15th International Conference on Fracture (ICF15)
June 11-16, 2023 Atlanta, GA USA

INTERFACE CRACK OR DELAMINATION: WHEN & WHERE TO INITIATE? HOW TO PROPAGATE & HOW BIG AREA TO ATTAIN?

Zheng-Ming Huang[1]*

[1] Tongji University, 100 Zhangwu Road, Shanghai 200092, China
** Presenting Author email: huangzm@tongji.edu.cn*

Abstract

After inserting a matrix, secondary layer in between the two adjacent primary layers of the bimaterial, the overall load causing the weakest secondary layer element to fail can be even bigger than the bimaterial's strength. The stresses in the element must be untrue. In this paper, two modifying coefficients (MCs) are applied to modify the stresses, which are then substituted into a strength failure equation of the matrix. If it is fulfilled, the failed secondary layer element is deleted, and an interface crack occurs within the two adjacent primary layer elements. Continued in this way step by step, all of the interface failure information is available without iteration. Only the critical displacements at the peak loads of a DCB (double cantilever beam) and an ENF (end notched fracture) tests are required as inputs in addition to the material properties of the two primary layers and the secondary layer.

1. Introduction

Interface crack or delamination is the most commonly occurred failure mode in any bimaterial such as coating on a substrate, a composite laminate, a hybrid plate of metal and plastic sheets, a honeycomb or foam sandwich panel, etc. Over the years, an uncounted number of attempts have been made to analyze the interface crack problem and to predict the interlaminar fracture or delamination [1-5]. However, given a bimaterial or laminate subjected to any arbitrary load, the following questions are not well answerable: when and where will an interface crack be initiated? how can it be propagated? and how big can a delaminated area be attained? Almost all of the existing attempts have two main drawbacks. First, a lot of input data from the bimaterial are required, some of which cannot be measured following existing standards. Thus, trials and errors have to be made to determine the data. Second, iteration has to be made at almost each solution step, consuming a huge amount of computation.

As a bimaterial is essentially bonded from its primary layers through the matrix or adhesive film, a surface crack or delamination must be resulted from a matrix or film failure. A simple and straightforward way is to insert a pure matrix layer into two adjacent primary layers before a finite element (FE) solution for the bimaterial is carried out. Unfortunately, the corresponding external load under which the weakest matrix layer element fails may be even higher than the measured strength of the laminate. We have established an interlaminar matrix stress modification method[6,7] to deal with the problem. Namely, the stresses of the matrix layer element are modified with two modification coefficients (MCs) before being substituted into a strength failure criterion. At a crack tip or a point where an interface crack initiation is going to take place, a stress of the matrix layer is singular or weakly singular. However, the stress obtained by an FEM is always an averaged value. Once an equivalent tensile or shear failure is attained, the matrix layer element is deleted, and the two adjacent primary layer elements with the matrix element contained in between are considered to have undergone delamination. Continued in this way, not only when and where an interface crack can occur in the bimaterial can be easily determined, but also the crack propagation direction and the cracked area at any but given load can be well predicted.

2. Results

The secondary layers inserted (Fig. 1) are assigned with the properties of the matrix or the adhesive film, with a thickness in between 1% to 10% of that of a primary layer or the same as that of the film. Discretize the laminate/bimaterial containing the secondary layers into FE elements. Let $\{\sigma_i^{SL}\}$ be the stresses of the weakest element of a secondary layer obtained through FE solutions. They are modified into true stresses as per

$$\{\bar{\sigma}_i^{SL}\} = \{K_1^h\sigma_{11}^{SL}, K_1^h\sigma_{22}^{SL}, K_1^h\sigma_{33}^{SL}, K_2^h\sigma_{23}^{SL}, K_2^h\sigma_{13}^{SL}, K_2^h\sigma_{12}^{SL}\}^T \quad (1)$$

