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MODELING OF MATERIALS SELF-HEALING

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In this paper the models of cohesive and bridged cracks are used for the efficiency evaluation of healing and self-healing of cracked structures. During healing and self-healing of materials the following stages of these processes are considered: 1) formation and growth flaws/cracks under external loading and aggressive environment; 2) activation of healing or self-healing mechanisms under external influence or internal agents; 3) healing of flaws/cracks with partial or total restoration of bonds between crack surfaces.

In the frames of cohesive/bridged approach is assumed: there are artificial bonds between crack surfaces (the interface layer); any zone of these bonds is considered as a crack process zone (cohesive or bridged) with distributed nonlinear spring-like ligaments between the crack surfaces. The bonds properties variation define the stress state at the crack process zone and, hence, the fracture toughness of the material. In a general case, the size of process zone of the crack is comparable to the whole crack size. The choice of the process zone model (cohesive or bridged) depends on the materials type and the self-healing mechanism. The transition between cohesive and bridged models is considered.

The main task of the modeling consists of the computational analysis of the bridging stresses distribution and in the computing of the stress intensity factors which are the main characteristics of healing and self-healing efficiency. The mathematical background of the stresses problem solution is based on the singular integral-differential equations (SIDE) and the boundary element methods (BEM) [1-2]. Different self-healing methods (microcapsules filled with a self-healing agent, microvascular fibers, mendable polymers) with various mechanisms of self-healing are analyzed. The thermo-fluctuation kinetic model [3, 4] is used to evaluate the time of the crack bridged zone formation and regeneration. The healing time and efficiency are dependent on the chemical reaction rate of the healing agent, the crack size and the external loads. The non-local fracture criterion [1, 5, 6] is used to evaluate the fracture toughness and the critical external loading in the frames of the bridged crack model. The model can be used for the evaluation of composite materials healing and durability. Some results of self-healing processes analysis are presented and discussed.

A straight crack on the interface between different materials under the external tension σ_0 (which is normal to the crack plane) was considered, see Fig. 1. It was assumed that at the initial time instant (when the surfaces of a crack are free of constraints) some healing process is activated inside of a crack and ligaments between crack surfaces are building, see Fig. 2, where d - is the built bridged zone size, $u_{x,y}$ - are the components of the crack opening at the bridged zone edge.

