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Application of the CZM Technique to Delamination Analysis of Coupled Laminate Beams

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Abstract. These days composite materials are widely used as elements of various machinery. They are applied as reliable machinery parts e.g. in aviation or automotive. This paper is referred to coupled laminates, which are one of composite materials types. Most common damage form in laminates is delamination. The aim of this paper is to show how to use Cohesive Zone Model technique (CZM) to model fracture propagation in laminate specimens. Finite element models were constructed using shell type elements in ABAQUS, which allows to analyze fracture propagation involving cohesive zone effect [5]. This operation needs many material constants which obtaining experimentally is problematic . The FE analysis is helpful in reasonable planning the stand tests and shows the accuracy of experimental studies. It also provides a lot of relevant information on laminate properties. Boundary conditions, loads and the obtained fracture toughness distributions of the numerical models of coupled laminate beams correspond to the mode I and mode II delamination propagation: the double-cantilever beam (DCB) and the end-notched flexure (ENF) [1, 3].

1. Numerical modeling technique

Cohesive zone theory was applied to fracture modeling by Dugdale in 1960 and Barenblatt in1962 separately. Since then there were many extension of this concept. For example it was recognized that cohesive elements are attractive in modeling composite laminates.

Abaqus offered two types of cohesive behavior: element-based and surface-based cohesive behavior. Cohesive elements can be used for modeling very detailed adhesive connections or for delamination in composites. Where comes to composites it must create a “zero” thickness adhesive layer – in point of fact an intermediate glue material, which is actually replaced in finite element model by cohesive element, is very thin. Modeling such materials is based on traction-separation law. In this paper FE model was created using surface-based cohesive behavior which is simplified and easier way to establish cohesive connections with traction-separation interface behavior. As distinct from cohesive elements it is defined as a surface interaction property in Abaqus. Damage is also an interaction property, material is defined only by Engineering Constants (Young’s modulus, Poisson’s coefficient and shear modulus). Surface-based modeling is mostly applied when interface thickness is so small it can be neglected. Surface-based behavior can be restricted to portion of surface that are initially in contact. It also allows define specific data like fracture energy as a function of the ratio of normal to shear displacement (mode mix) at the interface. Finite sliding, surface-to-surface option in contact is not allowed in Abaqus/Standard, so in this model small sliding was used.

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2. Model loading and boundary conditions

One of the main aspects of this paper is an impact of different boundary conditions on load – displacement curve. Fig. 1 represents boundary conditions of End Notched Flexure test [4-7] model in Abaqus. It can be seen that both ends of specimen cannot move – all displacements are prevented. The vertical displacement of 10 mm, along z-direction, is applied to the line in the middle of top surface. Displacement of this line in the x- and y-directions were also prevented. With those BCs, specimen is supposed to conform mode II during fracture propagation.

