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The axial crushes behaviour on foam-filled round Jute/Polyester composite tubes

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Abstract. The present paper investigates the effect of axial loading compression on jute fibre reinforced polyester composite round tubes. The specimen of composite tube was fabricated by hand lay-up method of 120 mm length with fix 50.8 mm inner diameter to determine the behaviour of energy absorption on number of layers of 45^0 angle fibre and internally reinforced with and without foam filler material. The foam filler material used in this studies were polyurethane (PU) and polystyrene (PE) with average of 40 and 45 kg/m^3 densities on the axial crushing load against displacement relations and on the failure modes. The number of layers of on this study were two; three and four were selected to calculate the crush force efficiency (CFE) and the specific energy absorption (SEA) of the composite tubes. Result indicated that the four layers' jute/polyester show significant value in term of crushing load compared to 2 and 3 layers higher 60% for 2 layer and 3% compared to 3 layers. It has been found that the specific energy absorption of the jute/polyester tubes with polystyrene foam-filled is found higher respectively 10% to 12% than empty and polyurethane (PU) foam tubes. The increase in the number of layers from two to four increases the mean axial load from 1.01 KN to 3.60 KN for empty jute/polyester and from 2.11 KN to 4.26 KN for the polyurethane (PU) foam-filled jute/polyester tubes as well as for 3.60 KN to 5.58 KN for the polystyrene (PE) foam-filled jute/polyester. The author's found that the failure of mechanism influence the characteristic of curve load against displacement obtained and conclude that an increasing number of layers and introduce filler material enhance the capability of specific absorbed energy.

1. Introduction

Material of composite have a wide variety of properties related to engineering application because they have their higher stiffness and strength with respect to weight ratio. In addition, composite materials have high corrosion resistance, thermal expansion, thermally resistive and considered as non-conductive materials. Many of crashworthy structures made of metallic materials play important roles in the last decade's dispose of composite materials [1]. The properties of composite materials given more advantageous because their lightweight and cheapest price compared to metal for vehicle applications [2]. Many researcher have been conducted to several studies on crashworthiness capability such as composite tubular cross-section like a tube [1-2], and cone [3] with different applied loading conditions.

Material of composite type of conventional were widely studied previously subjected to axial loading have been carried out many investigator to determine energy absorption performance. Due to the less studied on natural fibre composite, the author need to explore on how the natural fibre can give more impact on crashworthy application. However, several studies on natural fibre can exhibit unstable loaded when subjected to empty case, so that the purpose on this paper is to determine the influence of polyurethane and polystyrene foam as a filler material to strengthen the behaviour of tubular structures when applied to axial loading. Many researcher has been found that the natural fibre composite behaviour achieved fluctuation curve of load against displacement [8-9].

Othman et al. [10] conducted to pultruded foam filled structure subjected to axial loading with different wall-thickness and density foam filled material. They found that the influence of reinforcement internally filler material enhanced the specific absorbed energy when applied axial loading. On those studies, pultruded material was fabricated by pultrusion machine with conventional material like glass, carbon etcetera. In fact, unstable deformation is not found in conventional material. The major objective on this study to determine the failure occurred and specific absorbed energy on round composite jute fiber internally reinforced polymeric foam filler like polyurethane and polystyrene foam. The response behavior of jute/polyester with 2 to 4 layer laminate was investigated in term of load versus displacement curves.

2. Experimental work

2.1 Materials and fabrication

Jute/polyester composite tubes were fabricated using of hand layup methods using woven roving [±45˚] jute/epoxy. A stainless steel of tube was use as a mould to fabricate with length of 500 mm. with diameter of 50.8 mm. The plastic bag was use to wrap on surface mould in order to extract specimen from mandrels after curing. Table 1 shows the dimensions of the fabricated composite. Samples of the fabricated specimens are shown in figure 1. The terms J, R, L, PE, and PU are respectively jute, round, layer, polystyrene and polyurethane. The number 2, 3 and 4 referred to the number of layers of the composite laminate structures. The inner diameter of all specimen tube were fixed at 50.8.

Table 1. Dimensions of the composite tubes.

Specimen type				Composite tube	
	Mass (kg)	No of layers	Foam Filler	Wall Thickness t (mm)	Length
JR-2L	0.155	2	-	2.25	120
JR-3L	0.232	3	-	3.21	120
JR-4L	0.310	4	-	4.23	120
JR-2L-PE	0.164	2	Polystyrene	2.21	120
JR-2L-PU	0.166	2	Polyurethane	2.24	120
JR-3L-PE	0.242	3	Polystyrene	3.31	120
JR-3L-PU	0.243	3	Polyurethane	3.28	120
JR-4L-PE	0.320	4	Polystyrene	4.23	120
JR-4L-PU	0.321	4	Polyurethane	4.23	120

Figure 1. Sample of the fabricated composite tubes.

