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Crashworthiness Characteristics and Failure Mode of Composite Tubes

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Abstract: The woven plain weave/epoxy hexagonal tubes' capacity for energy absorption is investigated in present work. The experimental work was performed on composite hexagons with different hexagonal angles between 35° and 55° in aspect ratios L/t = 70 and 10° angular increments. Observation was made on how the configuration impacts the crash-worthiness behavior of the reinforced hexagonal tubes. Moreover, the impact on absorbed energy was also investigated. The highest energy absorption capability and average crashing load was demonstrated by the woven plain weave/epoxy hexagonal tube with β = 45°. Failure of the woven plain weave/epoxy hexagonal tube was found to be in progressive mode. Furthermore, apart from the influence of geometry, the energy absorption capabilities of the hexagonal tubes were also affected by the type of material.

Index Terms: Hexagonal Tubes, Specific Energy Absorption, Crushing History.

I. INTRODUCTION

One of the safety measures in the design of safety passenger vehicles is the crushing energy absorption. This is important in order to minimize the damage on the vehicle's occupants during collision. Thus it is crucial to improve the absorbed energy of the tubular composition used in the design of modern transportation. The ability of the car or train to absorb static or dynamic energy and to survivability of the people is known as the 'crashworthy of the compression.

Failure occurs in structural component as the component can no longer convey the load acted upon it. In general, the capability of the component to convey load is diminished as it no longer satisfactorily perform service functions due to breakage, excessive deformation, degradation, or other mechanisms. Permanent deformations ensued from such failure initiate redistribution within the structure and reduce the laminate strength and stiffness [9–11].

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One or both of these factors contributes to damage of the component. Energy absorption of a structure can be expressed through controlled failure mechanism and mode, in which gradual decay in the load profile is preserved [1–5]. Previous studies generally investigated the effects of number of layers, type of fibers, type of matrix, and fiber orientation angle on the crashworthiness of the tubular structure from load-displacement and energy absorption relationships [1,6-8]. Much recently, the focused of research on the crushing behavior of materials has included conventional and natural composite structures, such as the synthetic fiber reinforced composites such as aramid/carbon [9], polyester/E-glass [11], carbon and Kevlar [12], aramid /carbon/ [13], vinyl ester–fiberglass material [14], fibre glass [15], carbon fibre and glass fibre [16], carbon-epoxy mixed with carbon and glass to make sold composition [6]. However, the present work investigates the absorbed energy and crack mode of reinforced hexagonal tube an experimentally with axial crushing load.

II. METHODS

Traditional method Lay-up by hand

Fabrication and manufacturing of green composite materials is usually done using conventional and natural fiber composites [17–19]. The oldest and simplest method used is the hand lay-up technique. The present work implemented this technique to fabricate woven kenaf and aramid hybrid laminate (Kevlar) composites as shown in Figure 1 [20]. The kenaf woven-Kevlar were organized in dissimilar laminates arrangements. To keep the fiber in place, the liquid matrix was applied by spraying or brushing until the desired depth was achieved. This way, a high-quality kenaf-kevlar composite structure was produced. Furthermore, this technique presented versatility in terms of costing and feasibility of producing high quality knaf-kevlar composite structure with hexagonal composite tubes as shown in Figure 2 [3, 21and 22].

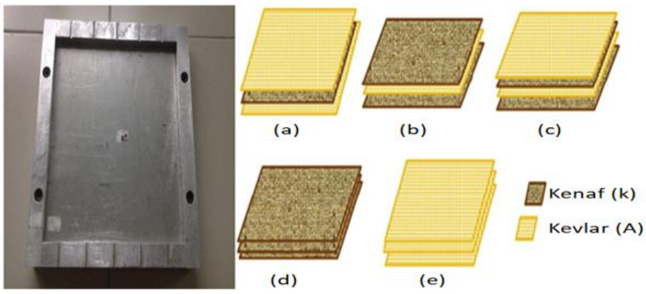

Fig. 1 Material preparation mold fabrication and composites structure for traditional methods [20]

