THE MODEL OF THE BRITTLE FAILURE IN A DUAL-PHASE COMPOSITE OF DAMAGED STRUCTURE

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The report presents the results that have been obtained by simulating the peculiar traits of the crack development mechanism in a two-component medium containing dispersed solid particles with allowances for the residual thermal stresses and the faulty character of particles in the dispersion phase.

INTRODUCTION

Lately much attention has been paid to the theoretical investigations into the mechanisms of failure in heterogeneous media and the singling out of the factors that affect changes in their resistance to the brittle fracture. Thus, a substantial success in this sense has been attained in the works dedicated to the increase of the fracture toughness in oxide ceramics, particles-reinforced zirconia (1,2,3), silicon nitride, silicon carbide reinforced with short rods (4) and so on. The positive results achicved in the practical realization were substantiated by the fact that the of rather brittle ceramics is based on the theoretical analysis of the crack development mechanism in a heterogeneous medium (5,6).

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THE DUAL-PHASE COMPOSITE FAILURE MODEL

Unlike structural steels and alloys wherein the energy dissipation occurs at the tip of a running crack when a metal is being-plastically deformed, the mechanism of the plastic deformation in its classic understanding is absent in brittle materials of ceramics, polycrystalline SHM and rock types but the energy dissipation takes place here as a result of microcracking in the vicinity to the crack tip (Figure 1). This region is named "dissipative".

Besides the above mechanisms, the fracture toughness is substantially affected by residual stresses present in the matrix which assist or resist to the development of the main crack in the structure of the composite. Thus, the effective elastic energy release rate G_{Ic}^*, can be, expressed as a sum of the energies exhausted on the enumerated mechanisms of the fracture (3)

$$G_{Ic}^* = 2\gamma_p + \frac{dU_d}{da} + \frac{dU_s}{da} \quad \cdots \cdots \cdots (1)$$

In the above works (2,3,5) a composite was considered to be a homogeneous medium and a change of its resistance to the fracture was related to the microcracks density in the dissipative region but a diamond-containing composite, such a one as is used to fit drill bits, is a dual-phase structure containing hard particles and cracks in which the energy dissipation in the process of microcracking occurs prior to its deformation. Therefore, we have a composite of dissipative structure wherein microcracks influence its fracture mechanism deterioratively.

Consider the diamond-containing composite material (DCM) as a dissipative medium in line with some conclusions made in the work of Pompe and Krecher (3).

In these works it has been shown that the DCM also contains microcrachs which are distributed within the composite volume and that they have been generated in diamond grains not in the process of the composite deformation but at the stage of hot pressing. Consequently, we have on hand an initial damage in the material occurring in its dissipative region. Thus, the energy of dissipation, dU_d/da was exhausted prior to the material deformation and the equation (1) acquires a different form:

$$G_{Ic}^* = 2\gamma_p - \frac{dU_d}{da} + \frac{dU_s}{da} \quad \ldots \ldots (2)$$

where $\gamma_p = \gamma_m \left\{ 1 - \left[1 - (\frac{h}{2d})^2 \right] \frac{\rho}{(E^*/E_o)^1/2} \right\}$ x

$$x \left\{ 1 + (\gamma_d - \gamma_m) \, Cd/\gamma_m \right\}$$

The values of the energy dissipated in the composite structure on the process of microcracking in diamond grains can be defined as:

$$U_d = \frac{G_{Ic}^*(1-C_d)\mathcal{E}^*}{3(1-\mathcal{E}^*)} \quad \ldots \ldots \ldots (3)$$

The value of the elastic energy introduced into the dissipative region by the residual stresses can be found by:

$$U_s = \frac{5}{6} \cdot \frac{G_{Ic}^* E_o^2}{\sigma_o^2} \cdot \frac{Cd(1-Cd^2)(\Delta\alpha\Delta T)^2}{2 - \mathcal{E}^* + Cd\mathcal{E}^*} \ldots (4)$$

By inserting the equations (3) and (4) into the equation (2) and carrying out the operations necessary we obtain the equation in its final form:

$$\frac{G_{Ic}^*}{2\gamma_m} = \frac{\gamma_p}{\gamma_m} / (1 + \frac{(1-Cd)\mathcal{E}^*}{3(1-\mathcal{E}^*)} +$$

$$+ \frac{5}{6} \cdot \frac{E_o^2}{\sigma_o^2} \cdot \frac{Cd(1-Cd^2)(\Delta\alpha\Delta T)^2\mathcal{E}^*}{2 - \mathcal{E}^* + \mathcal{E}^* Cd}) \ldots (5)$$

By using the known ratio between the liberation rate of the elastic energy and the stress intensity factor:

$$G_{Ic}^* = K_{Ic}^2 (1 - \nu^{*2})/E^* \quad \ldots \ldots (6)$$

and the equation (5) we obtain the final resolving equation permitting to calculate the effective fracture toughness for the composite:

