DIAGRAMS FOR QUASI-BRITTLE FRACTURE OF BIMATERIAL[1]

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Introduction

Crack-like defects in composite materials often occur at interfaces. Such a composite, for example, may be formed as a metal-ceramic junction [1]. Study of strength properties of welded junction is given in [2]. Obviously, “a single parameter is not sufficient to cover the whole range of structural constraint to compensate for the deviations of the actual stress fields from the reference stress fields” [3, p. 1965].
The modified Leonov-Panasyuk-Dugdale model in conjunction with the Neuber-Novozhilov approach is proposed for analytical study of fracture process.
In a numerical model, the general Lagrange definition of solid mechanics equations for deformed body is used together with Green-Lagrange strain tensor as a measure of deformations, and the Piola-Kirchoff tensor as a second tensor. Applying the finite element method, a plastic zone in the vicinity of the crack tip has been calculated.

Analytical fracture model

A crack of the finite length $2l_0$ (Fig. 1) at the interface between two structured media is considered. The normal tensile stress σ_∞ acting normally to the crack plane given at infinity.

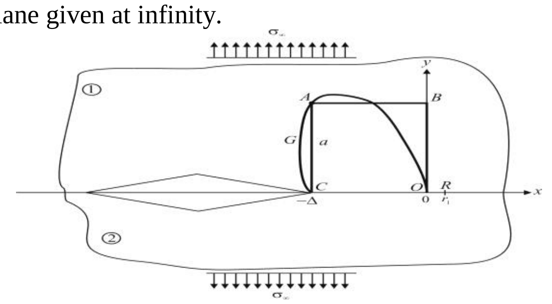

Fig. 1. Approximation of pre-fracture zone.Parameter r_i is specific linear size of a structure of the i th material. Let materials in the upper and lower half-planes differ only by limits of elasticity $\sigma_{Y1} < \sigma_{Y2}$.
The sufficient criterion for mode I crack [4, 5]

$$\frac{1}{kr_1}\int_0^{nr_1}\sigma_y(x,0)dx \le \sigma_{Y1}\ , \qquad (1)$$

$$2v(x) \le \delta_1^*,\ \ -\Delta \le x < 0\ . \qquad (2)$$

is used. Here $\sigma_y(x,0)$ is normal stress on the crack continuation, nr_1 is the averaging interval, $(n-k)/n$ are damage coefficients, $v(x)$ is the crack half-opening. Let δ_1^* denote the critical fictitious crack opening for material 1; in this case, a structure (fiber) of material 1 is broken at the tip C of a real crack (boundary point of the pre-fracture zone).
The width a and δ_1^* at the plane stress state are calculated as follows

$$a = 5\left(K_{I\infty}\right)^2 \Big/ 8\pi\left(\sigma_{Y1}\right)^2\ ,\ \delta_1^* = (\varepsilon_{11}-\varepsilon_{01})a\ . \ (3)$$

Inequality (2) for critical value of the parameter $x = -\Delta^*$ turns to be the equality $2v\left(\Delta^*\right) = \delta_1^*$, the latter with the help of (3) by applying the simplest approximation of fictitious crack opening and stress intensity factors (SIFs) leads to the approximate expression

$$\Delta^* = \frac{5^2}{2^{11}}\left(\frac{\varepsilon_{11}-\varepsilon_{01}}{\varepsilon_{01}}\right)^2\left(\frac{\sigma_\infty^*}{\sigma_{Y1}}\right)^2 l^* \qquad (4)$$

of critical length of the pre-fracture zone in material 1.
Inequality (1) for critical values of σ_∞^* and Δ^* becomes the equality

$$\frac{\sigma_\infty^*}{\sigma_{Y1}} = \left[\sqrt{\frac{n^2}{k^2}+\frac{2l^*}{r_1}\frac{n}{k^2}} - \frac{5}{16\pi}\frac{\sqrt{n}}{k}\frac{\varepsilon_{11}-\varepsilon_{01}}{\varepsilon_{01}}\sqrt{\frac{2l^*}{r_1}}\right]^{-1}. \qquad (5)$$

