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Property Modelling

Parametric study of crushing parameters and failure patterns of pultruded composite tubes using cohesive elements and seam: Part II – Multiple delaminations and initial geometric imperfections

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ABSTRACT

Part I presented the circumferential central delamination and triggering modelling of composite tubes and their influence on predicting the peak crush load and the corresponding energy absorption. The knowledge of failure patterns is very important for the design architecture of an energy absorbing element and its placement in the structure. In this study, the failure patterns of pultruded circular and square cross sectional glass polyester composite tubes were evaluated with pre-defined seams for an axial impact loading case. Furthermore, this paper demonstrates the importance of considering multiple delaminations to predict the appropriate energy absorption of composite tubes using cohesive elements. The influence of correct numerical modelling of triggering (especially 45° edge chamfering) on the peak crush load of the composite tubes is proved with multiple layers of shell elements. The effect of initial geometric imperfections on the energy absorption, peak crushing load and the deformation pattern of pultruded glass polyester composite tubes is also studied. In order to address the importance of above factors, a comprehensive numerical investigation was carried out with multiple layers of shell elements and with cohesive elements. Finally, the deformation patterns, peak crushing load and the corresponding energy absorption were compared with experimental results [1].

1. Introduction

Crashworthy efficient structures must be able to dissipate large amounts of energy in the event of a crash. From the success stories in the aerospace industry, it is widely accepted that polymer composite materials offer a number of technical advantages. Some of them are high specific mechanical properties such as stiffness and strength, design flexibility, reduced weight and less maintenance. Due to the above factors, in recent times the interest in composite materials has been much increased in the area of impact and blast loading applications [2]. One of the main reasons for this is the higher specific energy absorption of composites over metals and alloys. Few researchers have studied the numerical energy absorption of polymer composite materials for an axial impact event [3–5]. The accuracy of numerical predictions depends upon the correct modelling of the structural geometry, integrating the right damage mechanisms and the accurate modelling of the physics of impact. Part I of this paper dealt with the finite element modelling issues of triggering, especially the

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triggering type 1 (45°chamfering) with a single and two layers of shell elements approach to predict the correct peak crush load and the corresponding energy absorption. Furthermore, it was also proved that the incorrect prediction of the peak crush load of a composite tube will provide an unrealistic deformation length and energy absorption. Hence, the correct and accurate modelling of triggering which initiates the initial damage is very important. This paper demonstrates the correct finite element modelling of triggering using multiple layers of shell elements. In order to validate this approach, the numerical peak crush loads of circular and square pultruded glass-polyester composite tubes were compared with experimental data [1].

During an axial impact event, the compressive strength of a composite material will reduce significantly due to delamination. The reduction in compressive strength of composite laminates has been well studied numerically considering structural instability and delamination growth in [6,7]. The influence of delamination failure on concave cylindrical composite test specimens during an impact event using a continuum damage model was studied in [8]. However, the approach of delamination was not previously considered to predict the energy absorption for circular and square composite tubes. Furthermore, the actual deformation of a typical brittle composite tube exhibits multiple delaminations [1,7,9–11]. The consideration of multiple delaminations approach is important because it causes ply separation and loss in bending and compressive stiffness of each sub-laminate [7]. To understand the importance of multiple delaminations on the energy absorption, and to achieve the typical failure patterns of a brittle composite tube, a numerical parametric study was conducted with multiple layers of shell elements and solid cohesive elements.

The approach of two layers of shell elements with cohesive elements provided comparable peak and mean crush loads, deformation length and the corresponding energy absorption for the circular and square composite tubes with triggering type 2 (CP2 and SP2). However, due to the absence of axial cracks, the final deformation patterns were different from experimental results. Hence, an initial evaluation was made to study the effect of axial cracks on the deformation pattern of circular and square composite tubes for Case 2 (Two layers of shell elements with cohesive elements) of Part I. The axial cracks were modelled with pre-defined seams and, further, it was extended to complex models such as multiple layers of shell elements with cohesive elements. Moreover, the effect of the number of pre-defined seams on the peak crushing load and the corresponding energy absorption of the composite tube series was also evaluated.

Studies on composite shells [12–15] have proved that traditional (geometric tube-wall mid-surface imperfections) and non-traditional imperfections (tube wall thickness variation, local tube wall ply gaps, tube end geometric imperfections, non-uniform loading of tubes and variations in the boundary condition) have a large influence on the performance of composite shell structures. Non-traditional imperfections such as variation in the boundary condition and loading can be avoided with proper care during experimental testing. However, the initial imperfection caused during a manufacturing process, such as variation in material properties at different locations of a composite structure and a variation in structural dimensions, cannot be avoided during an experimental test. Hence, during an analytical study or a finite element calculation it is advisable to consider the above effects to predict the correct performance parameters of a composite structure. Of the mentioned initial imperfections, the influence of initial geometric imperfections on the performance of a composite structure is greatest [12,16,17]. As discussed in Part I, the numerical impact studies on square tubes with tulip triggering (SP2) yielded an unrealistic initial peak load. This may be due to the perfect geometry of triggering tulips. Hence, the effect of initial geometric imperfections on the peak crush load and the corresponding energy absorption is evaluated for square cross sectional composite tube. The results from these analyses are also compared with the experimental results [1].

2. Numerical study

2.1. Case 3– two layers of shell elements with cohesive elements and predefined seams

The details of the experimental impact study, material of the tubes, nomenclature, geometric details, material properties, used damage criteria and the corresponding modelling details are given in Part I.

2.1.1. Modelling with seams

As discussed in the Introduction, due to the absence of axial cracks the failure patterns of the tubes were different from the experimental results. During the experimental crushing of a composite tube, the inner and outer petals were subjected to bending inside and outside of the tube followed by circumferential delamination. The material splaying outwards flared into petals due to the phenomena of axial cracks, and the material splaying inwards showed progressive folding without any petalling [1,9,18]. As a result, a considerable amount of energy was dissipated due to the axial cracking of the outer petals and significant deceleration of the impactor was provided by the inner plies.

2.1.2. Seams

In order to simulate the axial cracks in the outer plies during the crushing process, the seams were introduced at pre-defined location in the outer shell layer of the composite tubes. A seam on the outer shell layer of the composite tube model defines an edge parallel to the axis of the tube that is originally closed; however, it can open during the analysis. These edges are free to move apart. During meshing, duplicate overlapping nodes are placed on the seam; these coincident nodes are free to move apart as the seam separates. Eventually, a seam pre-defines the surface along which the crack has to propagate. Creating duplicate nodes offers several advantages for fracture mechanics calculations. Using this approach, contour integral analysis and crack propagation analysis can be performed [19,20]. However, this work does not deal with