The mechanical properties of the jute and glass/ epoxy materials were obtained from the literatures [13] and listed in Table 2.

Table 2. Mechanical properties of jute/polyester lamina.

Property	Symbol	LS-DYNA parameter	Experimental value
Density	ρ	RO	$1350\ \mathrm{kg/m^3}$
Modulus in 1-direction	E_1	EA	4150 MPa
Modulus in 2-direction	E_2	EB	2072 MPa
Shear modulus	G_{12}	GAB	1508 MPa
Major Poisson's ratio	υ_{12}	PRAB	0.187
Minor Poisson's ratio	υ_{21}	PRAC	0.376
Strength in 1-direction, tension	F_1^{tu}	XT	200 MPa
Strength in 2-direction, tension	F_2^{tu}	YT	200 MPa
Strength in 1-direction, compression	F_1^{cu}	XC	100 MPa
Strength in 2-direction, compression	F_2^{cu}	YC	50 MPa
Shear strength	F_{12}^{su}	SC	100 MPa

2.2. Testing procedure

Quasi-static loading condition were tested on all specimens with constant speed of 5 mm/m compression using a computer-controlled servo-hydraulic Instron machine type GT instruments. The cross-section tube crushed between two parallel steel flat platens, one fix and one moving. The fixed platen was fitted with a load cell from which the load signal is taken directly to the computer. For each test, the axial loading was plotted on the Y-axis and the crosshead displacement on the X-axis. The end front of each specimens was chamfered at 45^0 to ensure that the load fluctuation characteristic were avoided [10].

The determination of crashworthiness mechanism some of following aspect of crush phenomenon is measured during crushes event. The all data were recorded and calculated there are Peak force P_{max}: maximum compressive force. Mean force P_{avg}: average compressive force obtained by the following equation where force and deformation are defined as P and d, respectively and the area of cross section, A, and the density of the material, ρ defined as

$$\bar{P} = \frac{1}{\delta}\int_0^{\delta} P d\delta \tag{1}$$

Energy absorption E: area under the load–displacement curve up to the compaction zone.

$$E = \int_0^{\delta} P d\delta \tag{2}$$

The units of E_s are used to express the crashworthiness parameters, hence they are written in kJ here P is the load acting on the composite specimens. Therefore, the specific energy absorption per unit mass kJ/kg (SEA) where m the crushed mass of the composite is recognized as:

$$SEA = \frac{E}{m} \tag{3}$$

Crash force efficiency (CFE): ratio of the average crushing load P_{avg} to peak load P_{max}.

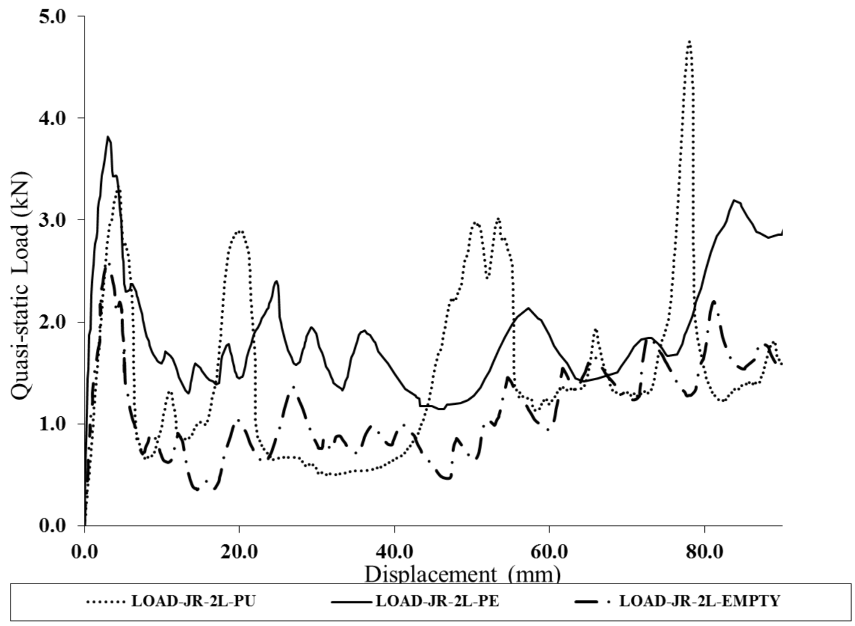
$$CFE = \frac{P_{avg}}{P_{max}} \tag{4}$$

