EFFECTIVE STRESS INTENSITY FACTOR OF A REAL-LIKE 3D INTERGRANULAR CRACK FRONT

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A 3D model was developed to study the stable intergranular crack growth within the process zone. It simulates conditions occurring at the front of the fatigue precrack during the stress corrosion cracking or in case of brittle fracture. In order to asses the stability of such intergranularly branched crack, the global effective stress intensity factor K_{eff} at its front is to be calculated. The numerical solution of local k_1, k_2 k_3 and k_{eff} obtained using the program system FRANC3D was compared with the analytical one in case of relatively simply branched crack front. Moreover, both the k_{eff} and the K_{eff} were calculated for a real-like crack front generated by means of 3D Voronoia cell network. It describes the geometrically induced shielding at the front of a branched crack.

INTRODUCTION

Intergranular relief is the most prevailing surface morphology in case of corrosion-assisted fatigue or brittle fracture of coarse grained high strength steels (e.g., Pokluda (1)). Accompanied shielding effects caused by irregular crack front can lead to a substantial reduction of the crack driving force (e.g., Surresh and Shih (2)).

In order to asses the amount of such shielding in case of intergranular fracture mode occurring after K_{Ic} test of some coarse grained AISI 4340 steels, a simple analytical 2D model was developed by Pokluda et al (3). The grain boundary network was approximated by regular hexagons with log-normal size distribution. This analysis has shown that more then 50 pct of the K_{Ic} increment can be explained due to the crack branching.

Subsequently, a quasi-3D model of intergranular crack branching was proposed by Šandera and Pokluda (4). Here, the boundary network was constructed using 2D Voronoia cells in a very close approximation to the real grain network in a cross section planes.

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Currently, the work on a full-3D model goes to its final stage. The aim of this paper is to present results of the local k_1, k_2 k_3 and k_{eff} stress intensity factors calculations at the intergranularly branched 3D-crack front. Moreover, a global K_{eff} value is presented which quantifies a geometrically induced shielding effect.

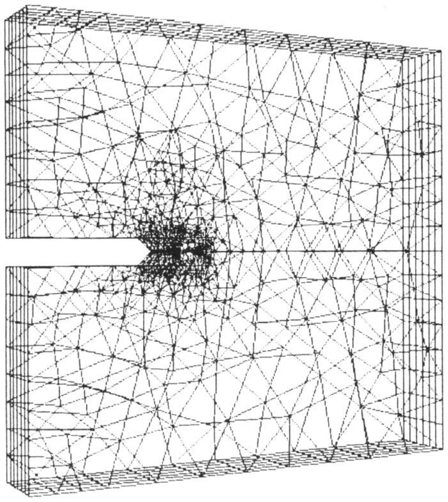

Figure 1: Boundary elements network in a CT-like specimen.

COMPARISON WITH ANALYTICAL APPROACH FOR SIMPLE BRANCHES

Numerical analysis was performed for a CT-like specimen (Fig. 1) where a precrack contains a small intergranular branch along its whole front (Fig. 2). A system of boundary integral equations was created and solved by boundary element method using the program system FRANC3D (5). On the basis of calculated displacement and stress fields, local values of k_1, k_2 k_3 and the corresponding k_{eff} value

$$k_{eff} = \sqrt{k_1^2 + k_2^2 + \frac{1}{1-\nu} k_3^2}$$

(normalized to the remote K_I value for the straight crack front) were obtained along the branched crack front.

In order to check at least the qualitative relevancy of the numerical approach, a comparison with an approximate analytical method proposed by Faber and Evans (6) was made in case of a simply branched crack front. Results of both the numerical and analytical approaches are shown in Fig. 3 and Fig. 4. Apart from the questionable accuracy of the analytical method, the agreement between both approaches seems to be quite sufficient.

As an appropriate parameter characterizing the stability of the branched crack can be considered to be a global effective stress intensity factor

$$K_{eff} = \frac{1}{w}\int_0^w k_{eff}(z)\cos\Phi(z)\mathrm{d}z,$$

where w is the specimen thickness, Φ is the local twist angle and z is the Cartesian coordinate along the crack front.

