Experimental and numerical study on axial impact loading of pultruded composite tubes

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***Abstract*: The application of fibre reinforced composites has been increasing in the area of impact and blast loading of structures. The major advantages of these materials over metals are higher specific energy absorption, more economical, low weight and less maintenance. In this work, an attempt is made to study the energy absorption characteristics of unidirectional pultruded composite tubes. Two different cross sections (circular and square) were used for the study. To absorb more energy during the impact or blast loading the composite tubes have to deform progressively. To induce the progressive deformation of composite tubes two different types of triggering mechanisms were used. The energy absorption of each tube was studied experimentally. A new approach was adopted using cohesive elements for the numerical assessment of the energy absorbing capability of composite tubes. Finally the experimental and numerical results were compared.**

***Keywords*: Specific energy absorption, triggering, finite element method**

I. INTRODUCTION

The need for safer vehicle design which (i) absorbs energy (ii) keep the occupant compartments intact (iii) ensure tolerable deceleration levels for driver and passengers during the crash event increases due to high speed operation (Figure 1a). The above said factors depend upon the design architecture and the materials which are used in the automobiles. On the other hand the entire world faces the problem of security for civil structures due to terrorist activities. A preventive solution is needed to safeguard the civil structures and to avoid human casualties due to explosion (Figure 1b). In connection with the above applications an experimental investigation (impact test) was carried out using composite material tubes. The energy absorption capability of composite material is evaluated by the term "Specific energy absorption" (SEA) [1] which means, the amount of energy absorbed (E) per unit mass (m_c) of crushed material. The SEA of composite material depends upon many parameters [2]. Some of them are the type of fibre, matrix, orientation of fibre, lay-up sequence, triggering and geometrical variables like diameter and thickness. The role of triggering is important to achieve the progressive deformation of the tube which yields higher energy absorption. Considering the above variables two different cross sections (circular and square) with two types of triggering mechanism were selected. Often conducting a real time experiment is an expensive affair. Hence an alternative cost effective method to assess the energy absorbing capability is very important. So a numerical simulation using finite element method [3] was carried out to assess the energy absorption capability of composite tubes. A good agreement between the experimental and numerical results was observed.

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Figure 1 (a) A Crashed automobile (b) Debris of a blasted building.

II. EXPERIMENTAL ANALYSIS

A. Materials

The pultruded composite tubes with circular (outer diameter =38mm and thickness 3mm) and square (width =60mm and thickness =4.5mm) cross sections were used for the test. The square tube was made of glass fibre-polyester and the circular was made of glass fibre-vinylester. Two types of triggering Type 1 (45° edge chamfering) and Type 2 (tulip pattern) were adopted for circular and square tubes as shown in Figure 2.

Figure 2 Test specimens.

B. Test Setup

All the tests have been performed with the impact test facility which is shown in Figure 3a. The experiment was conducted for three different impact velocities 9.3, 12.4 and 14 m/s. An impactor mass of 68.85 kg was used for all impact tests (See Figure 3b). A high speed camera (Photron APX RS 250K) was used to study the deformation and energy absorption characteristics of the composite tubes.

III. EXPERIMENTAL RESULTS

A. Failure Modes

During the crush event, the tubes dissipated the impact energy by circumferential delamination, transverse shearing and lamina bending modes [4] which are shown in Figure 4. The specific energy absorption (SEA) of each tube was calculated based on the following formula:

$$SEA = \frac{E_d}{l_d * \rho} \; J/kg \qquad (1)$$

where E_d is the dissipated energy (J), l_d is the deformation length (m) and ρ is the linear density (kg/m) of the tube

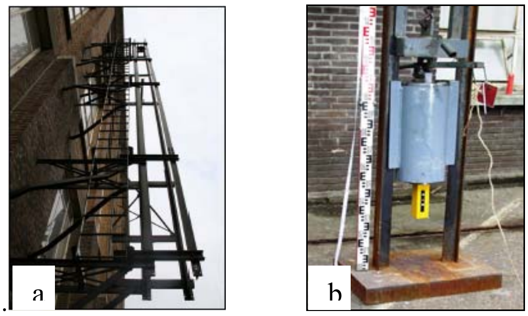

Figure 3 (a) Impact test facility (b) Detail view of Impactor.

Figure 4 Failure patterns of tubes from experimental test.

