
Volume 94, Issue 3, February 2012
ISSN: 0263-8223
ELSEVIER
COMPOSITE STRUCTURES
EDITOR: A. J. M. FERREIRA

Composite Structures 94 (2012) 803–812

Contents lists available at SciVerse ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Review

On the effect of geometrical designs and failure modes in composite axial crushing: A literature review

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ARTICLE INFO

Article history:
Available online 1 October 2011

Keywords:
Fibres
Buckling
Axial crushing
Numerical analysis

ABSTRACT

Composite materials have been known for its low density, ease in fabrication, high structural rigidity, and wide range applications, i.e. aeronautic applications and automotive industry. Due to this, extensive studies had been conducted to evaluate its axial crushing ability to replace metallic materials. In this paper, it reviewed the usage of fibre reinforced plastic composite (FRP) as an energy absorption application device. Failure modes and geometrical designs such as shapes, geometry and triggering effect have been studied where these factors affected on peak load and specific energy absorption significantly. Accordingly, numerical analysis for axial crushing of affected factors had been simulated to predict the failure mechanisms of FRP composites.

Contents

1. Introduction

In the past, thin wall metal tubes have been highly studied for its axial crushing ability [1,2]. Metal tubes subjected to axial crushing, energy was absorbed due to plastic deformation during the progressive fold formation [2]. In order to increase crashworthiness in term of unit mass volume energy absorption, some researchers had increased tube wall thickness [3,4]. Moreover, Cheng et al. had attempted with aluminium foam filled braided stainless steel tubes for better energy absorption [5]. However, these improvisations are no longer applicable especially for passenger carrying application due to fuel consumption such as in aerospace, automotive industry and other weight concerning application. As a results, new materials like fibre reinforced plastic (FRP) have been extensively studied for their capabilities due to the fact that it is lighter and stronger [6,7]. Research groups reported that energy absorption of a well design FRP composite can perform better than metals [8–10]. Unlike metals, composite materials such as carbon and glass fibre reinforced plastics composites subjected to axial crushing will undergo of fracture to obtain energy absorption rather than plastic deformation which exhibited in metal tubing [11,12]. As reported [9], most energy absorption were contributed by failure modes of Mode I and Mode II fracture, energy absorbed during frond bending, and fibre fracture as well as friction at and within the crushed fronds [13].

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doi:10.1016/j.compstruct.2011.09.013

In composite tubes fabrication, fibre orientations effects on axial crushing behaviour were studied. Carroll et al. [14] reported that for ±55° filament-wound glass fibre/epoxy under quasi-static compression, the failure depends on stress ratio and rate of loading. It was suggested that strength and stiffness were a function of loading direction and the total energy absorbed was related to the stress strain behaviour. On the other hand, epoxy/carbon fibre layers of (±0) and (±90) were able to crush progressively and absorbed more energy compared to layers ($+45_k/-45_k$) which deformed plastically without fracture due to higher flexural rigidity [7].

In another experiment, studies on different materials stacking and the effect on crushing ability. Segmented composite tubes were investigated for their energy absorption under lateral and axial compression. Abosbaia et al. [12,15] were using carbon, glass and cotton fabric to fabricate composite tube reinforced with epoxy by wet winding process. It was revealed that segmented composite tube performed better under axial loading compared to lateral crushing. In axial crushing, no significant improvement in segmented and non-segmented carbon/epoxy. However, it absorbed highest energy amongst tested segmented FRP composites (i.e. glass and cotton/epoxy composite). Interestingly, segmented cotton–cotton–carbon/epoxy (CT–CT–C) FRP composite was enhanced by 17% but segmented cotton–cotton–glass (CT–CT–GT) FRP decreased the energy absorption performance from the ones with cotton segmented (CT–CT–CT) FRP. On the other hand, Mahdi et al. [16] studied on the effect of using hybrid glass/carbon sequence on energy absorption capability and revealed that Glass–Carbon–Glass (GCG) combination has the best energy absorption rather than GGC and CGG. The reason to this was glass fibre layers were failed under transverse and axial shear, while the carbon layers were buckled. Unlike GGC and CGG segmented composites failure occurred when the glass fibre layers debonded and carbon layer fractured.