3. Results and discussion

3.1. Axial loading characteristics

In this section, results of the axial loaded composite jute/polyester were presented. Figures 2, 3 and 4 show the quasi-static load-displacement curves of the composite tubes using jute (J), layer (L), round cross-section (R), polyurethane (PU) and polystyrene (PE) respectively. In figures 2, 3, and 4 are referred to the number of layers with different with and without filler materials. Study indicated that the load progressively increased from the initial failure until final deformed then the load fluctuates with a sharp drop until failure of compaction zone. The foam filler with jute/polyester tubes supported increase load than the empty jute/polyester followed by increasing number of layers of tube composites. Obviously, increase in number of layers from two to four show a significant increase in the maximum load obtained for the composite tubes as shown in figures 2, 3 and 4.

It can be seen from figure 2 also that the increase fluctuation load of jute/polyester composite tubes from empty to polymeric foam profiles until reach the final deformed compaction. The figure 2, 3 and 4 generally indicated that the irregularity fluctuation load observed from up to down loading for empty profile with the internal and external tearing failure of layers of jute/polyester and show drop from maximum load to minimum strength.



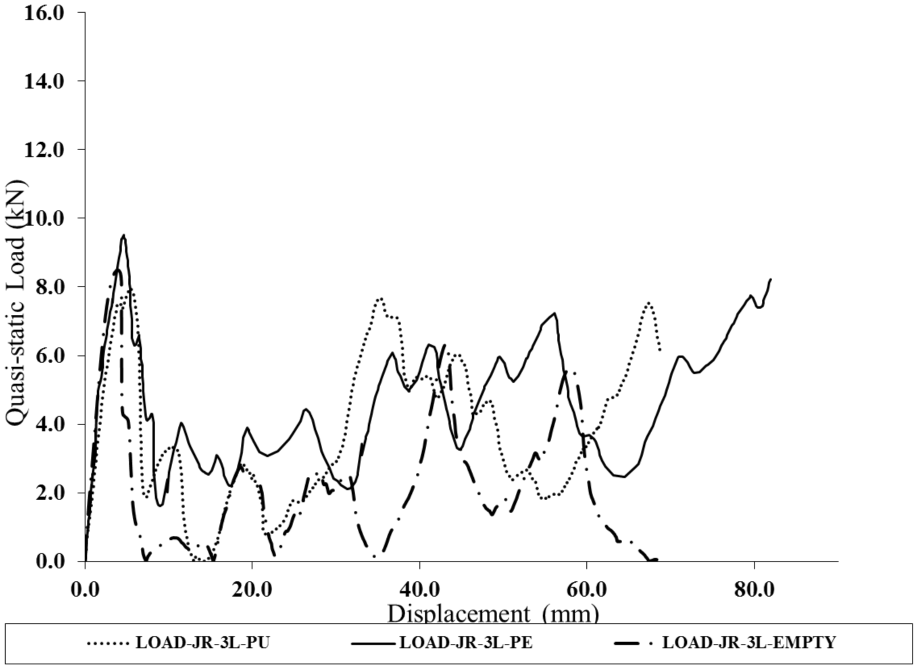
(a) Load against displacement curve of two layers jute/polyester composite tubes.

Unloading 20 mm 40 mm 70 mm 90 mm

(b) Empty profile of jute/polyester of two layers.

Figure 2. Load-displacement relation for jute/polyester tubes for two layers.

Figure 3 and 4 shows the effect number of layer three used on maximum load obtained from the load-displacement graphs. This figure explains that the jute/polyester tubes made of four layers improved crushes energy during quasi-static regime compared to two and three layers. The maximum axial load obtained for the three and four layer jute/polyester tubes with polyurethane and the increase number of layer laminate of the jute significantly affects polystyrene. Composite tubes were fixed between two flat platen as shown in figure 2 to 4 where the load applied axially on the tubes. Picture of each deformation were taken to see the characteristic of each specimen failure. The tested tubes of composite fractured at the surface position where cracks were propagated at the top front-end tube while contact between moving platen and specimen stated until reach the maximum deformation.



(a) Load against displacement curve of three layer jute/polyester composite tubes.