This global K_{eff} value is shown in Table 1 as a function of the shape characteristics Θ_m (mean deflection angle) and Δ_Θ (its standard deviation). It illustrates the dependence of the shielding effect on the branched crack shape. The first four rows correspond to qualitatively the same shapes as in Fig. 3. The last row corresponds to the real-like branch which will be discussed further.

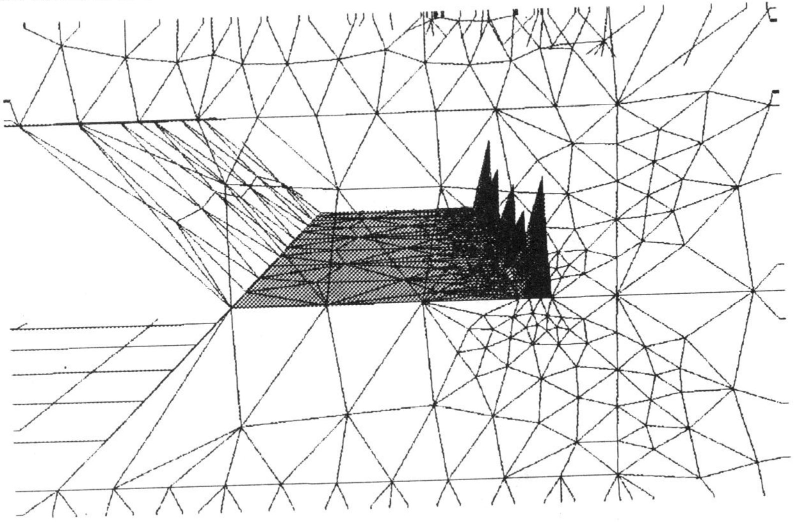

Figure 2: Detailed view of the precrack surface with a small branched subcrack.

REAL-LIKE BRANCHED CRACK

A stable growth of the intergranular subcrack within the process zone structuralized by 3D Voronoia cells according to Okabe et al. (7) is simulated like a quasi-continuous process starting from the defined straight front of the long fatigue precrack. Individual intergranular facets adjacent to the crack front are assumed to break subsequently in an instable manner according to some physically justified rules described by Šandera et al. (8). At the current phase of the model, no forking (splitting) of the subcrack front is allowed in the computer procedure. An example of the intersection of the plane vertical to the precrack plane with the crack generated in this manner is plotted in Fig. 5. In our simplified model for K_{eff} calculation, each point of this front is connected with the straight precrack front by a straight line. A set of all these lines creates the surface of the branched subcrack - see Fig. 2.

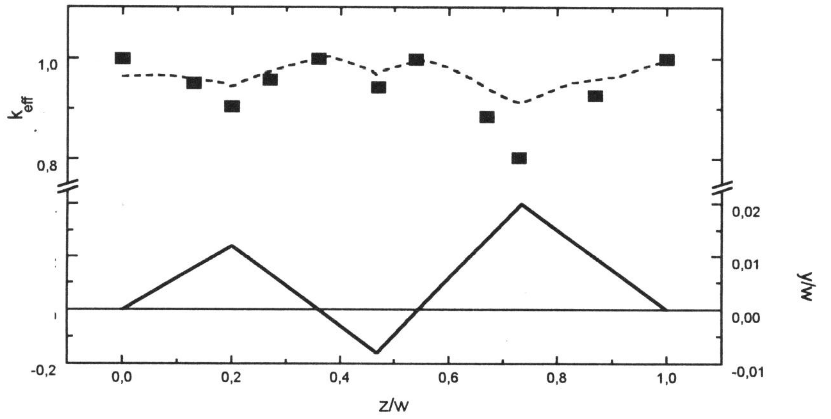

Figure 3: Local effective k_{eff} values along the simply branched crack front.

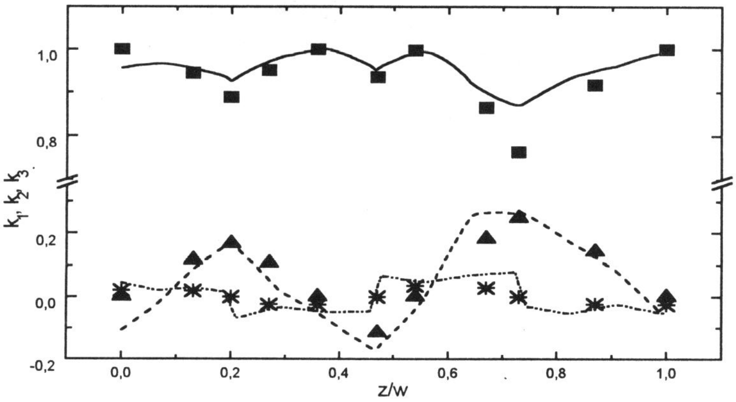

Figure 4: Comparison of analytical results (marked by symbols) and FRANC3D solutions (marked by lines) along the simply branched crack front.