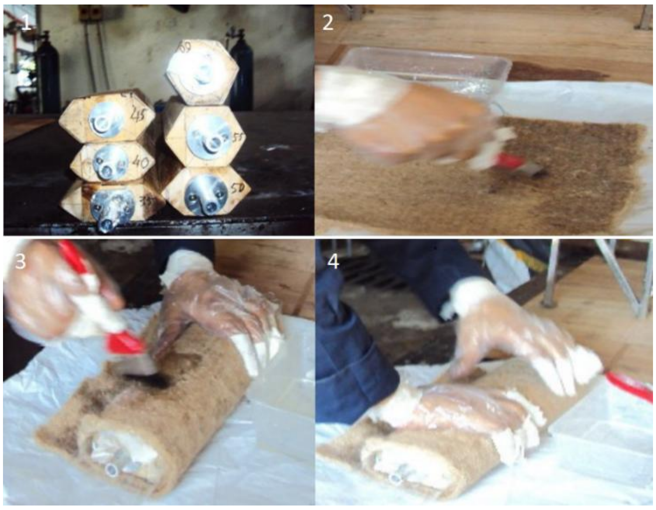

Fig. 2 Details of fabrication steps [3]

Further, the resin tank was used impregnate the material used. Then, on a solid wood spindle, the hexagonal composite tube with wet fiber was created. Wax layer was coated on the outer thickness of the samples. This was done to facilitate extraction of hexagons from the mold two laminitis of fibre arranged to get a thickness of about 2mm. The tubes produced were left at ventilated room for two days to gain the optimum hardness and dray.

Universal testing machine was used to perform the compression task with a maximum force of 100 kN, the speed was fixed at 15 mm/min. The schematic diagram of Figure 3and 4, shown the whereas the composite tubes used as main absorbed energy elements.

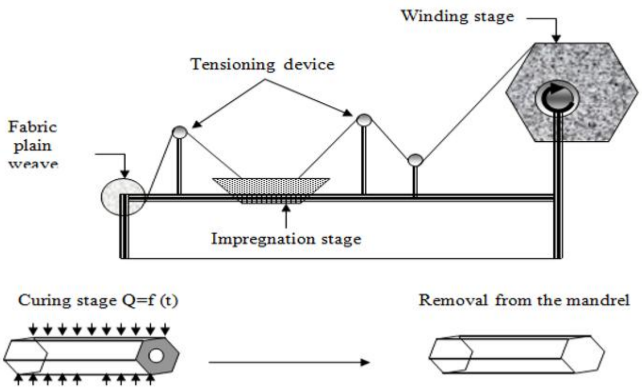

Fig. 3 Schematic diagram of fabric plain weave fabrication process

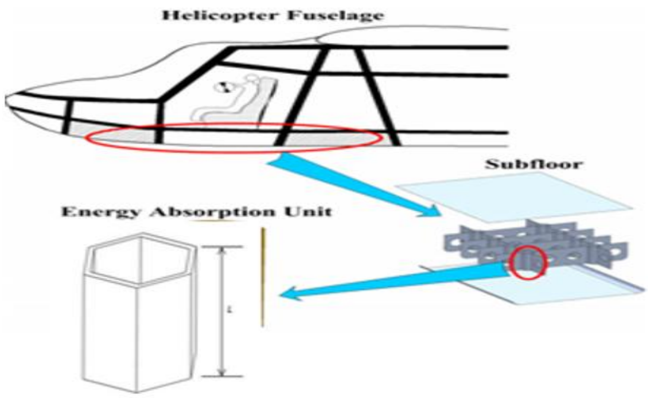

Fig. 4 Crashworthy subfloor in helicopter fuselage

Crashworthiness in composite structure

Crash-worthiness is reorganized as ability if vehicle to protect a passenger from high risk.