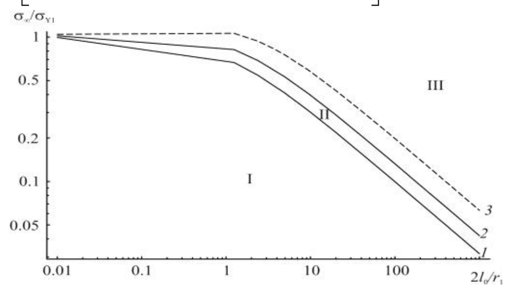

Fig. 2. Fracture diagrams of bimaterial. Curve 1 is plotted by necessary criterion (6), curves 2 and 3 are plotted by sufficient criterion (5) for biomaterial and homogeneous material.

$$\frac{\sigma_\infty^0}{\sigma_{Y1}} = \left(\frac{n^2}{k^2}+\frac{2l_0}{r_1}\frac{n}{k^2}\right)^{-1/2}. \qquad (6)$$

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2 Finite element fracture model

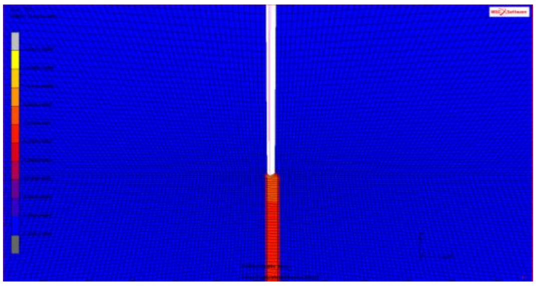

Fig. 3. Plastic strain zone in bimetallic plate.

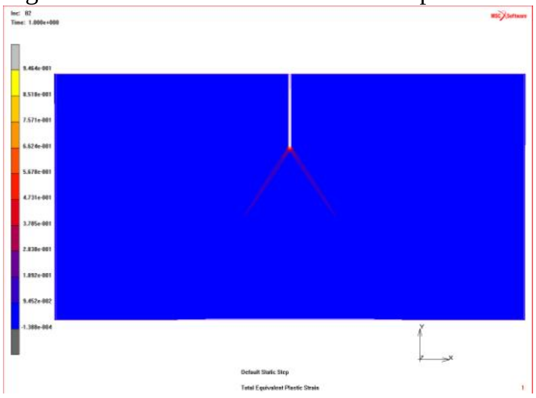

Fig. 4. Plastic strain zones in homogenous plate.

Fig. 3. features a narrow plastic zone arising in a weaker bimetal ($\sigma_{Y1} = 340 < 500 = \sigma_{Y2}$) under loading σ_∞ =206MPa.

3 Comparison between analytical and numerical results

Given in the fifth column of the Table are ratios between lengths Δ_E and Δ_T of pre-fracture zones obtained in a numerical experiment and analytically using expression (4).

$\frac{\sigma_\infty}{\sigma_{Y1}}$	Expr.	Theory		$\frac{\Delta_E}{\Delta_T}$
	Δ_E	$\frac{\varepsilon_{11}-\varepsilon_{01}}{\varepsilon_{01}}$	Δ_T	
0,068	0,040	2,96	0,007	5,7
0,0752	0,060	3,64	0,014	4,3
0,0821	0,081	4,18	0,022	3,7
0,0889	0,102	4,63	0,031	3,3
0,1026	0,146	5,36	0,055	2,7
0,1163	0,204	5,91	0,087	2,3
0,1436	0,356	6,70	0,170	2,1
0,1710	0,543	7,24	0,281	1,9
0,2326	1,219	7,99	0,632	1,9
0,3352	3,902	8,62	1,530	2,6

4 Discussion. Conclusion

Numerical modeling has supported that the narrow plastic zone in a weaker material is located on an interface of two media and crack blunting occurs. The results of numerical modeling are in good agreement with those obtained in full-scale tests (see [1], p. 62, Fig. 5) and correspond to analytical estimations of parameters of the pre-fracture zone. The performed numerical experiment has shown that it is expedient to consider relations (4)-(6) as structural relations acceptable for processing of results obtained in full-scale tests. The fracture assessment curve in Fig. 2 [6] may be useful for study of deformation and failure of composites. In the case of bimaterial, the fracture assessment curve indicates that the region of unstable crack growth is twice as large as that in a homogenous material. The numerical modeling has supported feasibility for embrittlement predicted in the analytical model: the plastic zone in a homogenous metal is presented in the form of two parts (whiskers in Fig. 4) and it is concentrated as a narrow band in a weaker metal in bimetal (Fig. 3).

References

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