The calculated normalized local values of k_{eff} along this crack front are shown in Fig. 5. The corresponding global value K_{eff} can be found in the last row of the Table 1. Clearly, the intergranular branching represents a considerable decrease in the effective stress intensity factor (or the crack driving force) when comparing with the straight crack front.

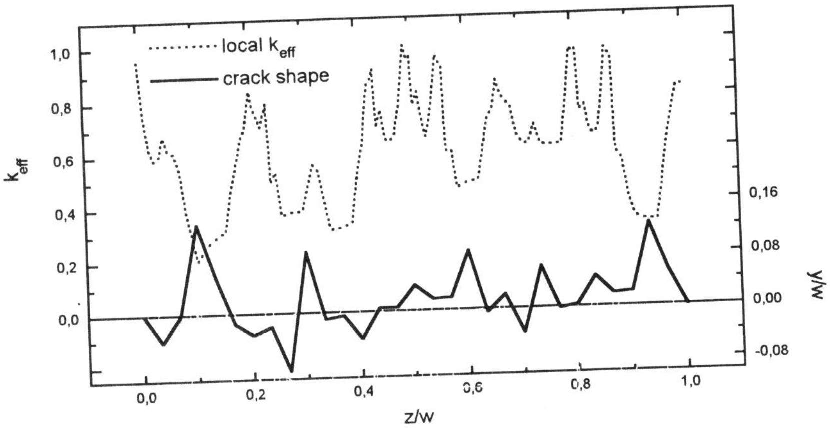

Figure 5: Local effective k_{eff} value along the real-like crack front.

As can be seen from Table 1, both the characteristics Θ_m and Δ_Θ for the real-like crack are much higher than those for the simply branched cracks. Consequently, the related K_{eff} value is much lower, i.e., the shielding effect of the real-like crack is extremely high.

CONCLUSION

The main results obtained in this work can be summarized into the following points:

1. For simply branched crack fronts, both the numerically and analytically calculated stress intensity factors are well comparable.
2. The effective stress intensity factor for a real-like intergranular crack front can be successfully calculated using the program system FRANC3D.
3. The geometry induced shielding of intergranularly branched cracks can considerably reduce the crack driving force in comparison with the ideal straight crack of the same length.

It is to believe that even more complicated subcrack space geometry (very close to the real fracture morphology) could be successfully analysed in the near future.

Tab. 1: Global crack shape characteristics related to the global K_{eff} factor.

Θ_m	Δ_Θ	K_{eff}
10.205	11.517	0.963
16.700	18.734	0.952
19.800	22.172	0.939
15.995	23.952	0.934
26.915	50.351	0.385

REFERENCES

(1) Pokluda J.: "Fractography '94", ed. Ľ. Parilák, IMR SAS Košice, 1994, 195.

(2) Suresh, S. and Shih, C.F., Int. J. Fracture, Vol. 30, 1986, pp. 237-259.

(3) Pokluda, J., Šandera, P. and Zeman, J., ASTM STP 1131, 1992, pp. 653-664.

(4) Šandera P. and Pokluda J.: Metallic Materials Vol. 34, 1996, pp. 230-240.

(5) Ingraffea T. et al.: "FRANC 3D" – 3D FRacture ANalysis Code. The Cornell University Fracture Group, Cornell University, Ithaca, NY, 1996.

(6) Faber K. T. and Evans A. G.: Acta Metall. Vol. 31, 1983, pp. 565-576.

(7) Okabe, A., Boots, B. and Sugihara, K., "Spatial Tessellations", J. Wiley and Sons, Chichester, 1992.

(8) Šandera P., Ponížil P. and Pokluda J.: "Fractography '97", ed. Ľ. Parilák, IMR SAS Košice, 1997, 151.

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