Figure 5 shows; Collision is associated with absorption of energy absorption within monitoring mode of failure that can remain a steady drop in the force through the absorbing the energy from car body. Figure 5 parameters that impact the crash in composition tubular [3].

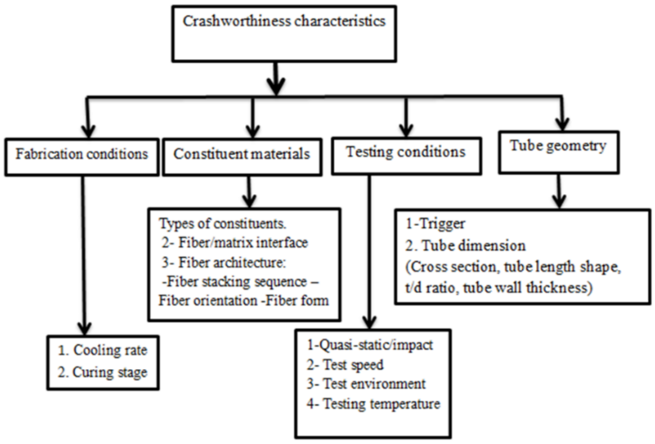

Fig. 5 Various parameters that impact the load caring capacity [3]

The major important parameter is absorption energy-carrying [6]. The energy can be absorbed once the structure starts falling [24, 25]. Figure 6 shows that force-displacement curves of composite tubes and shows crashworthiness characterization numbers that can be compared according to the load-crashworthiness and energy absorption with various composites configuration [17,26].

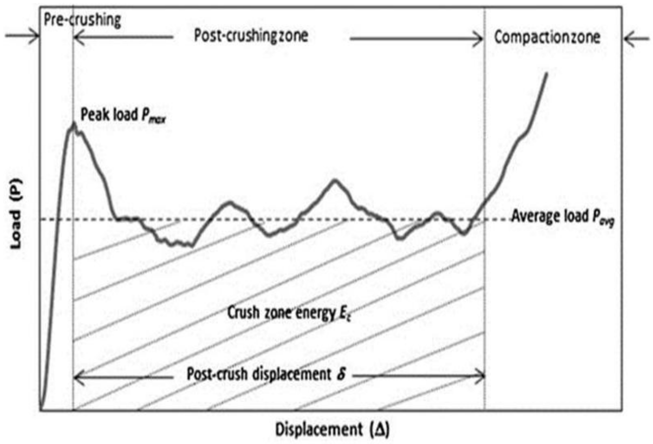

Fig. 6 Stages of crashworthiness materials [3]

Specific energy absorption (ES)

Identify as Specific energy absorption, ES, er kilogram (KG). The archived load done or the energy absorbed, W, within the process is stated in formula (1) [28].

$$W = \int_{SI}^{Sb} Pds = Pm(Sb - Si) \quad (1)$$

S_b and S_i recognized as the fill the intervals. The ability of specific energy, E_S, of a composite structure, as stated in formula (2)

$$Es = \frac{W}{m} \quad (2)$$

Where *m* is the weight of the tube, and P*m* is the mean failure load of the tubular composition [1, 21, 22, and 29].

III. RESULTS AND DISCUSSION

Effect of hybrid material in Initial peak load (Pi)

The initial failure load value is the highest load achieved before the tube specimen collapses. Ataollahi et al. [26] composite silk epoxy tube. They tested specimens had an effect on the initial load of values, Yan et al. [30] recently investigated the lateral crush of natural composite tubular filled with polyurethane foam. They found that the risk in peak capacity load nearly direct proportional to the risk in the plate layer.

Figure 7 and Figure 8 show a comparison of the load peak values between the current study and the previous study. Therefore, there is a significant correlation between the peak load values of the two studies and two types of fiber and tube geometry have been used [26].

