FAILURE PROCESS SIMULATION OF POROUS FRICTIONAL COMPOSITES WITH A POLYMER MATRIX

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ABSTRACT

A stochastic structure model of a composite material incorporating *n*-component is considered. Calculation results of the stress-strain state of multicomponental frictional composites are cited. Regularities of microcrack onset and growth are discussed, and failure mechanisms of composites with porous structure under service loading are illustrated.

1 INTRODUCTION

Friction and wear mechanism determination is in fact reduced to the solution of strength problem, i.e., the problem on surface layer destruction of solid bodies. The composition, structure and properties of rubbing body materials play a decisive role in wearing processes. Complexity of phenomena taking place in the friction contact consists in the diversity of outer, in the first place, mechanical effects on the rubbing bodies. So, without account of the stress state of the friction bodies the problem can't be solved at the level of materials science [1].

One of the promising directions in designing asbestos-free frictional composites with a polymer matrix either transforming or absorbing high kinetic energy of moving machines is the creation of capillary porous structure of the material by adding ingredients having a similar structure or by using vapor-forming agents. Porous structure of composites ensures the reduced heat strain in the joint and helps to stabilize frictional characteristics through absorption of friction induced polymer binder destruction products and abrasive debris [2]. It is therefore of interest to study pore effect on frictional material strength and wear resistance.

2 METHODS

The model of a composite stochastic structure is given as a square cell having side a containing n-components located on the plane of non-crossing circles with random radii distributed following the normal law. Number of used in calculations circles is about 200; diameter variation ratio is 10%; filling degree - 50% by volume. Microdamage was preset as a region with null elasticity module. Values of elasticity constants and component strength characteristics are known data for the given composite class.

The stress-strain state of structural elements was calculated by the finite element method. The total number of elements was more than 35,000. The initial non-stressed state of the structural element (*I*) and the initial state upon cooling by 100 K with having relaxed (*II*) and residual stresses (*III*) have been studied. The initial microdamage determined as defect area A_d ratio to matrix area A_m was obtained for variants *II* and *III* as a result of thermal stress effect in components. The initial microdamage for the *II* and *III* types of loading constituted ~2% of the volume. Microdamage in the composite is supposed to occur due to progressing random fractures of the polymer matrix under gradually increasing loading. Algorithm describing microcrack onset and propagation is based on the maximum deformation criterion. Loading was exercised as a uniaxial tension, uniaxial compression and pure shear. Stress, strain and macroscopic (mean across model field) stress and strain in components were calculated on each loading stage.

3 RESULTS AND DISCUSSION

Deformation diagrams based on macroscopic stress analysis are shown in Fig. 1. In Fig. 2 microdamage diagram is presented. Deformation diagrams prove the probability of brittle failure of the modeled structure being characteristic of micro inhomogeneous bodies. Their nonlinearity at stress close to breaking one is conditioned by additional deformation caused by microdamage of the structural elements. σ-ε dependencies illustrating graphically deformation behavior of the composite prior to failure are of the following kind:
I - at tension and compression display negligible nonlinearity;
II - tension is linear, compression is linear;
III - tension visualizes nonlinearity and rather big deformation of the polymer matrix.

It is to be marked that the kind of σ-ε diagram at compression (*IIIb*) depends much on matrix material. It has been proved that considerable difference in matrix filler rigidity leads to the growth of high local stress concentration in the matrix. Initial damage (i.e., maximum deformations ε_1 surpass limiting values ε_{lim}) takes place in the local zone between neighboring filler particles at applied stress values less than breaking ones.

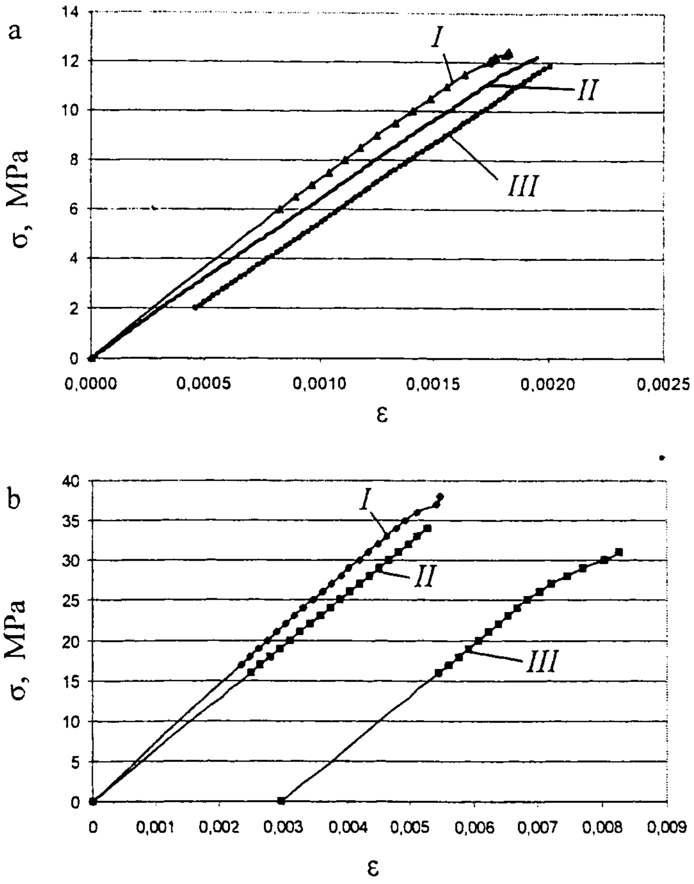

Fig. 1. σ-ε diagram at uniaxial tension (a) and compression (b)

