# ON CRACK ASSESSMENT AT BIMATERIAL INTERFACES

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Summary Based on the knowledge of the singular fields at bimaterial wedges, the direction of crack nucleation can be determined using the novel and numerically highly efficient Boundary Finite Element Method. An essential question in the context of crack assessment is to find a criterion for crack nucleation. For that aim, the hypothesis of Leguillon is modified. Herein, the crack is assumed to be critical when and only when both the released energy and the local stress reach critical values along a hypothetical crack of finite length.

## INTRODUCTION

The advantage of numerical simulation of the mechanical behaviour of complex systems is e. g. that potential initiation of failure may already be detected in an early state of development. Many modern multi-component structures require a number of joints and connections which consist frequently of at least two different materials. Thus, recent requirements for adhesive bonds place an increasing emphasis on the knowledge of the mechanisms responsible for fracture. As actual applications of the investigations presented here, ceramic thermal barrier coating systems or the sealings of high temperature fuel cells can be mentioned amongst others, like bonded joints of laminates for the use in aerospace, naval or automobile structures or soldered joints for electronics. For all these applications, particularly when they are under significant thermal loads, the regions in the vicinity of material and mostly additional geometrical discontinuities are considered to belong to the most critical locations of the whole component. In a first step, the local mechanical fields have to be analyzed. This can be done e. g. analytically by means of the complex potential method or by the semi-analytical Boundary Finite Element Method (BFEM) which is introduced as a novel approach by Wolf and Song [1]. At bimaterial wedges, these stress fields show a singular behaviour which differs from the crack tip singularity and depending on geometry and material combination, for real life situations it leads to non-separable singular fields in general.

## DETERMINATION OF DIRECTIONS FOR CRACK INITIATION

At a general bimaterial wedge under arbitrary loading, a crack may be initiated not only at the interface but also at a certain angle $\varphi_0$ to the interface. The identification of these angles $\varphi_0$ can be based on the hypothesis of Erdogan and Sih [2], knowing that alternatively, there are several criteria which could be used for this aim, see [3]. According to this criterion, it can be assumed that a crack will grow in radial direction of the largest circumferential tensile stress perpendicular to the direction of $\sigma_{\varphi max}$, starting at its tip in radial direction.

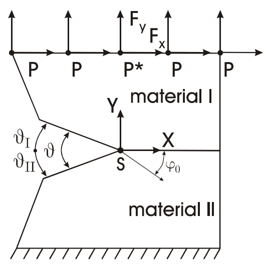



Figure 1: Model and presumed arbitrary mixed mode loading.

As shown in figure 1, a square respectively rectangular plane model with a notch like opening, and the centre of singularity S, has been analysed by the BFEM. The lower and the upper edge of the model have been kept straight and of equal length. No translations of the bottom boundary of the structure are allowed while the top edge nodes are tied to each other with a single master point $P^*$ by multi-point constraints. The load components applied at that point are noted as $F_x$ and $F_y$. A load factor $\beta$ characterizing situations of arbitrary mixed mode loading is introduced as: $\beta = F_x / (F_x + F_y)$. In that sense, pure opening mode I corresponds to $\beta = 0$, and pure sliding mode II to $\beta = 1$. Thus, any value between -1 and +1 represents a mixed mode case of the applied loading.

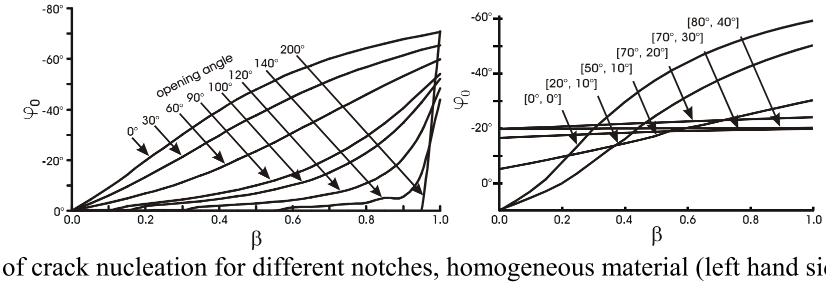



Figure 2: Directions of crack nucleation for different notches, homogeneous material (left hand side) and unsymmetric notch opening $[\vartheta_I, \vartheta_{II}]$ in a bimaterial with $E_I/E_{II} = 0.4$ (right hand side).