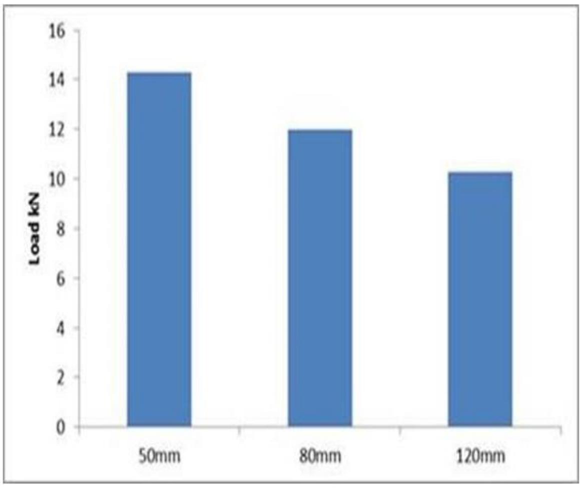

Fig. 7 Fillies and mean of crushing load

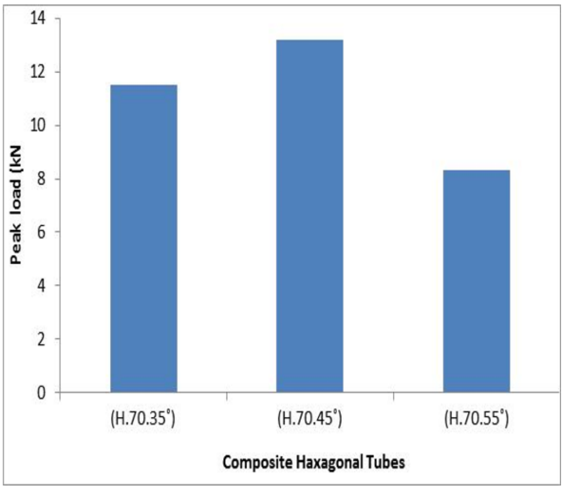

Fig. 8 Composition of Hexagon tubes and fillies load [Current study]

Crushing history and failure modes

(β=45° and L/t=30)

As shown in Figure 9, the displacement graph (L/t=30) and angle 45° the crush failure phase behaves totally elastic path. The load increases till fillies' crush signs at curves 9.2 kN at 2 mm (0.044 h) deformation. The highest failure mechanical mode then the load gradually decreases till 2.1kN at 9 mm (0.2 h) displacement refer to Figure 9 (a, b). In advance stage the tubular provides more opposition to the load of conduct resin the load again to 7.3 kN at about 19 mm (0.4 h) with that tubular is destroyed gradually by the failure mode fragmentation.

β=45° and L/t=50

The force-displacement curves for hexagon composition tubular are stated in figure 9, at first the load non-linearly behaved a matrix crack observed at 1 mm (0.013 h). The force upgrade to P_{er}=12.1kN at 4mm (0.05 h) deformation it can be identifying the type of failure mode as. The load drops suddenly 3.2 KN at 4 mm (0.05 h) with catastrophic behavior. Furthermore, the stable behavior of force behavior was reach consequently after enforcing drop on 2.1 kN for deformation ranges between 7 mm (0.08 h) to30 mm (0.39 h). The load begins to increase to the next stage which is peak value of 16.9 KN and 38.9 mm (0.53 h) displacement as stated in Figure 10. During the last failure phase, the load recorded its maximum value of 23.2 kN at around 55.9 mm (0.74 h) and an inner and outer frond absorbed as a outcome of fragmentation mode allied with inclusive longitudinal fracture see the last stage in Figure 9.