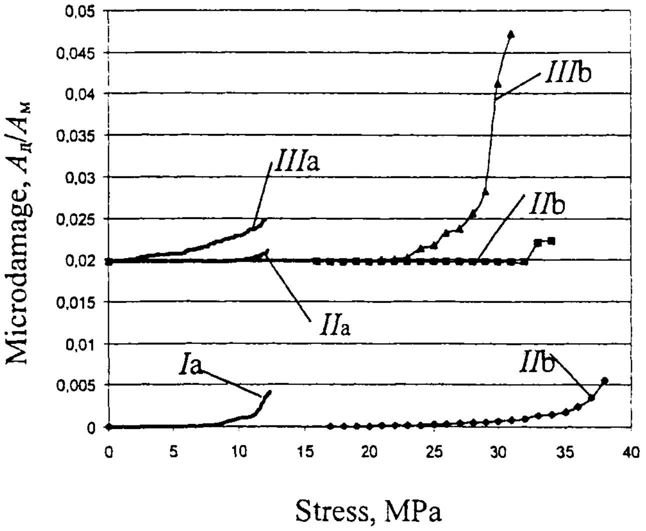

Fig. 2. Microdamage dependence on tensile (a) and compressive (b) stresses

Pore presence in the structure brings about stress redistribution in the composite under loading. Growth of already formed or emergence of new pores is of a random character and depends on mutual location of the particles, in particular, on the distance between neighboring particles. Reduction of this distance in direction of applied load results in increased local stress concentration and, as a consequence, to further growth of pore volume.

Process of damage accumulation proceeds quite slowly till some loading value (Fig. 2). Stress redistribution owing to accumulated damage in the matrix material creates an instability expressed in crack or stress wave formation leading to, in fact, instantaneous violation of the composite continuity. Pores were found to be originated at the interface, as a rule, when adhesive interaction is infringed in the filler-matrix system. High local stresses initiate the process of pore nucleation and assists their growth and amalgamation (Fig. 3). Maximum deformations are attained at some distance from the crack vertex in direction of its propagation and this distance is connected with the crack vertex opening. Thus, composite failure mechanism consists in formation of a chain of pores gradually growing and converging with the crack in its front region.

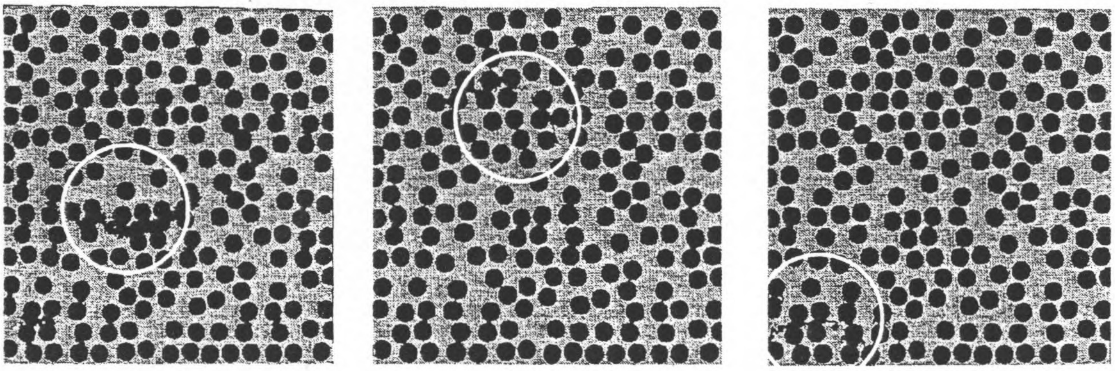

Fig. 3. Location of the trunk crack at tension (a), compression (b) and shear (c)

When composites are filled with fine-dispersed particles it is practically impossible to avoid crack generation [3]. This is especially apparent in composites containing small size particles with their amount above 30% by volume which is characteristic for frictional materials with a polymer matrix. Matrix and filler particles have different heat expansion indices and cooling below the composite production temperature gives rise to residual thermal stresses in the dispersed particles vicinity. It was theoretically justified that neither value nor distribution of those stresses depend on particles size but are determined, in the first place, by the difference in thermal expansion, elastic properties of the phases and temperature variation magnitude [4]. Microcracks originate in the process of structure formation both around dispersed particles due to difference in thermal and physical properties of the constituents and in the matrix between filler particles owing to emerged regions with high local stress concentration. The formed microcracks like pores do not transfer stresses thus facilitating elasticity module reduction and material compliance increase (Fig. 1, curves *II*a and *III*b).

4 CONCLUSIONS

From above procedure it follows that introduction of pore forming components aimed at attaining localization of residual thermal stresses turns to be useful for polymer frictional materials at increasing degree of applied stress which leads to pseudopore origination in response to violation of adhesive bonds between the binder and fillers. This lessens the probability of weak boundary layer formation which conditions elevated wear of frictional composites.

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