Geometrical parameters aspect ratio was also used for studies in axial crushing. Mamalis et al. [13] investigated on L/w (length/inner width) aspect ratio affected on axial crushing capability. He concluded that peak load (P_{max}) decreases as aspect ratio of the compressed tube specimen becomes higher. Palanivelu et al. [17] reported that t/d or t/w (wall thickness/outer diameter or width) aspect ratio of 0.045 for different shape influenced the crushing state i.e. square tube crushed catastrophically as compared to round tube both geometries crushed progressively However, both shapes were progressively crushed when aspect ratio of 0.083 [18].

In this paper, many studies have been done in order to understand on the axial crushing capability of FRP composite. The objective of this paper is to review failure modes and design factors such as shape, geometry, and triggers that affects on the peak load and total energy absorbed.

2. Energy absorption in composite characterisation

In axial crushing, tests are carried out by either quasi-static compression or impact loading. In static loading, a composite tube is compressed between two steel plates of a hydraulic press at low cross head speeds normally between the range of 1–10 mm/s. For impact loading dynamic test, it is carried out by using a drop hammer or an impactor. Accordingly, specimen dimensions were made based on the preliminary calculation to determine tube geometry in order to avoid buckling [13]. Tested tubes have typical length at 50–125 mm length, 20–100 mm outside diameter/width and 1–3 mm wall thickness. However, different shapes were applied for the test such as round, square, hexagon [17], cones [19], and plates [7].

Energy absorption capability is computed to determine its energy dissipation rate for a crushing event. Energy absorption capability on the total work done (W_T) for composite crushing is equal to the area under the load–displacement curve and evaluated as

$$W_T = \int P\,ds, \tag{1}$$

where P is the corresponding force on the structure and s is the cross head distance.

Energy absorption capability is also evaluated as per unit mass absorbed which commonly known as Specific Energy Absorption (SEA) and evaluated as

$$\mathrm{SEA} = \frac{W_T}{m} = \frac{W_T}{\rho v}, \tag{2}$$

where m is crushed mass, ρ is the composite material density, and v is the volume of the crush specimen.

3. Factors affecting on peak load and energy absorption

3.1. Failure mechanisms

Peak load is measured before material begin to fail under buckling such as local buckling, global buckling, yield (or fracture) or progressive crushing as shown in Fig. 1 [20]. This buckling failure can further lead to either catastrophic or progressive failure as shown in Fig. 2 [21] where the failure affected onto the load displacement curve. In the figure, the area under the curve represents the energy absorbed. When progressive failure happened, this area will be higher and constant load slightly occurred as crushing displacement increases.

Catastrophic failure will result in sudden drop of load thus lower energy absorbed. This happened due to specimen crushed was fractured in the mid-plane [22] or had longitudal cracks [17] as

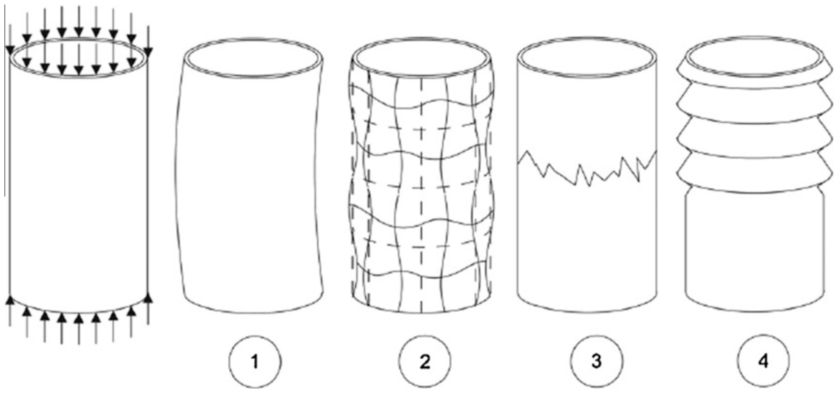


Fig. 1. Failure mode on axial compression: (1) global buckling, (2) local buckling, (3) fracture, and (4) progressive crushing [20].

