existence changes the strength of interfacial regions σ_{int} and determines the interrelation of stresses σ_f^m and σ_{int} . The value σ_{int} can be calculated according to the eq. (7) by replacing φ_{cl} with φ_{int} and supposing for interfacial regions $C_\infty = 9$.¹ In Figure 3, the relationship between strengths of bulk polymer matrix σ_f^m and interfacial regions σ_{int} is presented, from which follows the decrease of σ_f^m at an

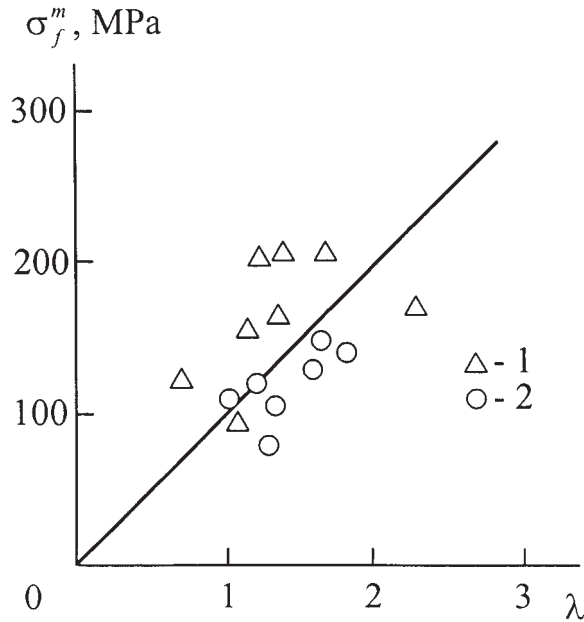


Figure 2 The dependence of bulk polymer matrix strength σ_f^m on feedback parameter λ . Meanings are the same, as in Figure 1.

increase in σ_{int} and vice versa. This interrelation was expected because of feedback effect and its structural expression: the “redistribution” of polymer material from one denselypacked structural component into the other.

As it is well known,^{15,16} the properties of interfacial regions determine to a larger extent the properties of

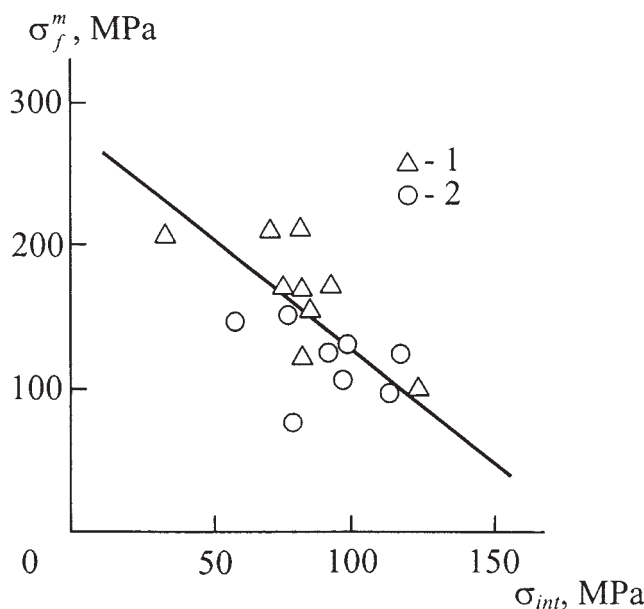


Figure 3 The relationship between the strengths of bulk polymer matrix σ_f^m and interfacial regions σ_{int} . Meanings are the same, as in Figure 1.

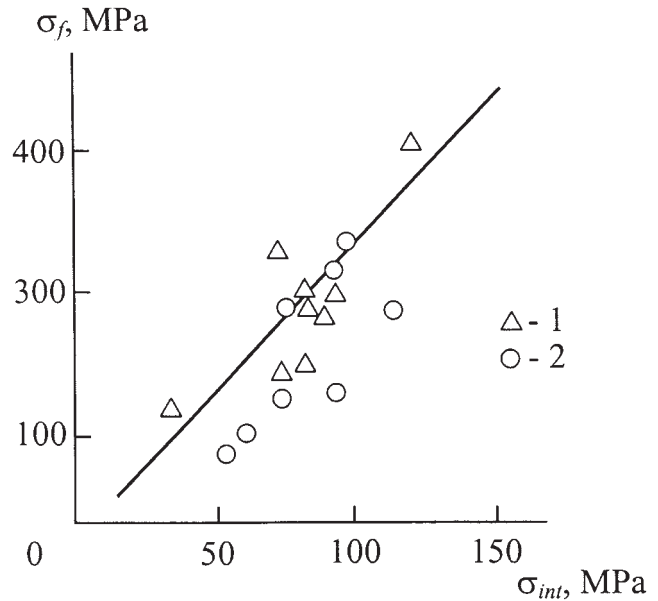


Figure 4 The dependence of microscopic strength σ_f on strength of interfacial regions σ_{int} . Meanings are the same, as in Figure 1.

