

Prediction of the crack kinking in a sandwich composite beam subjected to three point bending using the j integral concept

Abstract

In our study a sandwich composite beam under three point bending is considered. The core material of the beam contains an initially small crack oriented parallel to the longitudinal axis and very close to the upper skin interface. A code using commercial finite element software has been developed in order to predict the position, the length of the crack and the direction where kinking occurs inside the core of the sandwich beam. The code uses the energy criterion, and the code control points of decision concerning the propagation and the kinking of the crack are based on energy formulas from the fracture mechanics approach. A general flowchart of the proposed code and results from the critical crack length–kinking into the core, are presented.

Keywords: sandwich beam, fracture mechanics, j–integral criterion, finite element analysis, composite materials

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Ilias I Tourlomousis, Efsthios E Theotokoglou

Department of Mechanics, National Technical University of Athens, Greece

Correspondence: Efsthios E Theotokoglou, Department of Mechanics–Lab of Testing and Materials, National Technical University of Athens, Greece, Email: ilstayava@gmail.com, stathis@central.ntua.gr

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Introduction

Composite materials utilizing the sandwich structure are a basic family of materials and possess a highly increasing use in modern industrial applications. Since the traditional approach to structural design and material selection tends to be replaced by the Fracture mechanics approach, it is worth understanding the way that the Fracture mechanics approach is applied. The traditional approach to structural design takes into account two variables which have to be in contrast: The applied or expected stresses and the Yield or Tensile strength. The Fracture mechanics approach^{1,2} involves three important variables rather than two. The additional structural variable is the flaw size, and the Fracture Toughness replaces Yield or Tensile strength. This approach quantifies the critical combination of these three variables. In Fracture Mechanics there are two methods of studying a problem, the Stress Intensity Factors criterion and the Energy criterion. In this study we get involved with the Energy criterion and specifically with the J Contour integral calculation.^{3–5}

A sandwich material consists of a core material with thin laminas on each side.⁶ The laminas could be any combination of fibers and matrices, or even of a metallic material. The core is usually made of PVC, wood or a honeycomb material. The most interesting problems appeared in sandwich structures are, the failures modes in the core and the faces materials, the fracture of the core material and the interaction between the fractured core and the face materials.^{6,7} In sandwich structures the foam is typically the weakest part and is the first to fail under static or cyclic loading because it transfers the applied loads as shear stresses. In addition a very critical problem in sandwich structures is the debonding problem between the face and core materials.^{7–9} Unstable cracking propagation and kinking in core materials represents one of the weakest failure modes in sandwich composites.^{10,11} The fracture behavior in sandwich composites has been directed toward the understanding of crack propagation, and at the same time toward improving the durability of composites against fracture.^{12,13} A crack flaw may be introduced during processing or subsequent service conditions. It may result from low velocity impact,

from eccentricities in the structural load path, or from discontinuities in structures, which induce a significant out-of-plane stress.⁵

In our study a sandwich beam under three point bending is considered. In the core material of the beam an initially small crack oriented parallel to the longitudinal axis of the beam and very close to the upper skin interface, exists. A finite element analysis code has been developed in order to predict the position and the length of the crack when kinking of the crack occurs into the core material. The code uses the J–integral energy criterion, and the code control points of decision concerning the propagation and kinking of the crack are based on energy formulas from fracture mechanics. A general flowchart of this code is presented and numerical results are also given.

Description of the problem

A sandwich beam is considered less than three point bending shown in Figure 1. The material properties, the loading and the crack position are presented in Tables 1–3. In the sandwich beam and into the core material an initially very small crack is considered. The position and the orientation of this initially small flaw of the body has been chosen to be 1.5mm below the upper boundary of the core material, the right crack tip lays at the midspan of the beam and the crack is oriented parallel to the longitudinal axis of the beam. This initial loading, the length of the crack as well as the material data have been obtained from the experimental verification.⁶

The experimental data⁶ show that the crack propagation occurs parallel to the beam axis until the crack length reaches an approximate value between 65mm and 75mm. The direction of the crack is then suddenly changed and the crack is kinking into the core material. The sandwich beam at the same time loses completely its stiffness and is being collapsed. The presented study intends to show a numerical method which predicts the critical length of the crack as it is growing, keeping the applied to the beam load constant. The proposed procedure utilizing in the Finite Element Program ANSYS,¹⁴ a code in APDL (ANSYS Parametric Design Language), searches the maximum value of J for a particular crack length for which the direction of the crack