β=45°and L/t=70

The relationship between force deformation of hexagonal are shown in figure 9.variously the behavior of the load can be identified as linear case to the first crack Pi=12 kN at 2mm therefore, the resistance of tube smoothly degrees 1.5kNat 11 mm deformation at current phase the tube is ripped at down ward of the tube as result of transfers failure mode refer figure 9 (a and b) after this stage the tube resistance again and increase the load to maximum load to optimum p_h 40 at 24mm displacement. Another type of displacement mode can be specified nearly subline failure mode at that downward of tube as result of suddenly fail of the force. Refer to figure 9 c. upraising of force was identify. At the last stage the type of failure mode (subbing mode demonstrated as shown in figure 9 d and f) considerate that measure buckling whether minimum buckling meet specific link are to essential categories of due made from woven composite.

β=45° and L/t=100

As shown in Figure 9, the relation between the two parameters displacement-load and capacity at start the force increase to history of deformation of hexagonal tube with aspect a ratio (L/t=100) and β=45°. Th tube structure were more resistant drop at almost with L/t=50 peak P_i = 15 kN at 23 mm (0.15 h) displacement as shown in Figure 9 (a). Consequently, the load decreases gradually to its lowest value of P_L=1.8 kN at 79 mm (0.52 h) displacement.

The load rises to its second peak value of 6.2 kN at 130 mm (0.86 h) displacement. IN THE LAST PHASE the tube destroys in from upward of the tube structure as shown in Figure 9 (b-f).

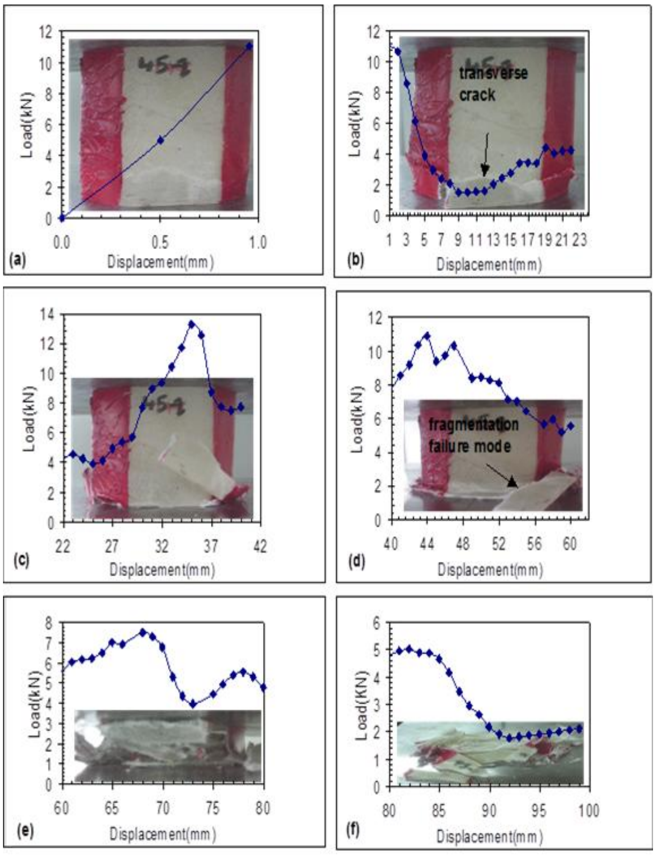

Fig. 9 Relationship between force and displacement (H.70.45°)

Importance of energy absorption in the industrial sector

In the industrial sector are particularly relevant to the precise of absorbing energy from material-reinforced and composite polymer structures. The main characterization of synthetic and nature fibers including energy absorption and load peak capacity.

At most similar, due to they can protect the travelling passenger from high risk. Dimension parameter combine with the density of fiber to reduce the heaviness of structure and create nature and traditional fibers. As example carbon and class. In addition, at the same time the error shows high console tense and hardness. This feature makes the fiber superior for implementation and energy absorption ambling and the manufacturing industries.

The specific energy can be compared with several type of natural and compensational fiber, see Table 1. It can be identified from the table; the caroled tube shows maximum energy absorption at this result can be provides to upgrade the ability of using natural and conventional fibers in manufacturing sector.