polymer composites as engineering materials. From Figure 4, in which the dependence of experimentally determined macroscopic strength of carbon plastics σ_f on σ_{int} is presented, demonstrates this law: the increase in σ_{int} from 35 up to 125 MPa results in an increase in σ_f from ~300 up to ~406 MPa. Figures 1–4 shows the influence of carbon plastics structural changes that take place because of feedback existence, on their mechanical properties: an amplification of feedback (the increase in λ) results in an increase of clusters relative fraction φ_{cl} in bulk polymer matrix (Fig. 1), growth in its strength σ_f^m (Fig. 2), decrease of interfacial regions strength σ_{int} (Fig. 3), and finally, decrease of composite macroscopic strength σ_f (Fig. 4). The practical conclusion from this is obvious: for the improvement of carbon plastics strength, it is necessary to decrease the feedback parameter. So, Figures 2–4 follow two limiting cases: at $\lambda = 0$ $\sigma_f^m = 0$, $\sigma_{int} = 180$ MPa, and $\sigma_f = 440$ MPa, then at $\lambda = 2,40$ $\sigma_f^m = 240$ MPa, $\sigma_{int} = 28$ MPa and $\sigma_f = 290$ MPa, i.e., the decrease of σ_f approximately in one and a half times at an increase in λ from 0 up to 2.40.

On the basis of the aforementioned factors arises the question: how can a feed back parameter be regulated purposely. The answer to this question gave the plot of Figure 5, where the dependence of λ on the controlling parameter of interfacial regions is presented. As follows to wait some retardion [reaction, see eq. (6)] λ in comparison with η , then in Figure 5 this dependence gave as $\lambda_{n+1}(\eta_n)$. From Figure 5 it is shown that the decrease in the value of λ can be made by an increase in fiber orientation factor λ . So, for the above-mentioned increase of σ_f from 290 up to 440 MPa or decrease in λ from 2.40 up to 0.55, is reasonable.

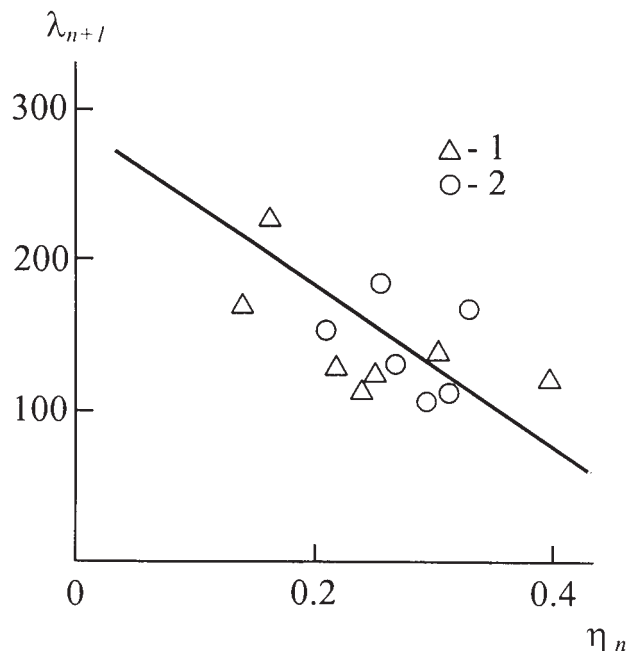


Figure 5 The dependence of feedback parameter λ_{n+1} on fiber orientation factor η_n . Meanings are the same, as in Figure 1.

CONCLUSIONS

Therefore, results in the present study allow to find a structural sense of feedback effect in carbon plastics based on phenylene, and demonstrated its influence on the strength of these materials. The decrease of feedback parameter can result in a substantial increase of carbon plastics macroscopic strength. The value of

this parameter can be controlled by the change of fiber orientation factor, which is a controlling parameter for interfacial regions.

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