If the true stresses fulfill the matrix failure equation, e.g., Tsai-Wu equation

$$F_1(\bar{\sigma}_{11}^{SL}+\bar{\sigma}_{22}^{SL}+\bar{\sigma}_{33}^{SL})+F_{11}[(\bar{\sigma}_{11}^{SL})^2+(\bar{\sigma}_{22}^{SL})^2+(\bar{\sigma}_{33}^{SL})^2 -\bar{\sigma}_{11}^{SL}\bar{\sigma}_{22}^{SL}-\bar{\sigma}_{11}^{SL}\bar{\sigma}_{33}^{SL}-\bar{\sigma}_{22}^{SL}\bar{\sigma}_{33}^{SL}]+F_{44}[(\bar{\sigma}_{23}^{SL})^2+(\bar{\sigma}_{13}^{SL})^2+(\bar{\sigma}_{12}^{SL})^2]\geq 1 \quad (2.1)$$

$$F_1=\frac{1}{\sigma_{u,t}^m}-\frac{1}{\sigma_{u,c}^m},\quad F_{11}=\frac{1}{\sigma_{u,t}^m\sigma_{u,c}^m},\quad F_{44}=\frac{1}{(\sigma_{u,s}^m)^2} \quad (2.2)$$

together with $\bar{\sigma}_1^m>0$ (2.3)

the secondary layer element is deleted and the two adjacent primary layer elements undergo a surface crack, either an initiation or a propagation. $\bar{\sigma}_1^m$ is the first principal true stress of the secondary layer element.

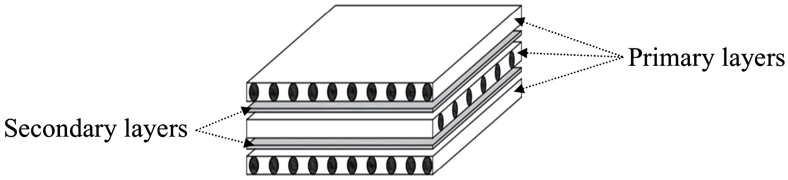
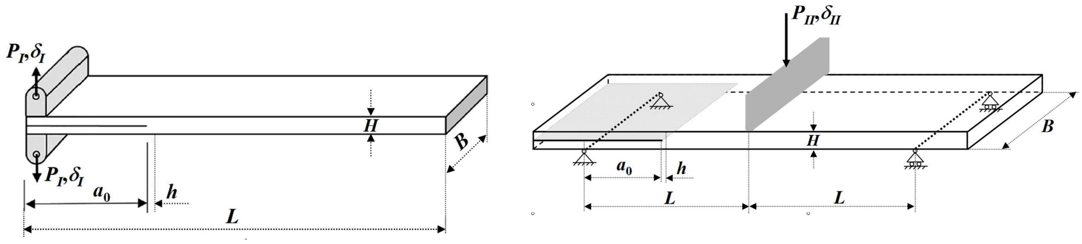


Fig.1 Schematic of a laminate inserted with matrix secondary layers in between primary layers

The MCs K_1^h and K_2^h are obtained by means of DCB and ENF test results (Fig. 2). After the DCB and ENF specimens inserted with the secondary layer on the central surface are discretized into FE elements, the critical displacements δ_I and δ_{II}, which correspond to the peak loads P_I and P_{II} on the DCB and ENF load-displacement curves respectively, are applied. The weakest secondary layer elements of both the DCB and ENF specimens are modified as per Eq. (1). Letting them fulfill Eq. (2.1) with equality respectively, the two MCs are easily solved.



(a) (b)

Fig.2 DCB (a) and ENF (B) tests on the bimaterial to measure the critical displacements δ_I and δ_{II}

Conclusion

The approach to surface crack of a bimaterial through interlaminar matrix stress modification method only requires a DCB and ENF tests on the bimaterial in addition to the basic mechanical properties of the materials involved. Essentially all of the failure information can be obtained with no iteration.

References

[1] J. W. Hutchinson, Z. Suo. Adv. Appl. Mech. 1991, 29: 63-191.
[2] A. Tabiei, W. Zhang. Appl. Mech. Rev. 2018, 70: 030801.
[3] G. I. Barenblatt. Adv. Appl. Mech. 1962, 7(1): 55-129.
[4] R. Krueger. Appl. Mech. Rev. 2004, 57(2): 109-143.
[5] T. Belytschko, T. Black. Int. J. Numer. Methods Eng. 1999, 45(5): 601-620.
[6] Z.-M. Huang, Li P. Eng. Fract. Mech. 2020, 238: 107248.
[7] J. C. Zhou, Z.-M. Huang. Eng. Fract. Mech.. 2022, 264: 108333.