CALCULATION OF PROCESS OF DAMAGE ACCUMULATION IN FILLED ELASTOMER COMPOSITES

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A hypothesis of statistical space-time reason for initiating every new damage is suggested to use for analysing the dependence of elastomers rupture strength on filler particles sizes. Concepts of occurring destructive thermofluactuations in a medium form the basis of this hypothesis. The accumulation process of matrix debondings from inclusions has been calculated in the framework of the model proposed. The results obtained qualitatively disagree with the data described the same process using the fracture criteria. Consideration is given to the dependence of the probability of generating the damage cluster in material on its size and degree of formation.

INTRODUCTION

According to numerous experimental investigations damage in material with large sizes particles of the solid phase is initiated earlier and accumulated faster than in materials with small particles. As a result, a macroscopic fracture of composite material occurs at lower loads than in materials with the same fraction of filler, but with finer particles of solid phase.

Different hypotheses have been advanced to explain this phenomena. Our consideration is based on the hypothesis suggesting that the probability of damage initiation at given time and point depends only on the stresses acting exactly at the same time and point (1,2).

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DAMAGE INITIATION PROBABILITY

The probability P of occurring at least one new damage in the material in time $[t_1, t_2]$ is determined by formula

$$P = 1 - \exp\left(\int_{t_1}^{t_2} \iiint_V F_k(\sigma_k)\, dV\, dt + \int_{t_1}^{t_2} \iint_S F_a(\sigma_a)\, dS\, dt \right),$$

where V is the matrix volume; S is the surface of all undebonded inclusions; σ_k is the invariant of tensor stress; σ_a is the scalar characteristic of the rupture effort. This formula may be used to generate a random process of damage accumulation in a medium.

COMPUTER MODELLING

Four samples are considered, each has a hundred of spherical inclusions. The computer simulates the situation when the specimens are extended with a similar macroscopic rate. The filler particles are widely spaced and, therefore, every particle has the same stress field near the surfaces of inclusions. According to standard concepts of strength criteria, the matrix debondings from the particle surfaces are supposed to start simulteneously near all inclusions, and vacuoles in the vicinity of the surface inclusions are formed by "a clap". The kinetic-statistical description of the process yields quite another situation. Under a defined value of macroscopic loading, only the initiation of the most probable instant of occurring debondings can be expected. The process is random and, therefore, no simulteneous matrix debonding from all particles is possible by one clap (Figure 1).

STATISTICAL REGULARITIES

Determination of the probability density of a number of debonded particles necessitates not 4 but 7000 - 10000 computer calculations. Two groups of specimens were studied being of identical macroscopic sizes but in each the filler particles of different sizes were used. All specimens had the same volumetric portion of a filler.

The computational results are shown in Figure 2. Densities of debonded particles portion ρ distribution fit the specimens with 100 inclusions (curves 1, 2 and 3) and 1000 inclusions (curves $1'$, $2'$ and $3'$) for the dimensionless loadings σ^*, equal, respectively, to values 0,6; 0,9; 1,2.

$$\sigma^* = \left(\frac{AR^2}{4E\varepsilon'} \right)^{\frac{1}{4}} \sigma ,$$

where

$$A = \frac{B_a}{R^2\sigma^3} \iint\limits_{S_R} {\sigma_{rr}}^3 \; H(\sigma_{rr}) \, dS_R \, dt;$$

R is the radius of inclusions; E is Young's modulus of a matrix; ε' is the macroscopic deformation rate; $\sigma = \sigma(t)$ is the macroscopic loading; B_a is the strength constant; σ_{rr} is the rupture effort; S_R is the surface of the inclusion on which no matrix debonding has been observed.

Figure 3 presents the dependence of the dispersion D on the mathematical expectation m of the part of debonded particles for specimens with 100 inclusions (curve 1), 150 inclusions (curve 2) and 1000 inclusions (curve 3). The number of the specimens considered is of primary importance on statistical modelling of the process. This is further distinction of the kinetic approach from the determinate description of the phenomenon.

CLUSTER FORMATION

The final stage of material macroscopic fracture starts with the generation of damage clusters which are the regions with a degree of damage slightly higher than that of the surrounding material. With the occurrence of such regions the material can not be considered as macroscopically homogeneous. Its further evolution is determined by the development of inhomogeneities.

The probability exists of occurring at some given specified time the macroscopic region with the concentration of debonded particles θ_α essentially exceeding the average value m throughout the sample

$$\theta_\alpha = (1 + \alpha) \, m .$$

In what follows the initiation of the damage cluster will be referred to as the random formation in a medium of the region of the volume ΔV with the excess of the debonding concentration over the expected one by $100 \cdot \alpha$ per cent, which qualitatively changes the overall further development of a damage and leads to the process localization. The parameter α specifies the degree of cluster concentration (the distinction of damage in the considered region from that in the surrounding material).

