



# Effect of multi stitched locations on high speed crushing of composite tubular structures



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## ABSTRACT

The present paper experimentally investigates progressive energy absorption of fibre-reinforced polymer (FRP) composite tubular structures under high speed loading conditions. Various multi stitched locations are studied to find a correlation between single and multi-locations of stitches and energy absorption capabilities of composite absorbers. The through-thickness reinforcements are applied into locations of 10 mm, 20 mm, 30 mm, 10–20 mm, 10–30 mm, 20–30 mm, 10–20–30 mm and 10–15–20–25–30–35 mm from top of the tubes. It is shown that multi-stitched location can cause several increase of crushing load and consequently increase of energy absorption of composite tube absorbers. The idea would be expanded to other designs which are followed by increase of stitched locations and reduction of the distance between stitches to improve the mean force with a smooth and progressive pattern of crushing load.

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## 1. Introduction

The energy absorption capability of composite materials offers an exceptional combination of reduced structural weight and improved vehicle safety by higher or at least equivalent crash resistance compared with metallic structures. Crash resistance covers the energy absorbing capability of crushing structural parts as well as the demand to supply a protective shell around vehicle occupants. The basic principle of occupant crash protection has been used in the automotive field since the early 1950s, and crash safety has meanwhile become a well-established car design requirement. In aeronautics, the first structural design requirements for better crash protection were studied for military helicopters and light fixed-wing aircraft in the form of the aircraft crash survival design guide [1–5].

In all previous researches several variables related to the energy absorption of composite thin-walled structural components have been investigated. Regarding crushing behaviour of composite tubular structures, their suitability is determined not only by the usual design parameters, such as geometry, layups and strain rate sensitivity [6–8] but by their progressive failure mechanisms.

One of the most important parameter which has a significant

effect on the crushing process is interlaminar and intralaminar fracture toughness. Various researches have studied the crack propagation and all alternative ways to control the failure within the structure of composite absorbers. The most important of these works can be summarised as below:

Zhou et al. [9] studied crashworthiness characteristics of rectangular tubes made from a carbon-fibre reinforced hybrid-polymeric matrix (CHMC) composite using quasi-static and impact crush tests. Their results showed that the load carrying capacity and total energy absorption tend to increase with greater polyurea thickness and lower elapsed reaction curing time of the epoxy although this is typically a function of the loading rate.

Solaimurugan et al. [10,11] investigated the effect of stitching, fibre orientation and stacking sequence on  $G_{IC}$ , SEA, and also progressively crushing of glass/polyester composite cylindrical shells under axial compression. According to their results the axial fibres placed close to the outer surface of tube led to more petal formation and stable crushing process, while axial fibres close to inner surface tube cause higher energy absorption. The energy absorption capability in the form of circumferential delamination increases for higher values of Mode-I fracture toughness. They also showed that through the thickness reinforcement improves the Mode-I interlaminar fracture toughness which results in improvement of energy absorption of cylindrical tube.

Ghasemnejad and Hadavinia [12] reviewed off-axis crashworthy

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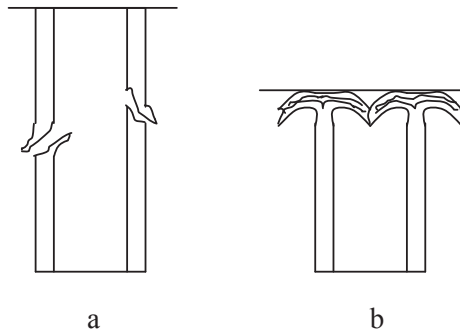


Fig. 1. (a) Catastrophic crushing failure (b) progressive crushing failure.