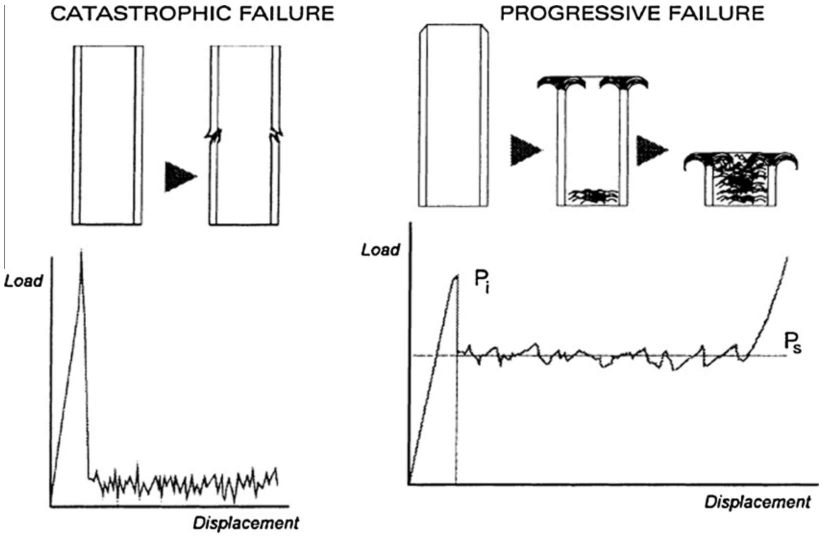


Fig. 2. Lower energy absorption in catastrophic failure as compared to progressive failure [21].

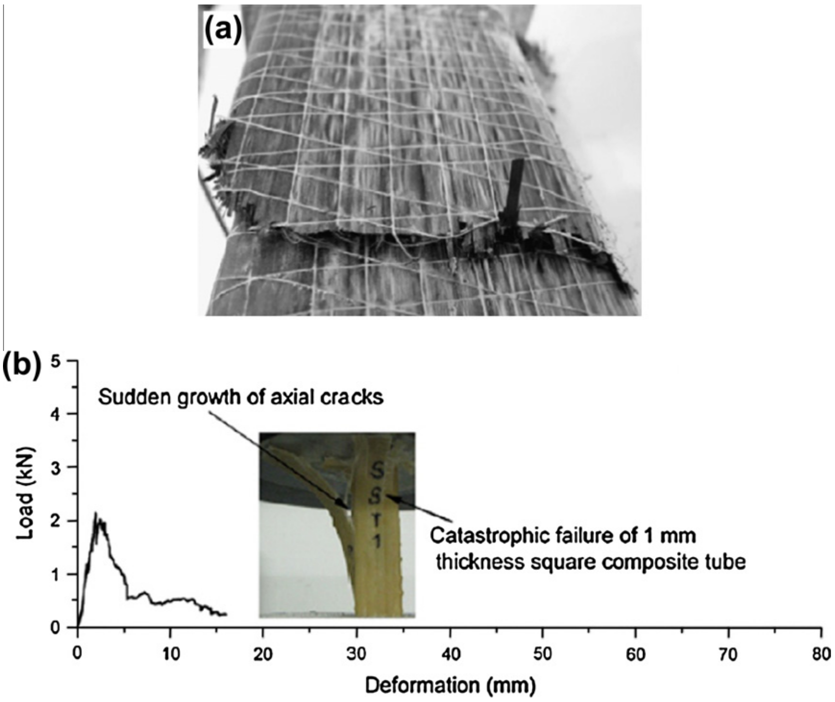


Fig. 3. (a) Mid-plane break and (b) longitudal crack in catastrophic failure [17,22].

shown in Fig. 3a and b, respectively. On the other hand, progressive failure is the opposite of catastrophic failure where by more area under the curve can be observed. This result is due to multi-failure mode combinations (Mode I, Mode II, and Mode III) and local buckling were initiated during progressive crushing [23] and different energy absorption level was obtained. In Mode I and Mode II, splaying mode and sliding mode, respectively, gave higher energy absorption [24] (c.f. Fig. 4) due to contribution of friction between laminates fibre and bending [7]. On top of that, fibre orientations played an important role in Mode I interlaminar fracture toughness which had been agreed with previous work [25]. In Mode III, energy absorption was lower as compared to Mode I and II. This was due to the mid-plane fracture and unstable collapse of the compressed tube [13]. However, this contradicts with another literature [23] that documented Mode III failure is due to matrix deformation and fibre fracture that moved progressively through the elliptical structure (ellipticity ratio of 2.00). Moreover, it showed stable crushing failure along post crush stage and gave highest normalised specific energy absorption, E_{NS} (explain in Section 3.2), which is 22273.79 kJ/kg m^2.