SCALE EFFECT IN CLUSTERS

Lines for the constant level of the probability $P_{\Delta V}$ of occurring the region of the volume ΔV with the characteristic of the increased damage α are given in Figure 4. Lines for level 1, 2, 3, 4 and 5 correspond to the specimen with inclusions of 100 μm radius; lines $1'$, $2'$, $3'$, $4'$ and $5'$ - to inclusions of 20 μm radius. They describe the following values of the probabilities: 1 and $1'$ - 0,1; 2 and $2'$ - 0,3; 3 and $3'$ - 0,5; 4 and $4'$ - 0,7; 5 and $5'$ - 0,9. This case is analysed for the macroscopic loading, equal to $\sigma^* = 0.91$. The material is studied at the uniform rate of macroscopic deformation.

At a defined value of α, the less the sizes of the considered region ΔV, the more probable is the initiation of the debonded particles cluster. On the other hand, the formation of the cluster with the fixed volume ΔV is highly improbable at large values of the index α, but this is quite natural at small values α.

The above allows us to conclude that the damage cluster (comparable with the specimens sizes) in a material with small particles is formed much later than in the material with large ones (under the same volumetric part of the solid phase). Thus, the process of fracture localization in the specimen with large filler particles should be expected earlier and the macrorupture in specimen will occur faster, i.e. the scale effect of strength takes place.

SYMBOLS USED

$F_k(...)$ = the function of matrix cohesive strength

$F_a(...)$ = the function of adhesive strength

$H(...)$ = the Heavyside function

θ = the debonded particles portion

N = the number of particles in specimen

REFERENCES

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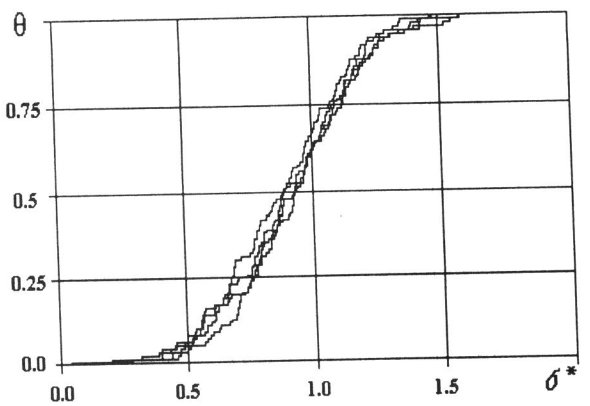

Figure 1 Process of damage accumulation

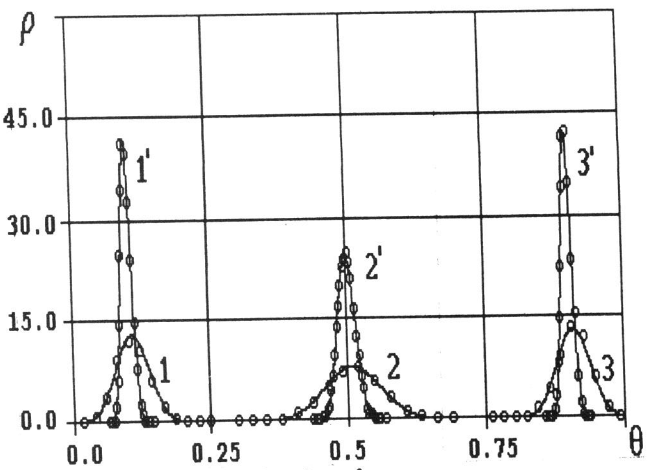

Figure 2 Probability density of debonded particles portion

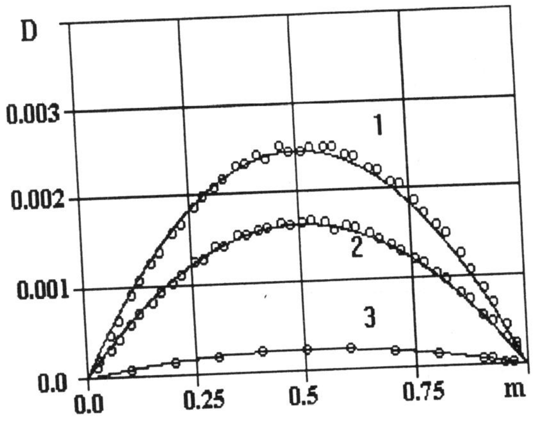

Figure 3 Relation between dispersion and expectation

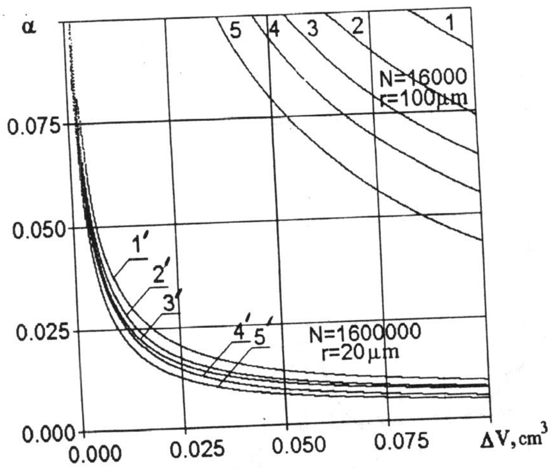

Figure 4 Lines for the constant level of the probability