The comparative absorbed energy of few types of natural and conventional fibers is listed in Table 1. It can be identifying that the corrugated circular tube shows maximum value energy absorbed energy. The outcome results are unique to the increased chance to more offer and request in the sustainable and industrial sector. The information clearly shows that the natural and conventional fibers can competitive part that use in transportation applications.

Furthermore, Table 2 lists the geometrical, shape, and triggers and corrugated tubes affected Specific Energy Absorption (SEA) for glass and carbon fibers reinforced plastics (FRPs) composites.

Table. 1 Natural and conventional fiber with value of SAE

Configuration	ID	Material	SAE (kJ/kg)	Ref.
Cylindrical corrugated composite tubes	CCT	Woven roving glass fibre/epoxy	10.2	[31]
Radial corrugated composite tubes	RCCT	Woven roving glass fibre/epoxy	12.2	[31]
Square tubes	ST	silk/epoxy	5.4	[26]
Radial corrugated surrounded by circular composite tube (RCSCT)	(RCSCT)	Woven roving glass fibre/epoxy	12.08	[5]
Cylinder composite tube	CCT	Woven roving glass fibre/epoxy	9.65	[5]
Radial corrugated composite tube	(RCCT)	woven roving glass fibre / epoxy	3.04	[5]
Corrugated tubes	GFRE	glass fibre / epoxy	9.53	[1]
Circular	H7	Aluminum/glass epoxy hybrid tubes	15.83	[32]

Table. 2 hexagon tube (L/t=70) and few angles

Specimens (ID)	Pi (kN)	Es (kJ/kg)	P_{cr}(kN)
(H.70.35°)	11.5	6.96	11.5
(H.70.45°)	13.2	10.7	13.2
(H.70.55°)	8.5	8.6	8.5

Various types of materials can be achieved different value of energy absorption. On other hands, different tube configuration can achieve different energy absorption. Furthermore, increasing of wall thickness of composite structure fieriest load will appraise by two folders as same as SEA by two folders. According to the current investigation, the changing of hexagonal angles has a significant effect on SEA.

IV. CONCLUSION

The main conclusion to draw is:

- It can be seen that the average load increases as each meat increases from 35 ° to the average breaking load, the breaking load reaches a maximum of 45 ° each, and as each meat increases to each meat, the average breaking load decreases 60 °.
- A hexagonal tubular with β = 45° optimum absorption energy capacity of 35% compared to other tubes.
- Hexagonal tubular with β = 45 ° showed an optimal absorbed energy compared with other tubes.
- The fracture of the hexagonal tube is a progressive type of grinding when subjected to compressive loads.
- Variables affecting impact- crashworthiness parameters of composite structure
- There is a significant correlation between the current peak load values used and the current study using two types of fiber and tube geometry.