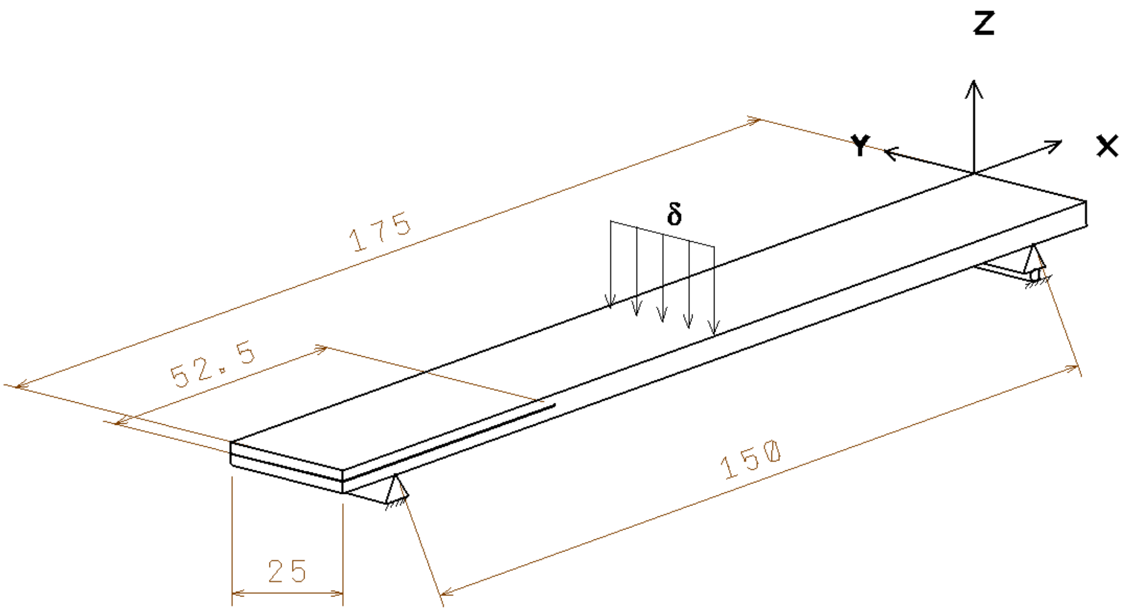

Figure 1. ENF specimen dimensions and boundary conditions

At this point it could be considered how will model respond when boundary conditions will be different. Numerical analyses were made also for other BCs, which are similar to that mentioned before. In addition to true ENF boundary conditions there were also prevented rotation along x axis of the specimenin order to avoid detachment of the specimen from support. This is due to observation of experimental tests of those laminates which tend to twist when bent.

2.1. Numerical models

Finite element method analyses were made using ABAQUS/CAE environment, ver. 6.14.5. Models of specimen were made as shell elements, which are the element with zero thickness. Material of the specimens is SEAL Texipreg HS160RM . The moduli were $E_1 = 109000$ MPa, $E_2 = E_3 = 8819$ MPa, $\nu_{12} = \nu_{13} = 0.342$, $\nu_{23} = 0.38$, $G_{12} = G_{13} = 4315$ MPa, $G_{23} = 3200$ MPa and ply thickness was 0.2 mm. In order to acquire accurate result it is logical to densify finite element mesh near delamination front and also at beam model's egdes, as figure 2 shows.

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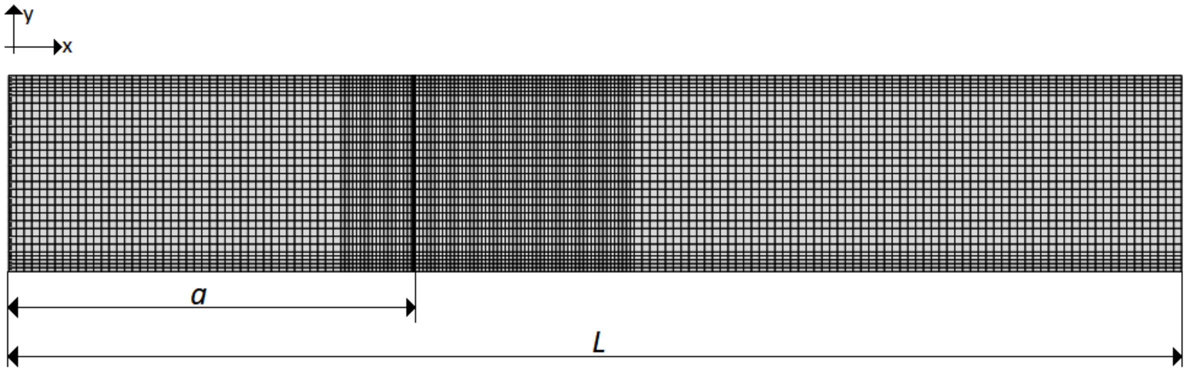

Figure 2. Finite element mesh

Fig. 3 shows force – displacement plots with two different boundary conditions – in first case (BC1) boundary conditions are the same as in true ENF test, in the other one (BC2) there are also prevented rotation along x-direction in points of support.

