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STARTING OF AN INTERFACIAL CRACK WITH CONTACTING FACES FROM THE CORNER POINT OF A POLYGONAL INTERFACE*

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The parameters of a small-scale failure zone in the bonding material of a piecewise-homogeneous body under plane strain condition are determined using the Wiener–Hopf method. The failure zone is located at the end of an interface crack with tip at the corner point of the polygonal interface of the materials. The crack faces contact according to the law of dry friction. The failure zone is modeled by discontinuity line of the normal displacement on which the normal stress is equal to the tensile strength of the bonding material. Expressions for the length of the failure zone, the opening displacement of the crack faces, and local stress field near the crack tip are derived. The starting mechanism of the initial crack is described. It is assumed that a microcrack nucleates in some part of the failure zone and coalesces with the initial crack with increasing load. The dependence of the parameters of the failure zone, the microcracks, and the limiting load on the load and the parameters of the composite are analyzed numerically.

Keywords: corner point of interface, interfacial crack, friction contact of faces, failure zone, microcrack, crack initiation

Introduction. An open interface crack modeled by a mathematical cut with faces free of loads was one of the first to be analyzed in the fracture mechanics of piecewise-homogeneous bodies in the 1960s [12, 13, 29, 34]. The main disadvantage of the model is the assumption of the oscillating dependence of the displacements of the crack faces on the distance from the crack tip, which leads to physically impossible interpenetration of the crack faces. This made it difficult to apply the criteria of linear fracture mechanics to such models [17].

Along with opening-mode and shear cracks, the failure of piecewise-homogeneous bodies under compression along interfacial cracks, causing the loss of local stability in the vicinity of the crack was addressed in [4, 15, 16].

The alternative model of an interface crack with faces contacting near its tip developed in [3, 5, 6, 11, 18] made it possible to avoid the above-mentioned disadvantage. However, the power singularity of the stress near the tips remains in this model, which means the presence of preconditions for crack growth. One of these preconditions is the failure zone as a stress concentrator near the tip of the interface crack. It is a zone of irreversible strains characterized by plastic yielding, increased number of dislocations, pores, microcracks, and other structural microdefects. The calculation of the parameters of failure zones near stress concentrators has become an integral component of studies of the structural integrity of engineering structures and mechanisms [21, 24. 25].

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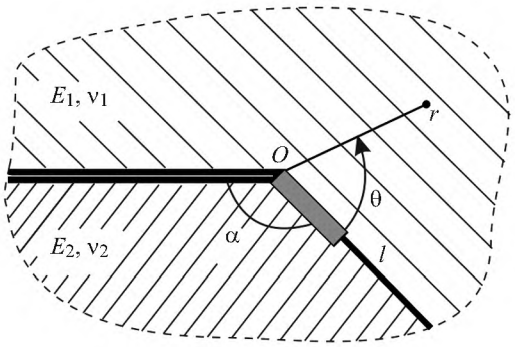


Fig. 1

The majority of publications on the determination of the parameters of failure zones in a piecewise-homogeneous body address cracks at a plane interface [2, 19, 20, 22, 27, 30, 31, 33]. Since the constitutive equations of nonlinear fracture mechanics based on the assumption of a strong influence of failure processes on the stress–strain state of the body are very complex, numerical methods or model simplifications were used.

Modern industrial products, construction materials, composites with granular reinforcement, and rocks quite often contain cracks located at a polygonal interface. For such a configuration of piecewise homogeneous bodies, various models of failure zones near the tip of an open interface crack coinciding with a corner point of the interface were studied in [7–9].

It should be noted, however, that the stress singularity exponent near the tip of an open crack at a polygonal interface appears to be complex [7, 32]. This suggests the presence of physically impossible oscillations of the crack faces and the necessity of using a Comninou-type contact model if the contact zone of the crack faces is large. For example, the stress–strain state of interface shear cracks with faces emerging from a corner point of the polygonal interface between two dissimilar materials and contacting without friction was analyzed in [1, 26]. In [1], it was concluded that the equilibrium of interface small-size cracks with full smooth contact of the faces is unstable, which means the possibility of further growth of the cracks.

Continuing the studies [1, 7–9, 26], we will study the initial stage of initiation of a crack with contacting faces emerging from a corner point of the polygonal interface between two dissimilar homogeneous isotropic materials. It is assumed that the small-scale failure zone origins on the continuation of the crack in the bonding material, followed by break of interparticle bonds within the zone and nucleation of a microcrack that grows with increasing load until coalescing with the initial crack. The goal of the present paper is to calculate the parameters of the failure zone, the microcrack, and the critical load under which the crack nucleates.

1. Problem Statement. To study the initial stage of crack initiation under plane strain, we will determine the parameters of the small-scale failure zone near the crack tip coinciding with the corner point of the polygonal interface with kink angle α between two dissimilar homogeneous isotropic elastic materials with Young's moduli E_1 and E_2 and Poisson's ratios ν_1 and ν_2, respectively. Assume that the bonding material is less crack-resistant than the bonded materials. Because of this, the mechanism of crack propagation in the bonding material is brittle. Neglecting the thickness of the bonding layer, we model the failure zone in it by a straight-line segment on which the normal displacement undergoes discontinuity, while the normal stress is equal to the tensile strength σ_0 of the bonding material. Assuming the contact of the crack faces near the crack tip, we model the contact zone by a cut with faces interacting by dry friction with friction coefficient μ. Since the size of the failure zone at the stage being examined is small, its length l can be considered to be much shorter than the length L of the crack and the length s of the contact zone. This allows restricting the analysis of the stress–strain state to the neighborhood of the crack tip and reducing the original problem to the determination of the parameters of the small-scale failure zone in the bonding material at a piecewise-homogeneous interface near the tip of a semi-infinite interface crack with contacting faces. It is assumed that the crack tip coincides with the corner point of the polygonal interface (Fig. 1).

With the above assumptions, we arrive at a static boundary-value elastic problem with the boundary conditions

$$\theta = 0: \quad \langle \sigma_\theta \rangle = \langle \tau_{r\theta} \rangle = 0, \quad \langle u_r \rangle = 0,$$

$$\theta = -\alpha \cup (2\pi - \alpha): \quad \langle \sigma_\theta \rangle = \langle \tau_{r\theta} \rangle = 0, \quad \langle u_\theta \rangle = 0, \quad \tau_{r\theta} = -\mu\sigma_\theta, \tag{1.1}$$