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REFERENCES

1. A.M. Elgalai, E. Mahdi, A.M.S. Hamouda, B.S. Sahari, Crushing response of composite corrugated tubes to quasi-static axial loading. Compos Struct 2004;66:665–71. doi:10.1016/j.compstruct.200, Compos. Struct. 66 (2004) 665–671. doi:10.1016/j.compstruct.2004.06.002.
2. P. Du Bois, C.C. Chou, B.B. Fileta, A.I. King, H.F. Mahmood, Vehicle and Occupant Protection, (2004) 27–280, 304–330.
3. M.F.M. Alkbir, S.M. Sapuan, A.A. Nuraini, M.R. Ishak, Fibre properties and crashworthiness parameters of natural fibre-reinforced composite structure: A literature review, Compos. Struct. 148 (2016). doi:10.1016/j.compstruct.2016.01.098.
4. M.F.M. Alkbir, S.M. Sapuan, A.A. Nuraini, M.R. Ishak, Effect of geometry on crashworthiness parameters of natural kenaf fibre reinforced composite hexagonal tubes, Mater. Des. 60 (2014) 85–93. doi:10.1016/j.matdes.2014.02.031.
5. E.F. Abdewi, S. Sulaiman, A.M.S. Hamouda, E. Mahdi, Quasi-static axial and lateral crushing of radial corrugated composite tubes, Thin-Walled Struct. 46 (2008) 320–332. doi:10.1016/j.tws.2007.07.018.
6. S. Ochelski, P. Gotowicki, Experimental assessment of energy absorption capability of carbon-epoxy and glass-epoxy composites, Compos. Struct. 87 (2009) 215–224. doi:10.1016/j.compstruct.2008.01.010.
7. D. Hull RE 1.pdf, (n.d.).
8. D. Siromani, G. Henderson, D. Mikita, K. Mirarchi, R. Park, J. Smolko, J. Awerbuch, T.M. Tan, An experimental study on the effect of failure trigger mechanisms on the energy absorption capability of CFRP tubes under axial compression, Compos. Part A Appl. Sci. Manuf. 64 (2014) 25–35. doi:10.1016/j.compositesa.2014.04.019.
9. E. Mahdi, T.A. Sebaey, An experimental investigation into crushing behavior of radially stiffened GFRP composite tubes, Thin-Walled Struct. 76 (2014) 8–13. doi:10.1016/j.tws.2013.10.018.
10. M.H. Zamri, H.M. Akil, Z.A. MohdIshak, Pultruded Kenaf Fibre Reinforced Composites: Effect of Different Kenaf Fibre Yarn Tex, Procedia Chem. 19 (2016) 577–585. doi:10.1016/j.proche.2016.03.056.
11. J.S. Kim, H.J. Yoon, K.B. Shin, A study on crushing behaviors of composite circular tubes with different reinforcing fibers, Int. J. Impact Eng. 38 (2011) 198–207. doi:10.1016/j.ijimpeng.2010.11.007.
12. A. Othman, S. Abdullah, A.K. Ariffin, N.A.N. Mohamed, Investigating the quasi-static axial crushing behavior of polymeric foam-filled composite pultrusion square tubes, Mater. Des. 63 (2014) 446–459. doi:10.1016/j.matdes.2014.06.020.
13. Y. Li, Q. Li, H. Ma, Composites : Part A The voids formation mechanisms and their effects on the mechanical properties of flax fiber reinforced epoxy composites, Compos. PART A. 72 (2015) 40–48. doi:10.1016/j.compositesa.2015.01.029.
14. A.G. Mamalis, D.E. Manolakos, M.B. Ioannidis, D.G. Chronopoulos, P.K. Kostazos, On the crashworthiness of composite rectangular thin-walled tubes internally reinforced with aluminium or polymeric foams: Experimental and numerical simulation, Compos. Struct. 89 (2009) 416–423. doi:10.1016/j.compstruct.2008.09.008.
15. N.K. Gupta, H. Abbas, Lateral collapse of composite cylindrical tubes between flat platens, Int. J. Impact Eng. 24 (2000) 329–346. doi:10.1016/S0734-743X(99)00173-6.
16. D. Hu, C. Zhang, X. Ma, B. Song, Composites : Part A Effect of fiber orientation on energy absorption characteristics of glass cloth / epoxy composite tubes under axial quasi-static and impact crushing condition, Compos. Part A. 90 (2016) 489–501. doi:10.1016/j.compositesa.2016.08.017.
17. S. Palanivelu, W. Van Paepegem, J. Degrieck, J. Van Ackeren, D. Kakogiannis, D. Van Hemelrijck, J. Wastiels, J. Vantomme, Experimental study on the axial crushing behaviour of pultruded composite tubes, Polym. Test. 29 (2010) 224–234. doi:10.1016/j.polymertesting.2009.11.005.
18. M.A. Saleh, E. Mahdi, A.M.S. Hamouda, Y.A. Khalid, Crushing behaviour of composite hemispherical shells subjected to quasi-static axial compressive load, Compos. Struct. 66 (2004) 487–493. doi:10.1016/j.compstruct.2004.04.073.
19. A.G. Mamalis, D.E. Manolakos, G.A. Demosthenous, M.B. Ioannidis, Energy absorption capability of fibreglass composite square frusta subjected to static and dynamic axial collapse, Thin-Walled Struct. 25 (1996) 269–295. doi:10.1016/0263-8231(95)00057-7.
20. R. Yahaya, S.M. Sapuan, M. Jawaid, Z. Leman, E.S. Zainudin, Effect of layering sequence and chemical treatment on the mechanical properties of woven kenaf-aramid hybrid laminated composites, Mater. Des. 67 (2015) 173–179. doi:10.1016/j.matdes.2014.11.024.
21. M.F.M. Alkbir, S.M. Sapuan, A.A. Nuraini, M.R. Ishak, Lateral crushing properties of non-woven kenaf (mat)-reinforced epoxy composite hexagonal tubes. International Journal of Precision Engineering and Manufacturing 17 (7), 965-972
22. M.F.A. Alkbir, M.S. Salit, N.A. Aziz, M.R. Ishak, Lateral crushing properties of non-woven kenaf (mat)-reinforced epoxy composite hexagonal tubes, Int. J. Precis. Eng. Manuf. 17 (2016). doi:10.1007/s12541-016-0118-5.
23. MFM Alkbir, AMS Hamouda, SM Sapuan, E Mahdi Effect of The crashworthiness behaviour of filament wound hexagonal glass fibre epoxy composite tubes. Polymers and Polymer Composites 15 (8), 653-654.
24. S.M. Sapuan, a. Leenie, M. Harimi, Y.K. Beng, Mechanical properties of woven banana fibre reinforced epoxy composites, Mater. Des. 27 (2006) 689–693. doi:10.1016/j.matdes.2004.12.016.
25. J. Datta, P. Kopczy??ska, Effect of kenaf fibre modification on morphology and mechanical properties of thermoplastic polyurethane materials, Ind. Crops Prod. 74 (2015) 566–576. doi:10.1016/j.indcrop.2015.05.080.
26. S. Ataollahi, S.T. Taher, R.A. Eshkoor, A.K. Ariffin, C.H. Azhari, Energy absorption and failure response of silk/epoxy composite square tubes: Experimental, Compos. Part B Eng. 43 (2012) 542–548. doi:10.1016/j.compositesb.2011.08.019.
27. L. Yan, N. Chouw, Crashworthiness characteristics of flax fibre reinforced epoxy tubes for energy absorption application, Mater. Des. 51 (2013) 629–640. doi:10.1016/j.matdes.2013.04.014.

