I-73 A MODEL OF FRACTURE PROCESS ZONE AND MICROCRACK TOUGHENING

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1. INTRODUCTION: Great efforts have been devoted recently to the application of fracture mechanics to brittle materials such as concrete, rocks and ceramics. The fracture toughness of these materials is observed to increase with the growth of the main crack. The microcracking in the fracture process zone has been considered to be an important mechanism. The linear elastic fracture mechanics, which is a well established method for brittle metals, breaks down for those materials. In the present study, a theoretical model is developed for the fracture process zone and its application to the microcrack toughening problem is discussed.

2. THEORETICAL MODEL: The present model consists of multiple microcracks at the tip of a semi-infinite main crack. The interaction effects between the main crack and microcracks are evaluated.

First, we consider the solution of one arbitrarily located microcrack near the tip of a semi-infinite crack as shown in Fig.1. General solutions, as well as closed-form approximate solutions, are obtained in Ref.[1], using the method of pseudo-tractions. The lowest order solutions for the stress intersity factors of both the main crack and the microcrack are derived explicitly, under mode-I loading (K_I^0 is the applied stress intensity factor), as

$$K_I^{MA}=K_I^0+K_I^0\left(\frac{c}{8d}\right)^2 A(\theta,\Phi), \qquad K_I^{MI}\Big|_{x=\pm c}=K_I^0\sqrt{c/2d}\ B(\theta,\Phi),$$

where

$$A(\theta,\Phi)=11\cos(\theta)+8\cos(2\theta)-3\cos(3\theta)+4\cos(\theta-2\Phi)+2\cos(\theta+2\Phi)+8\cos(2\theta-2\Phi)-6\cos(3\theta-2\Phi)-8\cos(4\theta-2\Phi),$$

$$B(\theta,\Phi)=\cos\left(\frac{\theta}{2}\right)+\frac{1}{4}\cos\left(\frac{\theta}{2}-2\Phi\right)-\frac{1}{4}\cos\left(\frac{3}{2}\theta-2\Phi\right).$$

Depending on the location (c/d,θ) and orientation (Φ) of the microcrack, the stress intensity factor at the tip of the main crack may either be increased (amplification, $K_I^{MA}/K_I^0>1$) or decreased (shielding $K_I^{MA}/K_I^0<1$). The regions of amplification and shielding predicted by the lowest order solutions are shown in Fig.2.

If microcracking due to the stress concentration near the tip of the main crack is considered, the preferred orientation of the microcrack is chosen so that the stress intensity factor at the tip of the microcrack is maximized. For the lowest order solution, it correspods to the principal direction of the undisturbed stress field with maximum normal tensile stress, which is shown by dashed lines in Fig.2. The stress intensity factors for the main crack and the microcrack are shown in Fig.3 and Fig.4.

In the case of multiple microcracks, the microcrack-microcrack interaction, as well as the main crack-microcrack interaction, must be evaluated. To estimate the effect of the microcrack-microcrack interaction, two microcracks near the tip of the main crack are considered in Ref.[1]. One microcrack is fixed at a chosen position, while the other microcrack is allowed to change its position. The obtained results are shown in Fig.5 and Fig.6, which shows the variations induced by the microcrack-microcrack interaction for the stress intensity factors of the fixed microcrack and the main crack, repectively. It is seen that when the two microcracks are far apart from each other and from the tip of the main crack, the lowest order solutions provide reasonable estimate for the stress intensity factors of both the main crack and the microcrack.

3. APPLICATION TO MICROCRACK TOUGHENING: Introducing assumptions for the distribution of the microcracks and an appropriate fracture criterion, the present model can be used to predict the size and shape of the microcrack process zone and the amount of microcrack toughening. Under the condition that the microcrack density is low so that interaction between microcracks can be neglected, results shown in Fig.3 might be used to determine the size and shape of the fracture process zone; see also Fig.5. The amount of the microcrack toughening can then be predicted from the reduction of the stress intensity factor at the tip of the main crack for the determined size and shape of process zone and distribution of microcracks. As the effect of interaction between the microcracks on the stress intensity factor of the main crack is found to be rather small as can be seen from Fig.6, the superposition of the result for a single microcrack shown in Fig.4 seems to be effective for the prediction of the microcracking. These aspects are under further invesigation.

4. REFERENCES:

[1] S.X.Gong and H.Horii, Int.J.Mech.Phys.Solids; accepted.

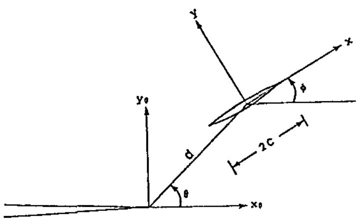

Fig.1 One arbitrarily located microcrack near the tip of a semi-infinite crack

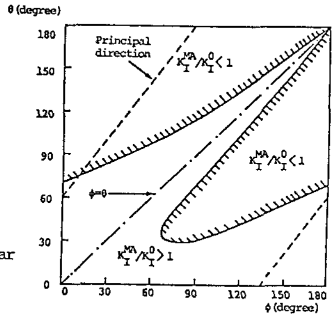

Fig.2 The regions of amplification and shielding

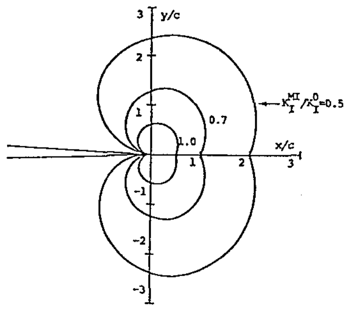

Fig.3 Variation of the stress intensity factor of the microcrack

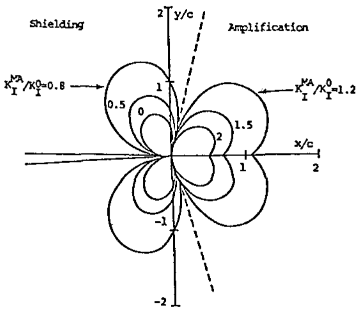

Fig.4 Variation of the stress intensity factor of the main crack

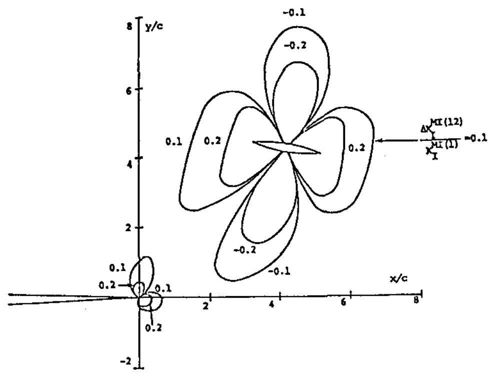

Fig.5 The effect of the microcrack-microcrack interaction on the stress intensity factor of the microcrack 1

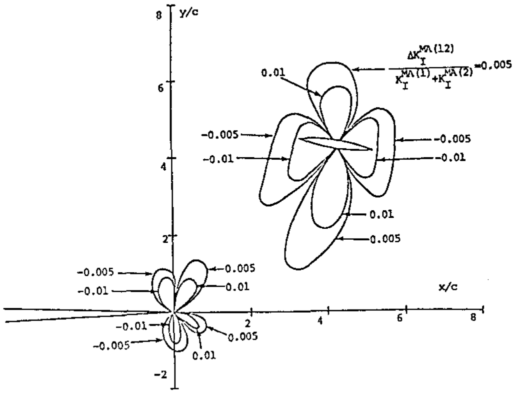

Fig.6 The effect of the microcrack-microcrack interaction on the stress intensity factor of the main crack