Table I Material properties and elastic constants

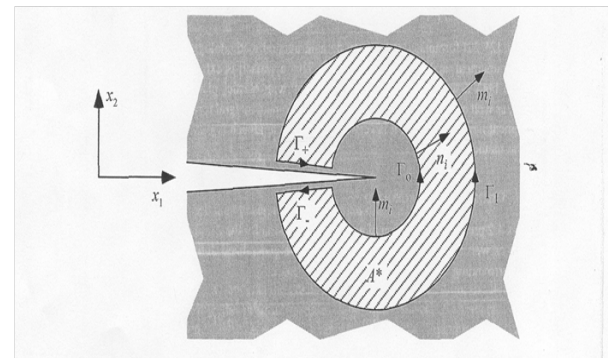
Material	E (Mpa)	Poisson ratio ν
Upper and Lower material Layers (isotropic glass reinforced)	16300	0.3
Core material (PVC foam, R75 by DIAB) 2	80	0.4

Length, L(mm)	228.6
Width, b(mm)	63.5
Width of the upper and lower layer t_1, t_2 (mm)	2.28
Width of the core t(mm)	12.7
Position of the displacement constraints L' (mm)	5

Transverse load $P(N/mm)$	14.5
Distance from the upper layer $d(mm)$	1.5
Initial crack length $a(mm)$	2

$$J = \int_{\Gamma} \left(w dy - T_i \frac{\partial u_i}{\partial x} ds \right) \quad (1)$$

Relation (1) is applied in a domain around the crack tip (Figure 2).


$$J = \frac{K_I^2}{E'} + \frac{K_{II}^2}{E'}, \quad (2)$$
$$E' = \begin{cases} E & \text{for plane stress condition} \\ \frac{E}{1-\nu^2} & \text{for plane strain condition} \end{cases}, \quad (3)$$

The model shown in Figure 1 is built considering the data from

Tables 1–3 and introducing them as loading, geometrical and material parameters inside an APDL code. By this way we are able to adjust the model according to the demands of the specific analysis. For example we can create various models with different materials different crack lengths, different crack positions and orientations and so on. The element type used in the proposed analysis is the two dimensional (2d) element: PLANE182.¹⁴

The proposed modeling of the sandwich beam is transformed gradually and imposes the discretion of the areas regarding the mesh density and quality in three different regions as shown in Figure 3. This discretion is a prerequisite in order to avoid the worthless consumption of computational resources and time. The model shown in Figure 3 corresponds to the maximum crack length ($a=70\text{mm}$).

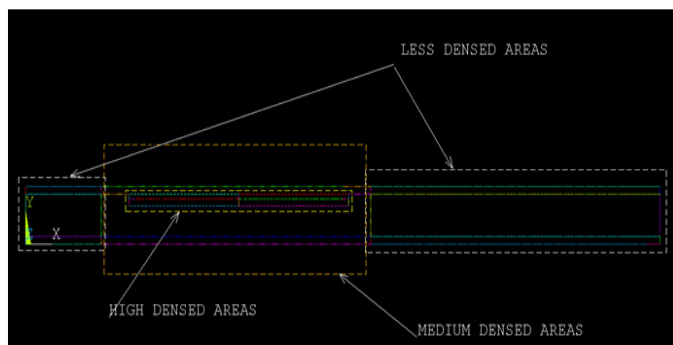


Figure 3 The meshing strategy of the model.

The appropriate density of the elements is controlled by an equivalent division of the lines circumscribe the areas. A parameter inside the code gives the capability of defining a meaningful division of the lines at each time the crack advances, and the highly dense areas become larger.

Another very important parameter and of high priority is to define the size and the number of the elements around the crack tip. These special elements called ‘singular elements’ play an important role in fracture analyses. They are constructed by the degeneration of the 8 node quadrilateral elements which results in singular triangular elements. In elastic problems the mid-side nodes of the singular elements are moved to the $1/4$ points and are shown in Figure 4.