28. E. Mahdi, T.A. Sebaey, Crushing behavior of hybrid hexagonal/octagonal cellular composite system: Aramid/carbon hybrid composite, Mater. Des. 63 (2014) 6–13. doi:10.1016/j.matdes.2014.06.001.
29. E. Mahdi, A.M.S. Hamouda, B.B. Sahari, Y.A. Khalid, Experimental quasi-static axial crushing of cone – tube – cone composite system, 34 (2003) 285–302.
30. L. Yan, N. Chouw, X. Yuan, Improving the mechanical properties of natural fibre fabric reinforced epoxy composites by alkali treatment, J. Reinf. Plast. Compos. 31 (2012) 425–437. doi:10.1177/0731684412439494.
31. E.F. Abdewi, S. Sulaiman, A.M.S. Hamouda, E. Mahdi, Effect of geometry on the crushing behaviour of laminated corrugated composite tubes, J. Mater. Process. Technol. 172 (2006) 394–399. doi:10.1016/j.jmatprotec.2005.07.017.
32. M. Mirzaei, M. Shakeri, M. Sadighi, H. Akbarshahi, Experimental and analytical assessment of axial crushing of circular hybrid tubes under quasi-static load, Compos. Struct. 94 (2012) 1959–1966. doi:10.1016/j.compstruct.2012.01.003.

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