3.2. Shape and geometry

Many design shapes and structures had been made and its crushing behaviours were studied for their energy absorption capability.

On axial crushing for cross sectional shape, Palanivelu et al. [17] reported that square and hexagonal shape with t/D or t/W aspect ratio of 0.045 crushed catastrophically but circular shape showed uniform and progressive crushing modes. Increasing the aspect

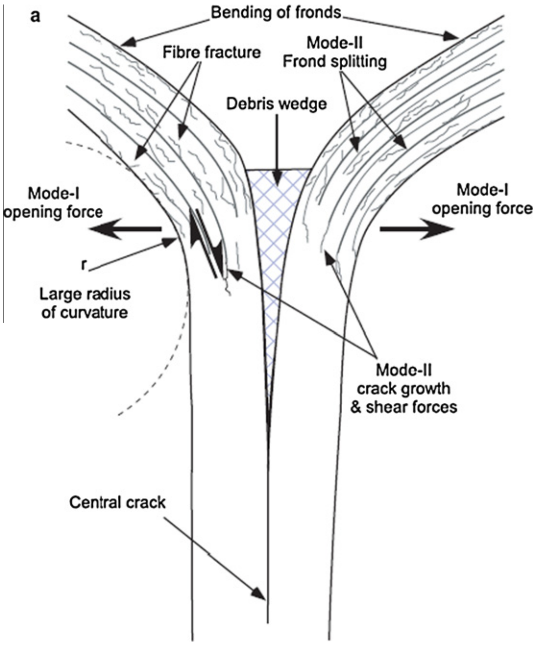


Fig. 4. Splaying (Mode I) and sliding (Mode II) in axial crushing [9].

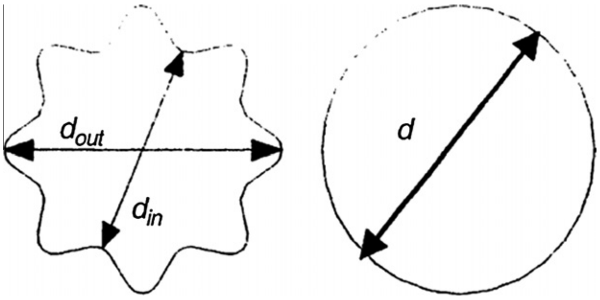


Fig. 5. Radial corrugated and circular shape [26].

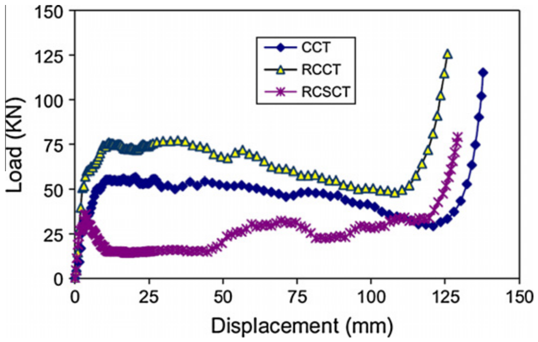


Fig. 6. Load displacement curves of circular cross section (CCT), corrugated circular cross section (RCCT), and combination of the circular and corrugated circular cross section (RCSCT) [27].

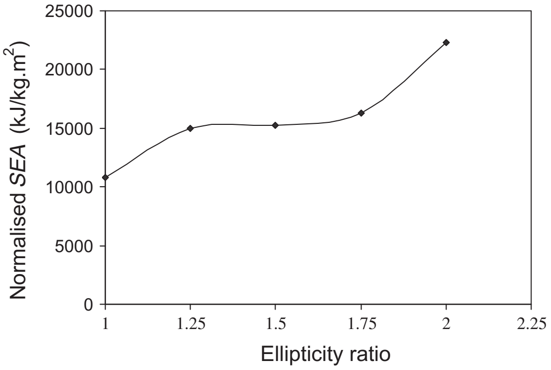


Fig. 7. Normalised specific energy absorption against ellipticity ratio curve [23].