behaviour of woven GFRP composite box structures. They found two fracture mechanisms of bundle fracture and delamination crack propagation in Mode-II for all composite boxes at various off-axis loading. Due to crack propagation in mixed-Mode-I/II and more friction and bending resistance at one side of composite box which firstly contacted the crushing platen, the amount of SEA at off-axis loading of  $10^\circ$  was the maximum in comparison with other off-axis crushing loadings. Ghasemnejad et al. [13] have also studied the effects of delamination failure of hybrid composite box structures on their crashworthy behaviour. According to their results it was found the hybrid laminate designs which showed higher fracture toughness in Mode-I and Mode-II delamination tests, will absorb more energy as a hybrid composite box in crushing process. In another work by author [14] the effect of delamination failure of stitched composite box structures in their crashworthy behaviour were studied and their performances were compared with non-stitched ones. The combination of unidirectional CFRP and GFRP composite materials with lay up of  $[C_{90}/G_0]_7$  were used to laminate the composite boxes. This laminate design showed the highest energy absorption capability in our previous study of authors. Delamination study in Mode-I with the same lay-up was carried out to investigate the effect of delamination crack growth on energy absorption of natural stitched composite box structures. The double cantilever beam (DCB) standard test methods were chosen for delamination studies. It was shown that stitching can significantly increase the interlaminar fracture toughness and consequently energy absorbing capability of composite materials and structures.

In engineering application generally the loading classification are static, fatigue, high speed loading and impact. These loads are categorised according to the rise time of the load. For static loading this time is three times greater than the fundamental period of the

mechanical system. Fatigue loading occurs when the rise time from one magnitude to another magnitude is greater than 3 times of fundamental periods. This time for high speed loading is between 1.5 and 3 times of fundamental periods of the mechanical system [15,16].

In all previous researches several variables related to the energy absorption of composite thin-walled structural components have been investigated. Apart from all these parameters, multi-location stitching is another factor which significantly influences the energy absorption of composite tubular structures under high speed loading. This paper experimentally aims to study the relation between locations of stitches and energy absorption capabilities of composite absorbers.

## 2. Valuation criteria for crushing behaviour

There are many important variables which must be considered in the study of energy absorption capabilities. These include material; manufacturing method; microstructure; geometry of specimen, including any crush initiator used; and rate of crushing speed. One of the most important parameters is the specific energy absorption (SEA) performance of collapsing or crushing specimens or structural parts. This value is related to the absorbed energy compared to the mass of the absorber or structure. In this case, it is an important criterion for lightweight designs. Another important factor in the study of energy management capabilities is the shape of the force-crush distance curve. One measure which is used to characterise the shape of the curve is called crush-force efficiency (CFE). This value relates the average crush force ( $F_m$ ) to the maximum force ( $F_{max}$ ) of the crush characteristic.

## 3. Crushing failure mechanisms

Catastrophic and progressive failures are two main failure mechanisms of composite tube structures (see Fig. 1). A progressive crushing is introduced at one end of the specimen using a bevelled trigger mechanism and then it progresses through the specimen without significant damage past this crush front. For a catastrophic failure the initial maximum force is very high and drops rapidly, therefore the average force is low.

In this work all composite tubes were fabricated by glass/epoxy material ( $\rho = 2000 \text{ kg/m}^3$ ) using hand lay-up techniques with a symmetric twelve-ply quasi-isotropic laminate of  $[-45/45/0/90/0/90]_s$ . Once the tubes had been laid-up, they were placed between pre-cut aluminium plates to keep them flat during the curing process. The plates were pre-treated with a mould cleaner to remove grease and debris and a monocoat wax was applied to prevent escaped epoxy from the prepreg bonding to the metal

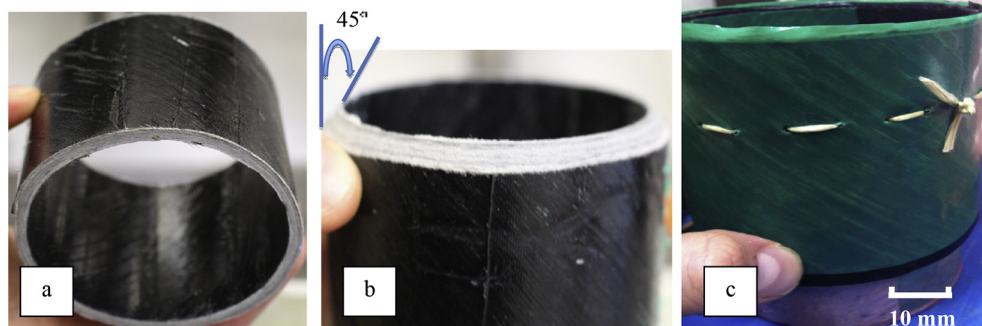


Fig. 2. a) Composite crushing tube, b) bevelled trigger mechanism, and c) stitching technique.

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