B. *Energy absorption*

The different levels of energy absorption by circular and square tubes with triggering mechanism Type 1 are shown in Figure 5. Based on the stiffness and other parameters the crushed lengths of tubes were varied.

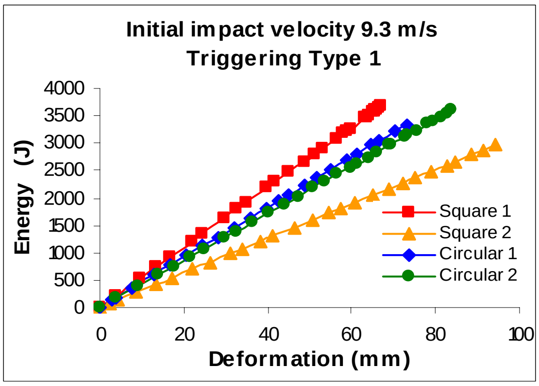

Figure 5 Energy plot for different tubes.

IV. Numerical Analysis and Comparison of Results

A. *Modelling methodology*

The tube was divided into three layers. The outer and inner layers of the tube were modeled with four-node quadrilateral shell elements. The middle layer was modeled by solid cohesive elements with zero thickness. The entire model was solved by using the commercial explicit code of ABAQUS/ Explicit V6.7.

B. *Failure Modes*

The failure modes obtained from the numerical simulation are shown in Figure 6. These results can be very well compared with ones presented in Figure 4.

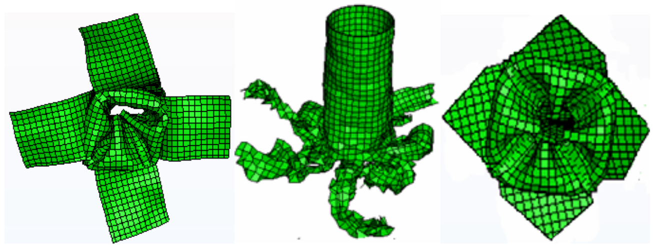

Figure 6 Failure patterns of tubes from numerical simulation.

C. *Energy absorption*

The energy absorption of the tube can be obtained from the force deformation curve. The area under this curve is the dissipated energy of the tube during the crushing process. The comparison of experimental and numerical result is given in Figure 7 for one of the square tube with triggering Type 1.

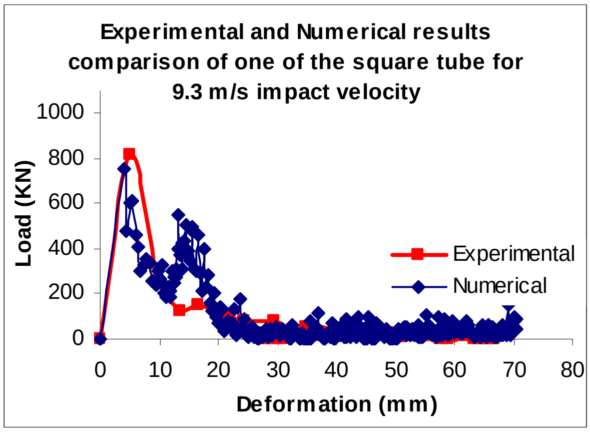

Figure 7 Comparison of experimental and numerical results.

V. Conclusion

The impact energy absorption characteristics and the crushing mechanism of glass fibre - polyester and glass fibre – vinylester square and circular tubes with different thicknesses were investigated. The different variables which affect the specific energy absorption of the composite tubes were studied. It was found that the specific energy absorption of the circular tubes is higher than the square tubes. Numerical simulation was carried out using cohesive elements. The failure patterns of the tubes and the corresponding energy absorption levels were comparable.

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References

[1] Mamalis, A.G., et al., *Energy absorption capability of fibreglass composite square frusta subjected to static and dynamic axial collapse.* Thin-Walled Structures, 1996. **25**(4): p. 269-295.

[2] Ramakrishna, S., *Microstructural design of composite materials for crashworthy structural applications.* Materials & Design, 1997. **18**(3): p. 167-173

[3] Han, H., et al., *A numerical study on the axial crushing response of hybrid pultruded and +/-45[degree sign] braided tubes.* Composite Structures, 2007. **80**(2): p. 253-264

[4] Bolukbasi, A.O. and D.H. Laananen, *Energy absorption in composite stiffeners.* Composites, 1995. **26**(4): p. 291-301