411

$$\frac{K_{Ic}^{*}}{K_{Ic}^{m}} = \left\{ \frac{G_{Ic}^{*}}{2\gamma_{m}} \cdot \frac{E^{*}(1-\gamma_{m}^{2})}{E_{m}(1-\gamma^{*2})} \right\}^{1/2} \quad \dots (7)$$

The computer-assisted numeric simulation has shown that the increase of the diamond concentration in the DCM entails an increase of the tensile residual stresses in the matrix (7) and the enhancement of the structure damage caused by the increased number of diamond grains being cracked. The comparison between the theoretical curves and the experimental K_{Ic}^{*} values shows a good conformity in them what bears witness to the feasibility of the factors chosen to characterize the influences on the DCM damage mechanism.

When equalizing ΔT to 0 in the equation (5) we assume the residual stresses to be absent in the structure. The corresponding theoretical diagram is given in Figure 2 whence it follows that by lowering the residual stresses we positively influence on the resistance of the composite to the fracture, the effect growing higher with the diamond content in the composite, and it can amount to 26%. However, if the coefficient of the diamond grains integrity, K, were equalized to 0 in the equation (5) which corresponds to $\varepsilon^{*} = 0$ then all the diamond grains would be undamaged after the DCM sintering and, subsequently, the whole structure would be free of the damage. In this case the theoretical results shown in Figure 2 indicate at the increase of the effective fracture toughness in the DCM, this increase amounting to 86% as compared to the corresponding real conditions.

It can be said in conclusion that the model described makes it possible to imitate in a quick way the effects produced by all the parameters of a structure, the conditions of its formation, the peculiarities of the components state in a structure and its fracture mechanism in the change of the fracture toughness of the composite. The comparison of calculated functions with the experimental results (7,8) gives as the ground to affirm that the model proposed reflects the actual fracture mechanism for a dual phase composite containing dispersed particles quite realistically.

412

SYMBOLS USED

γ_p = effective specific work of the fracture in the "process zone" (J/m^2)

U_d = energy of dissipation in the dissipative region (J/m)

U_s = elastic energy introduced into the dissipative region by the residual stresses (J/m)

γ_d, γ_m = effective specific works of the diamond and matrix fracture, respectively (J/m^2)

h = width of the "process zone" (mm)

d = given grain size (mm)

ρ = density of grains with microcracks in the dissipative region

E^*, E_o = effective elastic moduli for the damaged and the initial structure of the composite (GPa)

ν^*, ν_m = Poisson ratios of the composite and the matrix, respectively

N = number of grains in a volume unit

K = damage factor of the second phase

ε^* = parameter indicating the level of the structure damage ($\varepsilon^* = \frac{1}{240}(5-4\nu^*)(1+\nu^*)\, kNd^3$)

σ_c = ultimate strength of the matrix (MPa)

K_{Ic}^m = fracture toughness for the matrix (MPa $\sqrt{m}$)

$\Delta\alpha$ = $\alpha_m - \alpha_d$ (K^{-1})

ΔT = temperature gradient in the process of the composite sintering (K)

C_d = diamond concentration by volume

413

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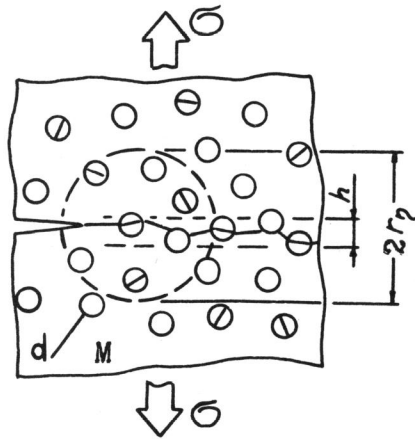   India, 1984, Vol.4, pp.3021-3028.

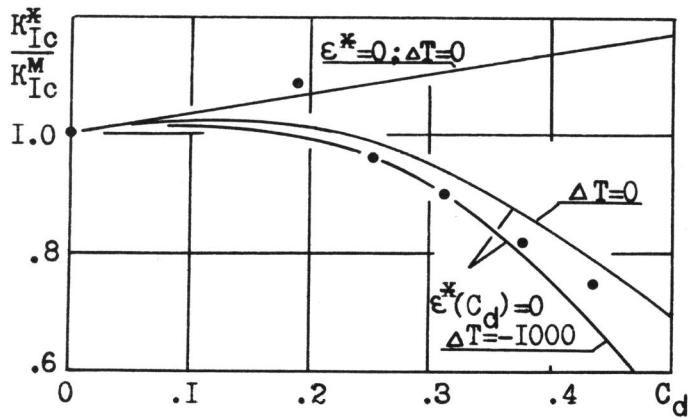**Figure 1** The schematic view of the model

Figure 2 The calculation of the variation of the effective fracture toughness values in a real composite

415