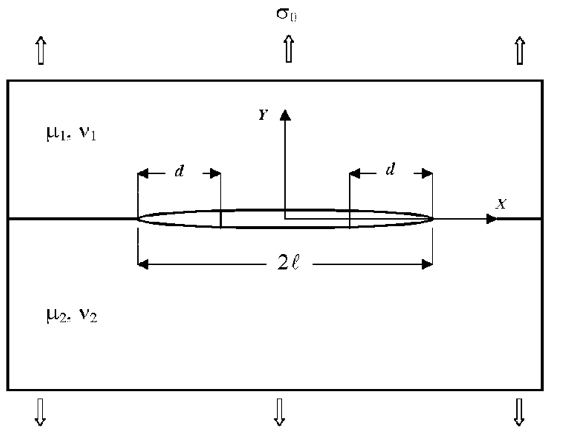

Fig.1 A crack on the interface between different materials

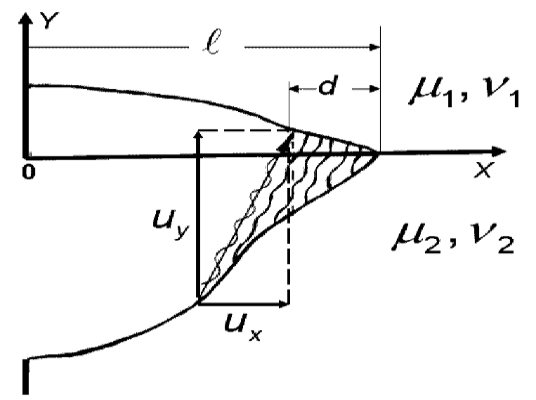

Fig.2 Ligaments between crack surfaces

The numerical calculations were performed for plane strain conditions and the following elastic constants of the joint materials and bonds (*Cu*-epoxy polymer): $E_1 = 25GPa$, $E_2 = 135GPa$; $E_b = E_1$ (elastic modulus of bonds), $\nu_1 = 0.35, \nu_2 = 0.3$. The purpose of calculations was the dependence analysis of the self-healing process efficiency (the measure of efficiency is the level of SIF at the crack tip) on the bridged zone length (the crack filling with bonds) and on the bonds stiffness. In Fig. 3 the dependencies of the SIF module versus the relative bridged zone length are shown for different values of the relative bonds stiffness $\kappa = \ell/H$ (here ℓ - is the crack half length, H - is the thickness of the interfacial layer between materials). For bonds with relative stiffness more than 10 the healing efficiency reaches the saturation if the crack has filled with bonds more than on the half of its length. The saturated bridged zone size here is defined as the zone size above that the SIF is changed less than 5%. The evolution of the healing process as the dependence of SIF module versus a relative bond stiffness (in logarithmic scale) is shown in Fig. 4, where d - is the built bridged zone size. Saturation of the healing effect is observed for bonds with rather big stiffness. In Fig. 3 and Fig. 4 values of SIF for cracks with bonds were scaled by SIF for the same crack length without bonds, $K_0 = \sigma_0\sqrt{\pi\ell}$.

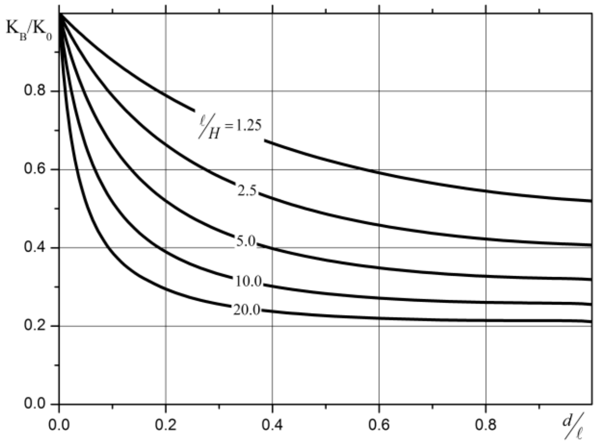

Fig 3. SIF module vs relative bridged zone length

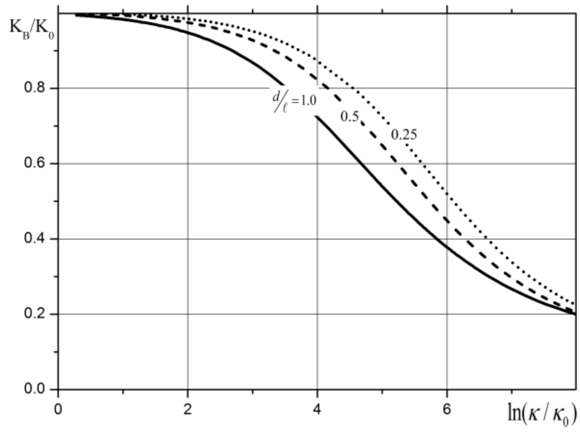

Fig.4. SIF module vs relative bond stiffness

Analysis of the healing process in finite size structures can be performed by boundary elements method [2]. Growth prediction of healed cracks can be performed on the basis of the bridged cracks growth criterion [5, 6].

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References

1. R.V.Goldstein, M.N.Perelmuter, Modeling of bonding at the interface crack, Intern. J. of Fracture, 1999. V.99. no.1/2, P.53-79.
2. Perelmuter M. Boundary element analysis of structures with bridged interfacial cracks // Computational Mechanics, 2013, V. 51. no. 4. P.523-534.
3. Goldstein R.V., Perelmuter M.N. Kinetics of interface cracks formation and growth, Mechanics of Solids, 2012, V.47, no.3. P.87-102 (in English).
4. Perelmuter M. Kinetics of interfacial crack bridged zone degradation, Journal of Physics: Conference Series. 2013. V. 451, no 1. P. 012–020.
5. Perelmuter M. Nonlocal criterion of bridged cracks growth: Weak interface, Journal of the European Ceramic Society. 2014. V. 34. no. 11. P. 2789–2798.
6. Perelmuter M. Nonlocal criterion of bridged cracks growth: analytical analysis, Acta Mechanica. 2015. V. 226, no. 2. P. 397–418.