NUMERICAL ANALYSIS OF THE CRACK DEFLECTION AT CERAMIC - METAL INTERFACE

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ABSTRACT

Deflection of a crack at the bimaterial interface is the initial mechanism required for obtaining enhanced toughness in bimaterial system. In this paper, a criterion is presented to predict the competition between crack deflection and penetration at the interface, using an energy release rate criterion. The finite element methods is used to calculate the strain energy release rates at the crack tip of ceramic-metal bimaterial that either deflect or penetrate at the interface as a function of elastic mismatch and length of the deflected or penetrated crack.

1 INTRODUCTION

A perpendicular crack to a bimaterial interface has attracted the attention of many investigators. .Zak and Williams [1] used the eigenfunction expansion method to analyse the stress singularity ahead of a crack tip ,which is perpendicular to and terminating at the Interface. Cook and Erdogan [2] used the Mellin transform method to derive the governing equation of a finite crack perpendicular to the interface and obtained the stress intensity factors. Erdogan and Biricikoglu [3] solved the problem of two bounded half planes with a crack going through the interface. Bogy [4] investigated the stress singularity of an infinite crack terminated at the interface with an arbitrary angle. .Wang and Chen [5] used photoelasticity to determine the stress distribution and the stress intensity factors of a crack perpendicular to the interface. Lin and Mar [6] , Ahmad [7] and Meguid et al [8]. used finite element to analyze cracks perpendicular to bimaterial in finite elastic body. Chen [9] used the body force method to determine the stress intensity factors for a normal crack d terminated at a bimaterial interface. Wang and Stahle [10] investigated a crack growing towards a bimaterial interface. Their results showed that the crack can be deflected and to follow a smooth curved path. Singly and doubly deflected interface cracks were considered within the limitations of plane strain. He and Hutchinson [11] also considered cracks approaching the interface at oblique angles. Gupta et al [12] extended He and Hutchinson's work [11] to the area of anisotropic materials for the case of a crack approaching perpendicular to the interface. Martinez and Gupta [13] also examined the effect of anisotropy on the crack deflection by manipulating the anisotropy-related parameters including the other Dundurs' parameter. In this study the finite element methods is used to calculate the strain energy release rates of ceramic- metal composite cracking. The first part of this work has been contributed to the deflection/penetration for the crack normal to the interface, and the second one is consecrated to the oblique crack.The effects of the distance between the crack tip and the interface were highlighted as well as the effects of the elastic properties of two bonded materials.

2 RESULTS AND DISCUSSIONS

2.1 Crack perpendicular to the interface

To study the interaction effect of a crack with an interface, let consider a plate formed by a ceramic / metal bimaterial (Fig. 1.a). A perpendicularly oriented crack to the interface is localized in the ceramic. Under the effect of the applied loading σ, this crack is susceptible to propagate until the interface. The plate is modeled by eight node isoparametric quadratic elements (Fig. 1.b). The singularity in crack tip is modeled by special elements of ¼ point type [14].

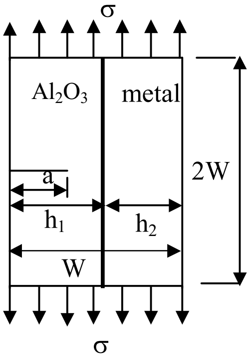

Figure 1.a: Crack normal to interface.

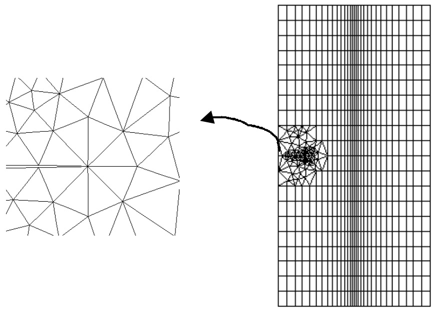

Figure 1.b: Mesh of the plate and near the crack tip.

Table 1 regroups the two Dundurs parameters α and β for different couples considered in this study.