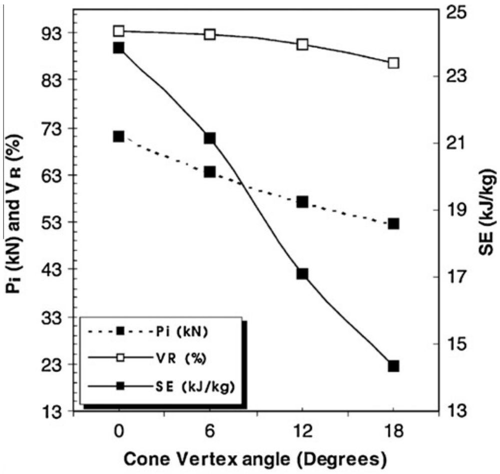


Fig. 8. Failure crush load, specific crushing energy and structural volume reduction of conical shells [6].

ratio to 0.083, square and hexagonal shapes were crushed progressively. From the work, it is revealed that circular cross section with t/D ratio of 0.083 was having the highest SEA of 30.4 kJ/kg compared to square and hexagonal cross section which recorded SEA of 12.3 kJ/kg and 16.4 kJ/kg, respectively. Abdewi et al. [26] tested on using radial corrugated cross section (RCCT) and circular cross section (CCT) composite tubes showed in Fig. 5. The author concluded that corrugated tubes exhibited higher peak loads as well as specific energy absorption when compared to circular shape composite tubes. However, combination of radial corrugated surrounded by circular (RCSCT) composite tube failed to improve the load carrying capacity [27] as observed in Fig. 6. In the figure, corrugated circular cross section exhibited higher peak load at longer displacement stroke compared to circular as well as combination of that two cross sectional shapes. Furthermore, the area under the curve (represent SEA) of RCCT is larger than those two.

Mahdi et al. studies on the effect of elliptical ratio on the normalised SEA, E_{Ns}, which the structure made of glass/epoxy composite [23]. In the work, E_{Ns} has been modified where SEA equation was further divided by contacted cross-sectional area of the elliptical area. From the work, it is found that ellipticity ratio of 2.0 has higher E_{Ns} compared to circular tubes and tubes with ellipticity ratio of 1.5 and 1.75 shown in Fig. 7. In the figure, as increasing ellipticity ratio, higher E_{Ns} can be produced.

In geometrical studies, Mahdi et al. [28] investigated on the effect of conical shell angles onto the crushing capability. It is reported that SEA of cylindrical structure absorbed better energy from conical shell which the E_s value of 24 kJ/kg. Moreover in Fig. 8, increasing cone vertex angle will decreased SEA, peak load (P_i) as well as volume reduction (V_R) values. Alkateb et al. [29] reported that vertex angle in elliptical cone design was sensitive to crushing behaviour. Fig. 9 showed E_{NS} and peak crush load-vertex angle curves. From the figure, increasing vertex angle decreasing crushing load except for elliptical cone vertex angle of 12°. However for E_{Ns}, one can see that it is increased exponentially with increasing the vertex angle.

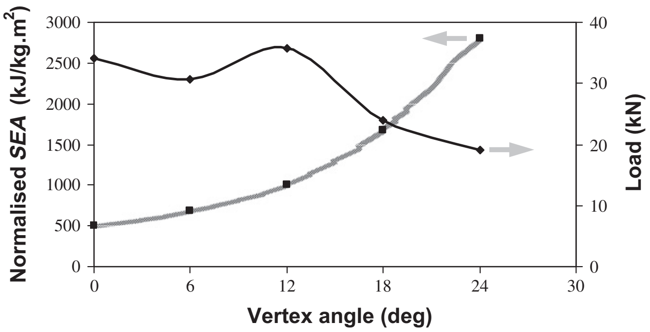


Fig. 9. E_{NS} and peak crush load-vertex angle curves [29].