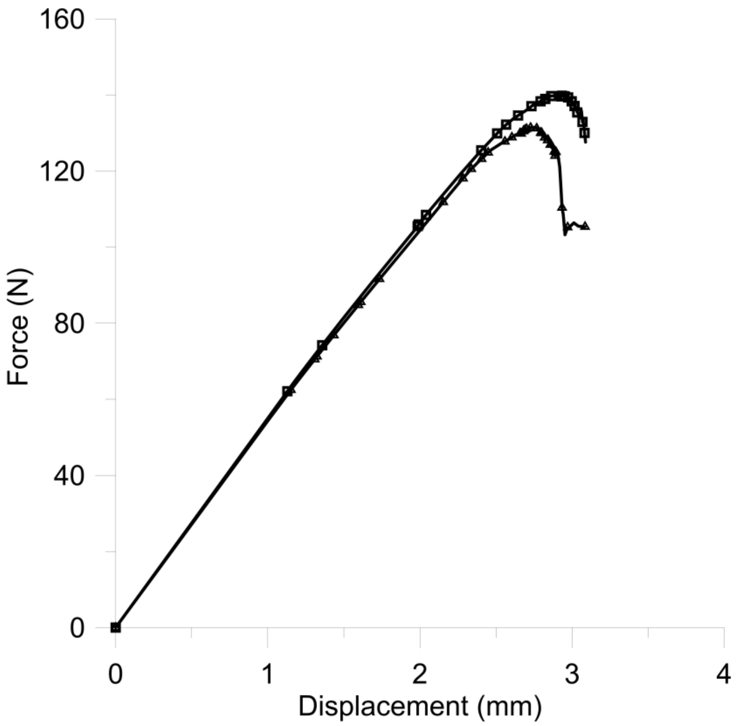

Figure 3. Load displacement curve for bending-twisting specimen

3. Results and discussion

Finite element model was made in Abaqus/Standard. It was modeled using shell elements which are easy to apply and shorten significantly the time of numerical calculations. Cohesive zone model technique was applied here to model delamination in coupled laminates instead of Virtual Crack Closure

Technique (VCCT). As fig. 4 shows, CZM technique is relevant technique to model fracture propagation [6].

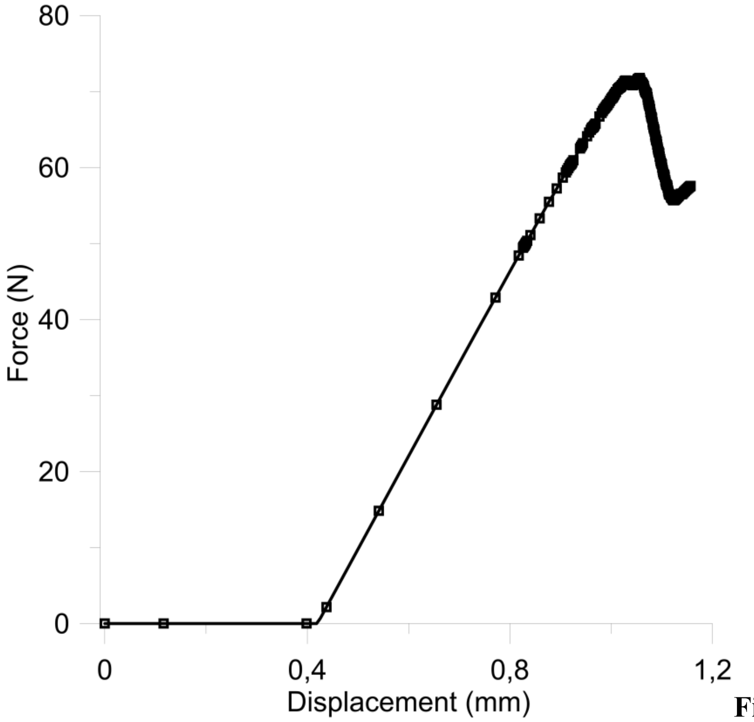

Figure 4. Load displacement curve for CZM Simple [+45/-45]$_9$ specimen

Force increase begins at displacement of 0,4 mm because of numerical reasons. For Abaqus, it is easier to start analysis when there are some straight calculations at the very beginning. In the first part of process force grow linearly, then first fracture occur and force drop sharply. Such force application is compatible with experimental force distribution as well as numerical analysis with VCCT [6]. The main difference between CZM and VCCT techniques is the time of calculations. Analysis using cohesive behavior needs much more time to succeed than model with VCCT. There must be further tests whether CZM reflects real effects in coupled laminates better than VCCT and, in relation to that, if it is reasonable to expend much time to get more valuable results.

4. Conclusions

As proved above, cohesive zone model can be widely applied not only for adhesive bonding but also for modeling delamination in composites. It has numerous advantages: it easier to use with FEM than VCCT, nonlinearities are not negligible with CZM in contrast to other methods and that is why it can be alternative to virtual crack closure technique. However there is one concern about using CZM – it needs much more computing power than VCCT because it requires higher mesh density to provide a more reliable results which cause much more time to do the analysis.

5. References

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