Couples	α	β	Couples	α	β
Al_2O_3 / Ni	0,18	0,04	Ni / Al_2O_3	- 0,18	- 0,04
Al_2O_3 / Cu	0,39	0,07	Cu / Al_2O_3	- 0,39	- 0,07
Al_2O_3 / Au	0,43	0,08	Au/ Al_2O_3	- 0,43	- 0,08
Al_2O_3 / Ag	0,64	0,10	Ag / Al_2O_3	- 0,64	- 0,10
Al_2O_3 / Al	0,67	0,11	Al / Al_2O_3	- 0,67	- 0,11
Al_2O_3 / Mg	0,77	0,12	Mg/ Al_2O_3	- 0,77	- 0,12
Al_2O_3 / Pb	0,91	0,13	Pb / Al_2O_3	- 0,91	- 0,13

Table 1: Dundurs parameters of different couples.

Figure 2 present the variation of the normalized energy release rate G / G_0 ($G_0 = \sigma^2 \pi a/E_1$) according to the a/h ratio for different values of the parameter α. It is noted that the energy release rate increases with the increase of the a/h ratio. It is also noted that the energy rlease rate increase with the parameter α. When the Dunders parameter tends toward 1, the energy release rate grows in an exponential manner with the ratio a/h. An increase of the parameter α in absolute value drives to a reduction of the energy release rate. When this value is higher than 0.5, the energy release rate doesn't vary practically with the increase of the ratio a/h. We notice that independently to the Dunders parameter, there is a critical ratio a/h equal to 0.5 beyond of which the energy release rate at the crack head grows appreciably. This growth is marked more when the parameter α increases. For weak ratio a/h <0.5, the energy release rate becomes constant and its variation according to the parameter α is almost weak. The critical ratio is reached when the crack size tends toward the mid-width of the bi-material.

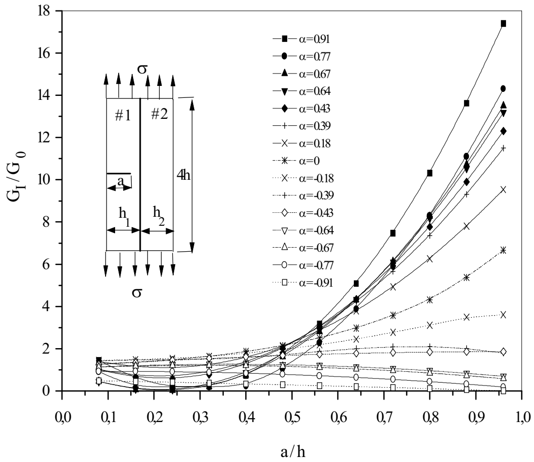

Figure 2: G_I/G_0 versus a / h_1 with various α

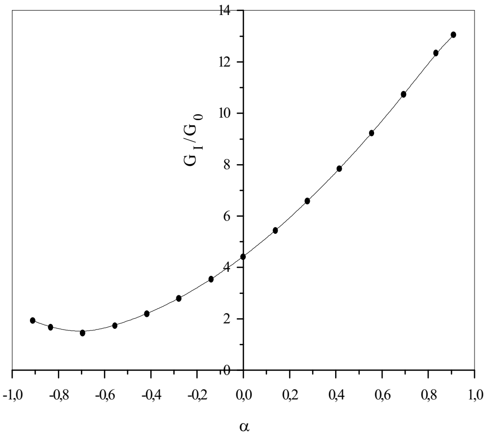

Figure 3: G_I/G_0 versus α (a /$h_1 \rightarrow 1$)

To better illustrate the effect of the parameter α on the energy release rate at the crack tip, we represented on the figure 3, the variation of this energy according to this parameter of a bimaterial for a/h tend toward 1, which means that the crack is in the vicinity of the interface. When the crack propagates from the ductile material (metal) toward the brittle one (ceramic) the energy release rate decreases toward the value of the homogeneous material near the interface . An inverse behaviour is observed therefore when the crack propagates from the most brittle material toward a more ductile material causing an increase of the energy release rate.