For other geometrical structure, Palanivelu et al. studied on hand lay-up glass fibre reinforced polyester composites namely on hourglass (HG) type A, B, X and Y, and conical circular (CC) type X and Y [17,18], c.f. Fig. 10. Form the work, the author reported that HG-A and HG-B exhibited higher SEA (21.1 kJ/kg and 22.5 kJ/kg, respectively) compared to HG-X and HG-Y which recorded 6.96 kJ/kg and 13.0 kJ/kg, respectively. Interestingly, from the failure mechanisms point of view, HG-X and HG-Y did not fail catastrophically but it was due to the absence of circumferential delamination. Palanivelu et al. [17,18] reported conical circular geometry, CC-Y showed higher SEA compared to CC-X where the values of energy absorbed were 28.8 kJ/kg and 23.5 kJ/kg, respectively [17,18].

On the other hand, a study on cone–tube–cone composite structure which the structure was similar to structure HG-A was investigated [30]. In the study, Mahdi et al. reported that tubular part height influenced specific energy absorption where tubular height/total height ratio (normalised tubular height) between 0.06 and 0.11 showed high SEA, c.f. Fig. 11. From the figure, vertex angle of 10° gave E_s of 85.5 kJ/kg and it was higher about 18% than vertex angle of 15°. Another identical geometrical structure as HG-B was also studied by Mahdi et al. [31]. In the reported work, cone–cone intersection composite with vertex angle of 20° and 25° absorbed more energy compared to 10° and 15° vertex angle. Comparing between two materials namely carbon fibre and glass fibre reinforced epoxy composites, it showed that material used (fibre as reinforcement) influence in energy absorbing capability due to the materials properties. However, both of the composite materials showed the similarity in trend where increased the

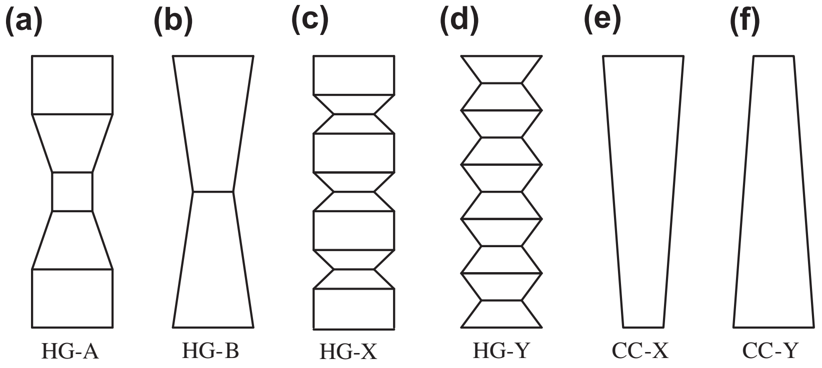


Fig. 10. Types of hourglass (HG) and conical circular structure tested [17].

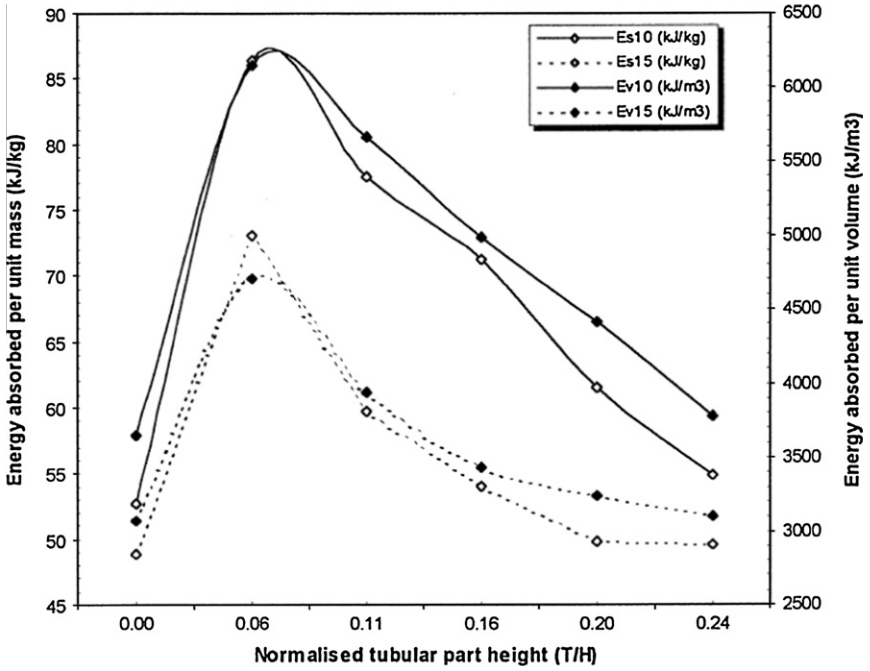


Fig. 11. Energy absorption in cone–tube–cone vertex angles of 10 and 15° with respect to normalised tubular part height [6].

vertex angle, SEA and crushing load increases (initial crushing load, ICL, and average crushing load, ACL) except for volume reduction (V_R), c.f. Fig. 12.