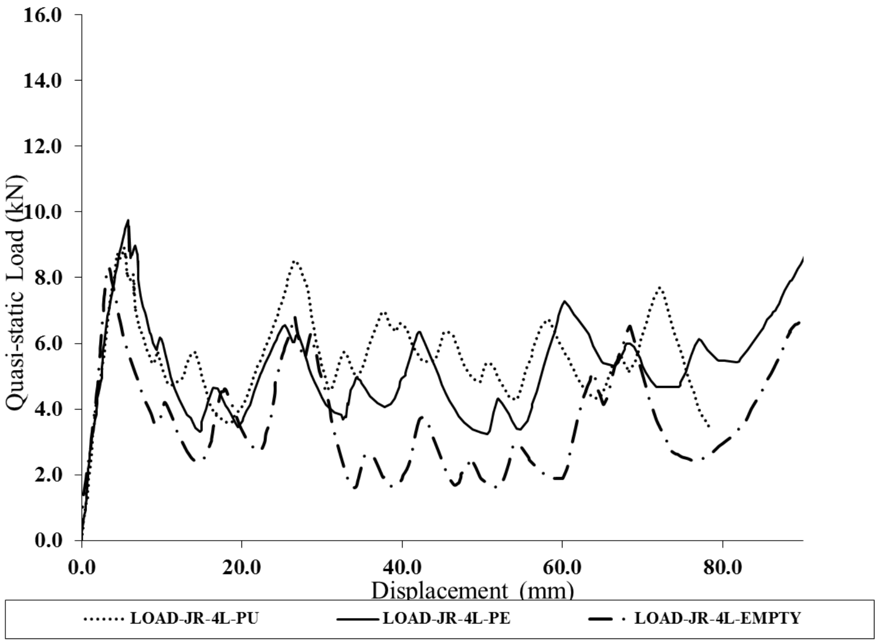
Unloading 10 mm 50 mm 70 mm 80 mm

(b) Profile of jute/polyester of three layers with polystyrene foam

Figure 3. Load-displacement relation for jute/polyester tubes for three layers.

3.2. Quasi-static loading characteristics

The initial peak and average loads are two characteristics of the failure profile of crashworthy structures. The force needed to crush the surface of the crush box during the initial stages dramatically increased and reached a certain peak force shown in figure 5. Throughout the initial peak force, the influence of failure pattern depended on the initial stages of the force. The load-displacement curve continued with a drop in the force at certain stages, especially during the failure pattern of composite pultruded tubes, whereby the load was decreased with progressive failure.



(a) Load against displacement curve of four layers jute/polyester composite tubes.

Unloading 20 mm 50 mm 60 mm 90 mm

(b) Profile of jute/polyester of four layers with polyurethane foam

Figure 4. Load-displacement relation for jute/polyester tubes for four layers.

Figure 5 shows the comparative graph of the initial peak load and the average values of the empty and polyurethane foam-filled specimens. The crush force efficiency (CFE) is an important factor to measure the crush performance and to evaluate the crashworthiness of energy absorber components. The CFE for the composite tubes under quasi-static axial loading is determined using equation 4. Results showed that an almost specimen ranging from 0.4 to 0.6 efficiency.