2.2 Deflection/Penetration for a crack perpendicular to the interface

The effect of deflection and penetration of the cracks at interface is represented on the figure 4. Two types of deviation were studied: the single and double deviation. We note that whatever is the value of α, a single deviation of the crack leads to more meaningful of energy release rates than those given by a double deviation of the crack. This phenomenon can be explained by the fact that for a double deviation of the crack, the energy release rate is subdivided in two values in consequence to the division of the initial crack in two small cracks and each of them corresponds to a distinct energy release rate. We note that the variation of the energy release rate ratio of deviation on the one of the penetration (G_d/G_p) is nearly similar to the one represented on the figure 3. On the figure 5, we illustrated the variation of the phase angle Ψ for a single and double deviations of the crack according to the parameter α. We note that a propagation of the crack from the hardest material toward the ductile material causes a considerable decrease of ψ. For the same value of the Dundurs parameter α, a crack with double deviation drives a weak value of ψ compared with single deviation.

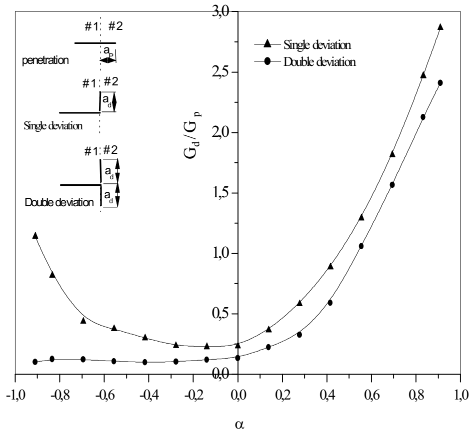

Figure 4: G_d/G_p various α.

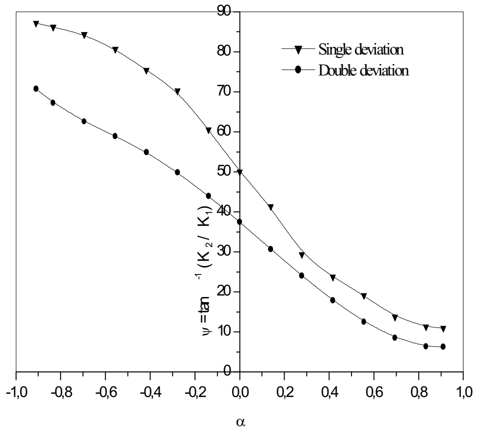

Figure 5: ψ various α.

2.3 Deflection/Penetration for a inclined crack

Figures 6 and 7 represent respectively the variation of the normalised energy release rate in mode I and II, for different orientations of the crack and for the case of couple Al_2O_3 / Al (α= 0,67).and Al / Al_2O_3 (α= -0,67).

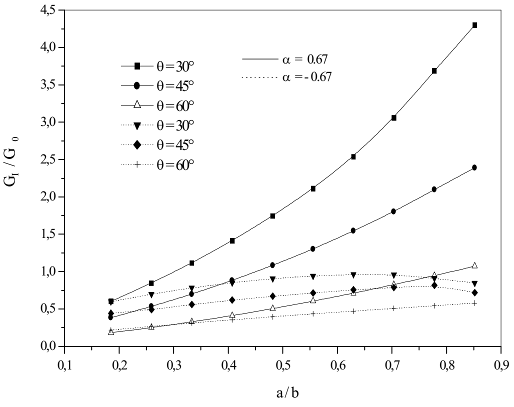

Figure 6: G_I / G_0 various a /b.

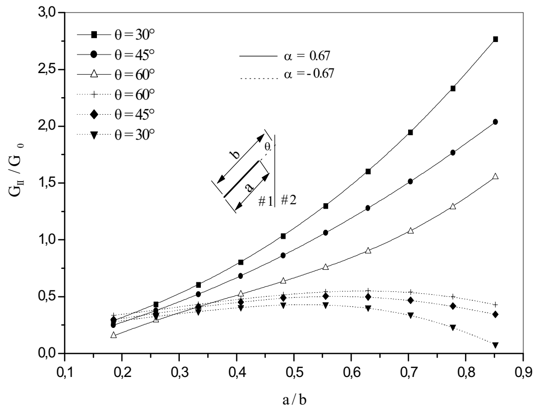

Figure 7: G_{II} / G_0 various a /b.