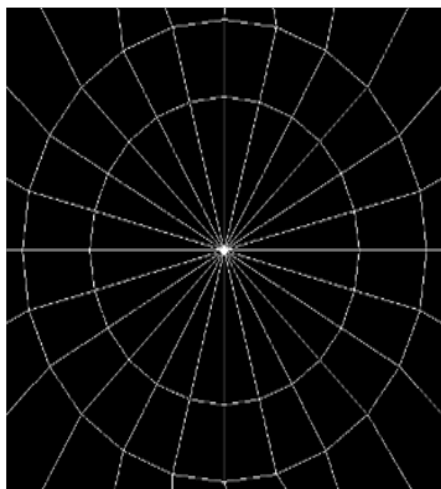


Figure 4 A common arrangement of the singular elements around the crack tip.

In order to estimate the J integral values in the post processing stage and for a good numerical approximation even though J in (1) is independent from the integration path, an adequate number of proper annular concentric paths around the crack tip must be defined. From the determined numerical values for each path an average value is finally obtained. These paths are considered as the contours Γ of relation (1), and are shown in Figure 5.

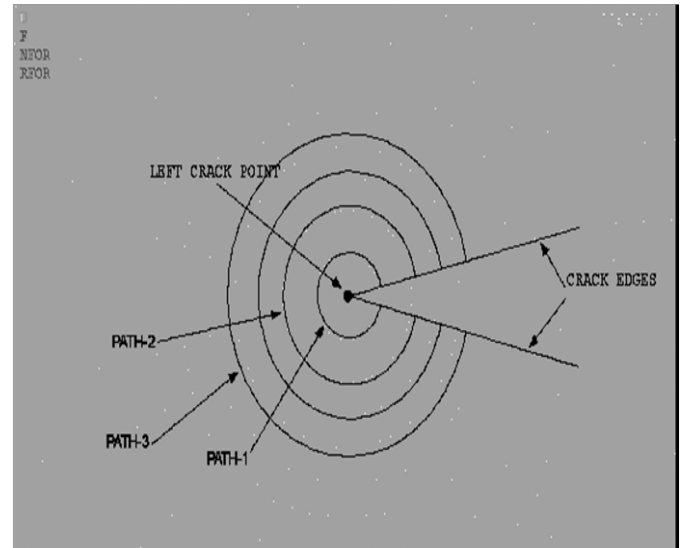


Figure 5 The annular paths used in the J integral calculations.

The next essential point of the generalized modeling and meshing strategy arises from the observation that the loading and the stress fields are much more complicated because of the nature of the problem.

It is obvious that the crack flaw lies in the compressed area of the body, and the analysis of this kind of problem involves the approach with methodologies which take into account mixed mode fracture theories. Such an approach is the energy criterion approach namely the J–integral estimation in Fracture mechanics.

The nature of the problem (presence of a crack or material flaw in three point bending) imposes the use of contact elements between the crack flanks in order to avoid a penetration between them. The chosen elements selected in order to avoid penetration are the CONTACT178,¹⁴ point to point contact elements which are shown in Figure 6.

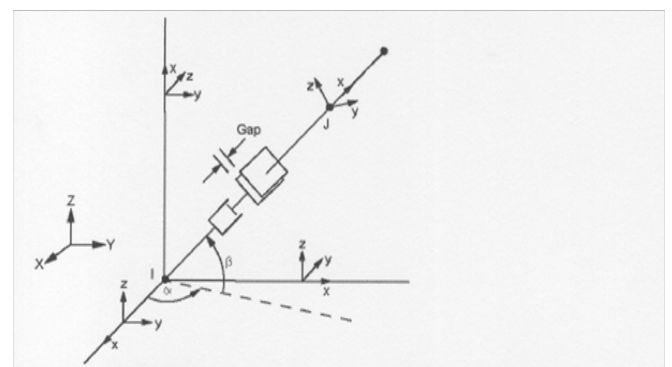


Figure 6 CONTACT178 point to point type contact elements, which act as an absorber between the crack flanks and prevent the penetration.

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directions (acute angle with respect to the main x-axis) are presented for the first crack length ($a=2\text{mm}$). Figure 9 shows the iterations and the results of J for different crack lengths versus the angle between the main x axis and the direction where the maximum value of J occurs. The solution reveals that the critical crack length for a crack close to the upper skin interface is about 65mm. At this length the crack kinks into the core material, an unstable cracking propagation begins and finally the sandwich beam collapses.