The variation of predicted crack propagation directions under various mixed mode situations is depicted in figure 2. For the homogeneous wedge of linear-elastic material, one conclusion can be drawn directly, namely that under pure mode I loading, crack initiation starts at the interface and under pure mode II loading the well-known characteristic angle $\varphi_0 = 70{,}5°$ is calculated. The graph on the right side illustrates the directions of crack initiation for unsymmetric bimaterial configurations.

## INITIATION OF CRACK OF FINITE LENGTH

Apart from the more general example considered above, in this section a real geometry of a high temperature fuel cell stack is considered. For this case, the crack will grow along the interface, since the interface toughness is lower than the fracture toughness of the joined material. A composite part of thin ceramic layers is the membrane electrodes assembly (mea) which is embedded in a frame within the interconnect. In the first instance, a hypothetical crack growth along the interface between a thin glass ceramic sealing joint and an interconnector plate made of steel is assumed as given in the section sketch, figure 3. For this model, the energy release rate is calculated using the method of Rybicki and Kanninen [4] and integrated, so that the released energy E is known and can be compared to the critical value of the individual toughness of the joined materials and to that of the interface itself which is marked by $E_{crit.}$ in figure 4.

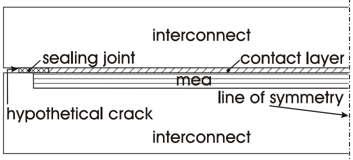
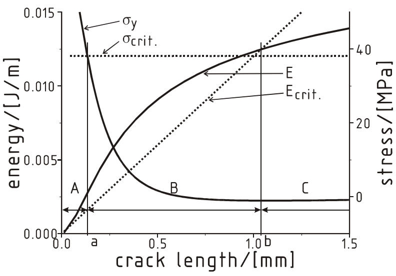



Figure 3: Sketch of the investigated geometry (not in scale), mea and sealing joint may be regarded as thin layers.

As a further necessary condition for crack initiation, in addition to a critical energy release sufficiently high stresses are required: Fracture occurs, if the material specific strength $\sigma_{crit.}$ as characteristic value of the tension $\sigma_y$ is exceeded. According to Leguillon's hypthesis [5], both criteria together are necessary conditions of fracture.



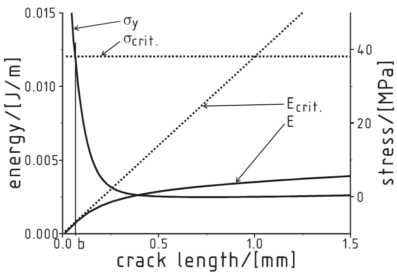




Figure 4: Assessment of critical crack lengths, joint thickness reduced to one half for the graphs on the right.

The graphs showing the released energy and the tensile stress on the left side of figure 4 are calculated for a virtual crack along the interface with a length of one half of the whole length of the interface (10 mm). In the illustration, the range is restricted to 15 %. Considering the released energy E, it is conspicuous that up to a crack length b of little more than 1 mm, corresponding to a section point between E and $E_{crit.}$, the amount of energy is sufficient for the creation of new crack surfaces. At the same time, the admissible tension exceeds the material respectively interface specific strength up to a crack length a, so that together both conditions for crack initiation are fulfilled within range A. This can be understood as a period of crack initiation. Range B corresponds to instable crack growth as here the necessary energy is available and the singular stress field moves with the crack tip and thus again violates the strength criterion. Since the energy E afterwards decreases below the critical value, the crack is assumed to stop at a length b, according to the hypothesis. For the case that no section point with a virtual crack length b between E and $E_{crit.}$ exists, no crack arrest will happen. The graph on the right side represents a geometry for which there is no crack initiation as the joint thickness is reduced to one half of the original thickness considered before.

## CONCLUSIONS

The tendency to fracture may be appraised studying the energy available for crack growth, and at the same time comparing the local tensile stress to the specific interface strength. Together these two conditions allow the assessment of fracture. Using the criterion of maximal circumferential strength for the BFEM-calculation of the singular stress fields, a potential direction of crack propagation can be identified.

### References

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