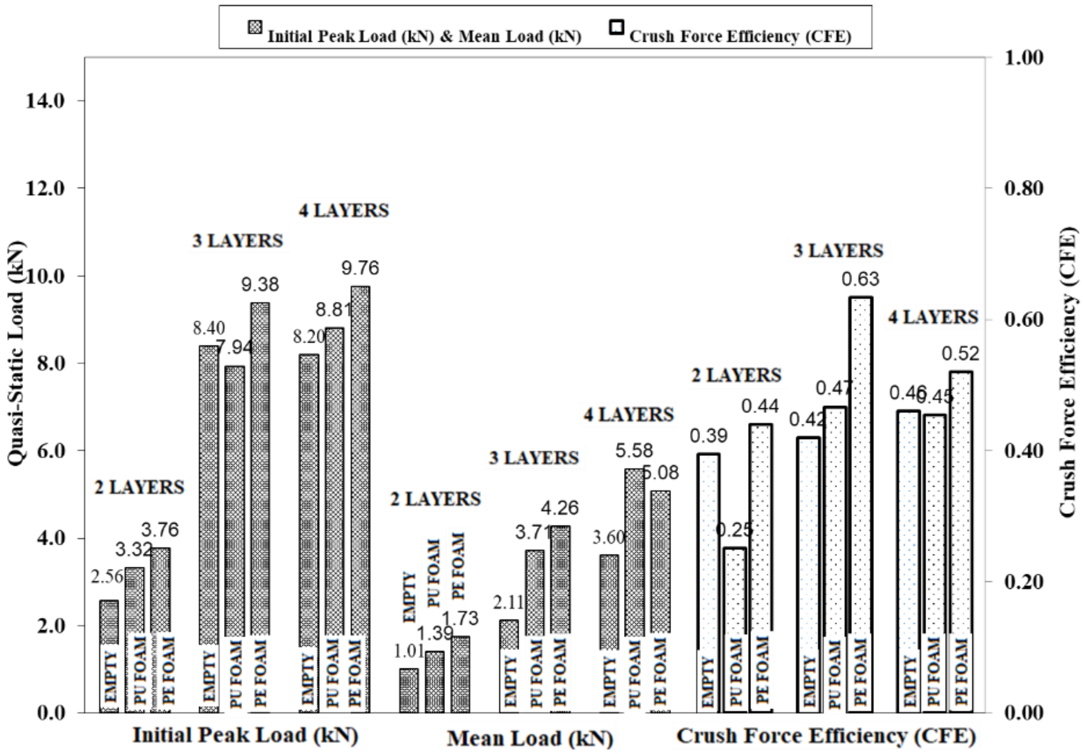


Figure 5. Initial, mean and crush force efficiency relation for jute/polyester tubes for each layers.

3.3. Specific Energy Absorption

Energy absorption is defined as the total area under the load-displacement curve. The absorbed energy is calculated to measure the performance of the crush box as a crashworthy structure. Hence, the total area under the load-displacement curve was measured before the crushing occurred. The capability of the structures and the comparison between each specimen analysis are using equation 1, 2 and 3.

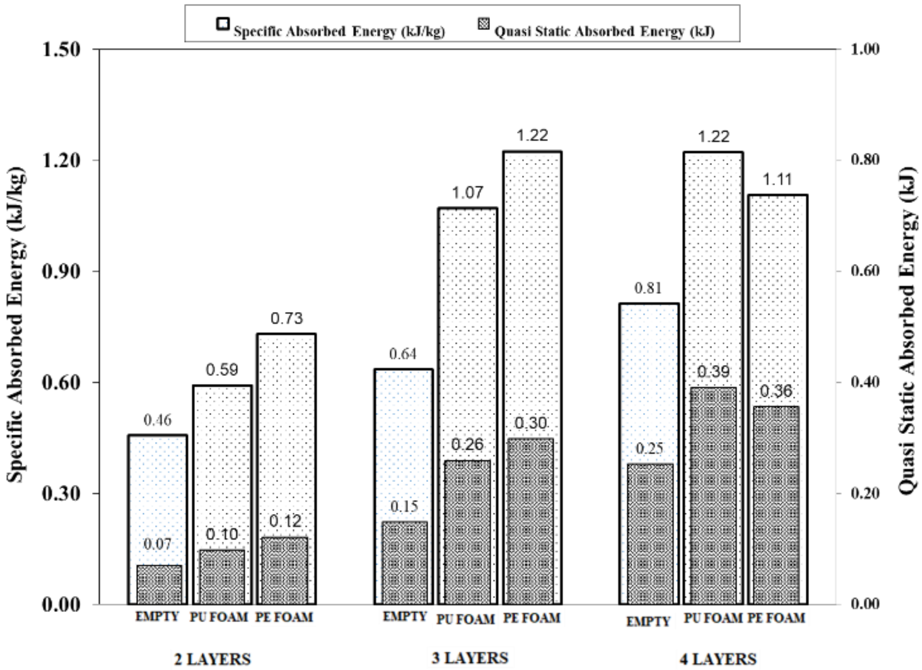


Figure 6. Energy absorption and specific absorbed energy relation for jute/polyester tubes for each layers.

4. Conclusion

In this paper, experimental tests were carried out to investigate the effect of axial loading on the load-displacement curve and specific energy absorption. Hand lay-up method was used to fabricate each specimen of the composite tubes of two, three and four layers, respectively. Results of the load-displacement curve show that the mean axial load obtained for four layered jute/polyester polyurethane is found higher 8.9% than polystyrene. The specific energy absorption of the four-layered jute/polyester polyurethane and three layered jute/polyester polystyrene tubes is found higher respectively 47.5% and 33.6% than empty tubes profile. The increase in the number of layers from two to four increased the mean axial load from 1.01 KN to 3.60 KN for empty jute/polyester tubes. The increase was from 1.39 KN to 5.58 KN for the jute/polyester polyurethane. In general, similar failure mechanism has been obtained from the fractured composite tubes where cracks propagate at the center position of the tube at the top until bottom sides of the tube. The post peak failures showed a significant deformation at the crack line position and then lead to the final fracture.

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