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CRITERION OF INTERFACIAL BRIDGED CRACKS INITIATION AND QUASISTATIC GROWTH

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To model the adhesion fracture toughness of the interfacial junctions the bridged crack concept is used. In the frames of this concept is assumed: there are bonds between joined materials (the interface layer); a zone of weakened bonds in this layer is considered as the interface crack with distributed nonlinear spring-like bonds between crack surfaces (bridged zone). Bonds properties define the stress state at the crack bridged zone and, hence, the reliability and the fracture toughness of the interfacial junction. In a general case, the size of bridged zone of the interface crack is comparable to the whole crack length. The conditions of a crack limit equilibrium and quasistatic growth for the case of the crack with bridged zone of large scale should be considered to model quantitatively the bridging effects. The quantitative analysis of the interface bridged crack growth consists of the following steps: 1) development of the bond deformation law; 2) evaluation of the crack opening and stresses around of the crack; 3) development and application of the nonlocal criterion of bridged crack growth to analyze the interfacial junction fracture parameters.

For given bonds deformation law the crack opening and bridged stresses can be defined on basis of the singular integral-differential equations (SIDE) method or boundary elements method (BEM), [1, 2].

The non-local fracture criterion [1, 3, 4] is used to evaluate the fracture toughness and the critical external loading in the frames of the bridged crack model. The state of the crack limit equilibrium corresponds to the condition (Π is the total potential energy, $w(\varepsilon_{ij})$ is the density of the deformation energy, ε_{ij} are the components of the strain tensor; t_i, u_i are the tractions and displacements at the body boundary s_e ; $\Phi(u)$ is the density of the strain energy of the bonds in the crack bridging zones, u is the crack opening at the bridging zones of area s_i , ℓ is a crack length, G_m the material intrinsic toughness)

$$-\frac{\partial \Pi}{\partial \ell} = -\underbrace{\frac{\partial}{\partial \ell} \left[\int_v w(\varepsilon_{ij}) dv - \int_{s_e} t_i u_i ds \right]}_{G_{tip}(d, \ell)} - \underbrace{\left[\frac{\partial}{\partial \ell} \int_{s_i} \Phi(u) ds + G_m \right]}_{G_{bond}(d, \ell)} = 0 \quad (1)$$

The terms in this relation represent the strain energy release rate at creation of a new crack surface $G_{tip}(d, \ell)$ and the rate of the energy absorption in the crack bridging zone, $G_{bond}(d, \ell)$, respectively. Note, that within the framework of the model the rate of the energy absorption depends on the bridging zone size and bond characteristics. The equilibrium bridging zone size is not assumed to be constant during cracks growth. It can be determined from condition (1) while the searching for the critical load needs additional conditions of the bond rupture. In the general case the strain energy release rate can be defined through the stress intensity factors, [1, 4].

The condition of the crack tip limit equilibrium (1) can be rewritten as follows

$$G_{tip}(d_{cr}, \ell) = G_{bond}(d_{cr}, \ell) \quad (2)$$

Condition (2) is necessary but insufficient for searching for a limit equilibrium state of the crack tip and the bridging zone. This condition enables us to determine the bridging zone size d_{cr} at the crack tip limit equilibrium state for given level of the external loads. To search for the limit state of both the crack tip and the bridging zone trailing edge within the framework of the model one should introduce an additional condition, e.g., the condition of bonds limit stretching at the trailing edge of the bridging zone $x_0 = \ell - d_{cr}$ (δ_{cr} is the bond rupture length)

$$u(x_0) = ([u_x(x_0)]^2 + [u_y(x_0)]^2)^{1/2} = \delta_{cr} \quad (3)$$

Секция 2. Неустойчивость и локализация деформации и разрушения в материалах с иерархической структурой

The regimes of the bridged zone and the crack tip equilibrium and quasi-static growth can be considered on basis of these two fracture conditions:

1) the crack tip propagates and the size of the bridged zone d increases without rupture of the bonds (subcritical crack growth)

$$G_{ip}(d, \ell) \geq G_{bond}(d, \ell), \quad u(\ell - d) < \delta_{cr} \quad (4)$$

2) the size of the bridged zone decreases due to rupture of the bond without the crack tip propagation (subcritical crack growth)

$$G_{ip}(d, \ell) < G_{bond}(d, \ell), \quad u(\ell - d) \geq \delta_{cr} \quad (5)$$

3) the crack tip propagates with simultaneous bond rupture at the trailing edge of the bridged zone

$$G_{ip}(d, \ell) \geq G_{bond}(d, \ell), \quad u(\ell - d) \geq \delta_{cr} \quad (6)$$

The last case corresponds to quasi-static crack growth because the both fracture conditions are fulfilled.

The critical external loads, σ_{cr} , the bridged zone size d_{cr} and the adhesion fracture resistance at the crack limit equilibrium state for the given crack length and the bond characteristics can be determined from the solution of Eqs. (2) and (3).

The main features of the nonlocal fracture criterion are the accounting of energy consumed by bonds during cracks growth and the analysis on this ground of non self-similar crack growth. This criterion has implemented in the frames of the bridged crack model with assumption of singularity at the crack tip, but it includes the cohesive model as the special case, see [3, 4]. The application of the nonlocal fracture criterion will be helpful for cracks filled with bonds in the most part of its length. The effects which are connected with bonds deformation accounting are the most noticeable in this case. The nonlocal criterion consists of two conditions and the appropriate equations are defined by several physical-mechanical parameters or functions, in dependence on bonds deformation law which can be defined experimentally or obtained starting from the micromechanical modeling. In the simplest cases (uniform bonds stresses or linear-elastic bonds) the criterion contents only two experimentally defined parameters 1) the maximal bonds stress) and 2) the critical crack opening and can be regarded as the two-parametric fracture criterion, as in [1].

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1. Goldstein R.V., Perelmutter M.N. Modeling of bonding at the interface crack // International Journal of Fracture. 1999. V. 99. P. 53-79.
2. Perelmutter M. Boundary element analysis of structures with bridged interfacial cracks // Computational Mechanics. 2013. V. 51. No. 4. P. 523-534.
3. Perelmutter M. Nonlocal criterion of bridged cracks growth: Weak interface // Journal of the European Ceramic Society. 2014. V. 34. No. 11. P. 2789-2798.
4. Perelmutter M. Nonlocal criterion of bridged cracks growth: analytical analysis // Acta Mechanica. V. 226. No. 2, P. 397-418.