Figure 10 provides a closer description of the last six iterations as the crack length exceeds the value of 60mm. For the 7th iteration a maximum value of J results at a direction different than the horizontal and at a crack length of 70mm. Next the code seeks the maximum value of J in an interval values for the crack length between 60mm and 70mm. It 'jumps' to a crack length of 62mm (iteration 8, now the interval is considered between 62mm and 70mm), then to 68mm (iteration 9, and the interval changes accordingly) and it continues with iterations 10 and 11. Finally the inequalities of the control points in the flowchart are fulfilled in iteration 11. Then the code exits and the final data are stored. As it can be seen from Figure 10, the maximum value of J occurs at a direction of 10 degrees as the crack length approaches the 65mm.

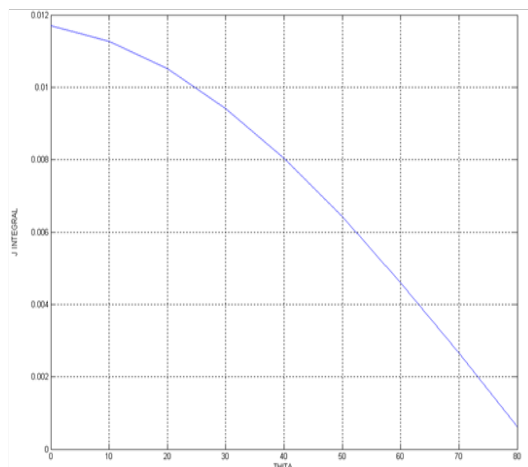


Figure 8 J integral values for various angles for a crack length $a=2\text{mm}$.

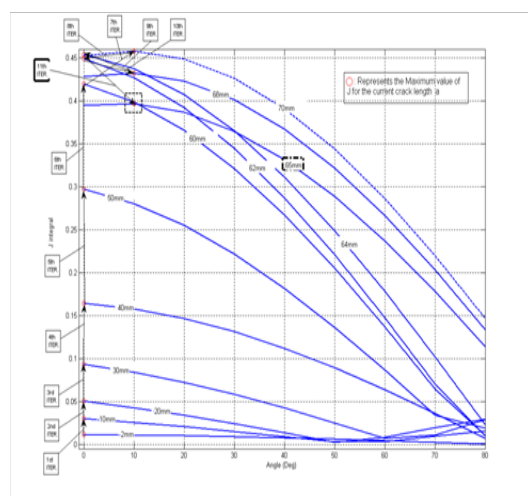


Figure 9 Solution steps and oscillation until J reaches a constant value along a direction other than 0 degrees.

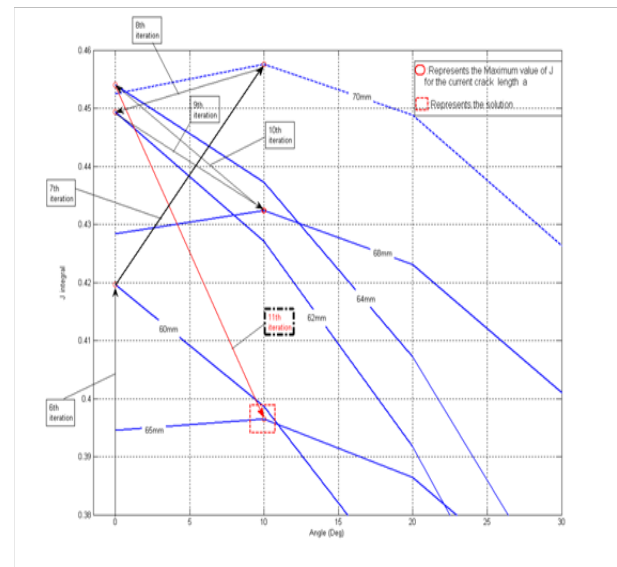


Figure 10 The steps of the crack propagation in order to find the non parallel to the x axis direction where the values of Jmax occur.

Conclusion

The results data are in good agreement with the experimental results.⁶ A further investigation based on the same procedure and with different orientations and positions of the initial small crack can be easily obtained. The two dimensional approach can be extended in the three dimensional analysis by making impertinent modifications in the code.

The proposed method of investigation, Energy criterion using the J integral approach, is much more reliable with respect to the traditional approach using the Stress Intensity Factors (K_i , $i = I, II$) approach. Furthermore with the application of relation (2) in linear elastic problems, J and K_i are related.

J integral calculation takes into account the stress state of the body and not the crack flanks displacements inside the crack lips and near the crack tip. As the distance of the crack from the upper face increases, the influence of the shear stress field is expected to become larger.

Acknowledgements

None.

Conflict of interest

The author declares no conflict of interest.

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