These two figures show, that for all sizes of the crack, the energy release rate decreases as he angle θ increases. According to the figures 6 and 7 we note that for positive value of the parameter α, the increase of the crack size gives more important energy release rate. This behavior is observed for all orientations of the crack and whatever its mode ofpropagation. . When α is negative , the variation of the energy release rate according to the crack size and its inclination is less important. The maximum of this rate is obtained for a crack size (a/b = 0,5) and when the crack is normal to the interface. Figure 8 shows the variation of as a function of α for different inclinations of the cracks

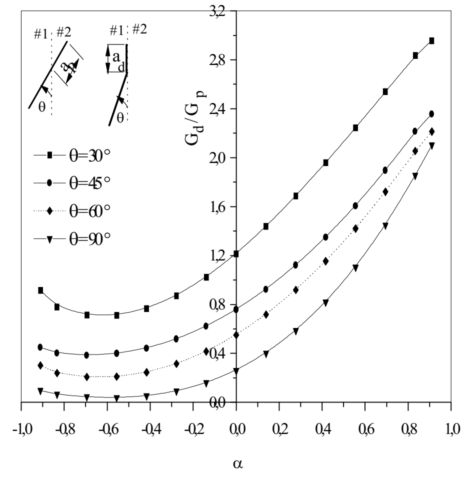

Figure 8: G_d/G_p various α.

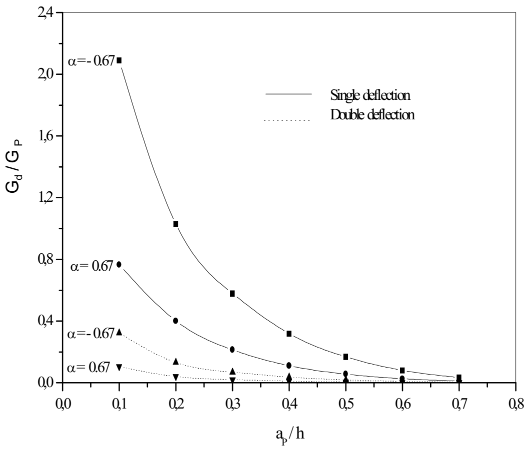

Figure 9: G_d/G_p various a_p /h.

The ratio G_d / G_p increases with the increase of α and with the decrease of the inclination of th crack . The effect of crack penetration on the variation of the ratio G_d / G_p is shown in figure 9. A growth of the ratio a_p/h provokes a decrease of the rate of energy release characterized by the ratio (G_d/G_p). This ratio is more important for a crack with singe deviation and for a negative value of the parameter α. This phenomenon is observed when the crack is close to the interface. The G_d/G_p ratio tends toward a null value when the crack length increases . It is noted that the G_d/G_p ratio varies slightly with the increase of the penetration depth of the crack with double deviation. In this case the energy is distributed in the two senses of deviation.

4 CONCLUSION

In this study the finite element method has been used to analyse the interaction effect between crack and interface and the effect of the deflection/penetration for normal and inclined cracks to the ceramic- metal interface. The obtained results allow us to deduce the following conclusions:

- When the crack propagates toward a less rigid material it drags an increase of its energy release rate: case of the couples ceramic/metal.
- The presence of the crack in a ductile material (metal / ceramic) decreases the energy release rate.
- The energy release rate at crack with a single deviation is more important compared with crack with double deviation
- The propagation of the crack for the brittle material toward the ductile one leads to a considerable reduction of the angle ψ. For the same values of the parameter a crack with double deviation leards to the significant reduction of the G_d/G_p ratio compared with a single deviation.
- The ratio G_d/G_p increase with α and with the decrease of the crack orientation de la fissure.
-The G_d/G_p vary slightly with the crack penetration of a double deviation .

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