Collectively, circular shape give a valuable comparison amongst all the shape tested. Furthermore, it can absorb most of the axial crushing energy compared to the other shapes except for radial corrugated circular ones. For geometrical studies, structure body parallel to the applied load gave the highest resistance in the event of crushing. Moreover increasing structure angle in any part of structure body for axial crushing affected to the SEA.

3.3. Triggering

Triggering is a process to form stress concentration on the edges of profile geometry to originate localised failure, thus this avoid the loads transfer to the whole structure. Therefore, triggering mechanisms on composites profile can prevent composite structures from crushing catastrophically. As described in Fig. 2 on the progressive crushing curve, proper selection of triggering helps in contributing crush load to maximum level and the load can be maintained consistently as crushing displacement increases due to fracture mechanisms (i.e. splaying, fracture modes, etc.) took place. Accordingly, failed material during the crushing filled in the closed profile of the composite. As a result, crushing load increased which describe in the end of the figure.

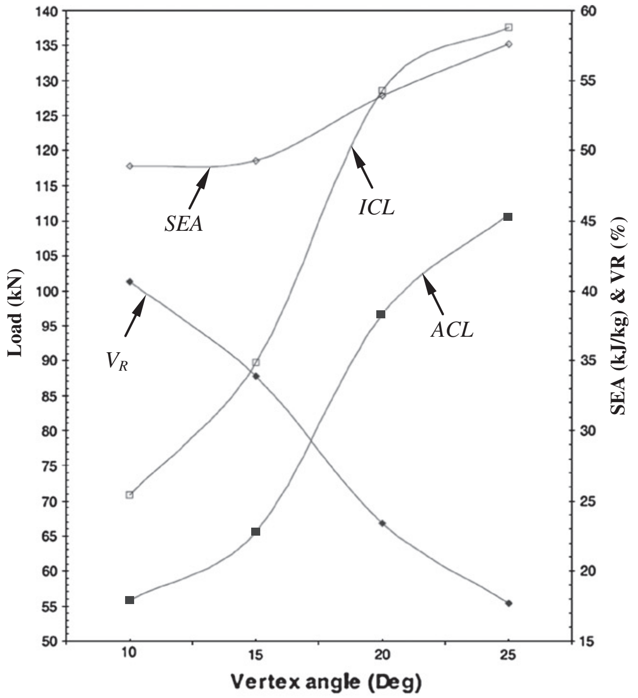
Jimenez et al. [21] reported that triggered composites profile lead to different energy absorbing capabilities. Composite box for type-B triggering shown in Fig. 13 (with α-angle of 30° and 60°) showed 25% different in specific energy absorption level. Peak load on the type-B composites (at 60°) showed highest loading at 74.7 kN. Comparing with box section, I section had 15% smaller capability. Furthermore peak load for I-beam composite has 60% smaller crush load. Investigation on triggering effect on different cross-sectional shapes was reported. Under quasi-static axial crushing, it is reported that peak load for edge triggering at 45° was higher than 90° tulip triggering [18]. However, specific energy absorption for tulip triggering was higher than edge triggered for all cross section tubes tested. Palanivelu et al. [32] reported an increase of 7–9% in specific energy absorption for round shape with edge triggered compared to tulip type. However, square shape acted in opposite characteristics, instead. An increase of 16.5% of specific energy absorption was recorded for tulip type triggering. Carbon and glass for non-hybrid and hybrid of composite braided rod was fabricated and tested for its triggered effect on the energy absorption analysis [33]. It was concluded that conical triggered rod crushed progressively compared to non-tapered rod which lead to axial crack.

3.4. Summary

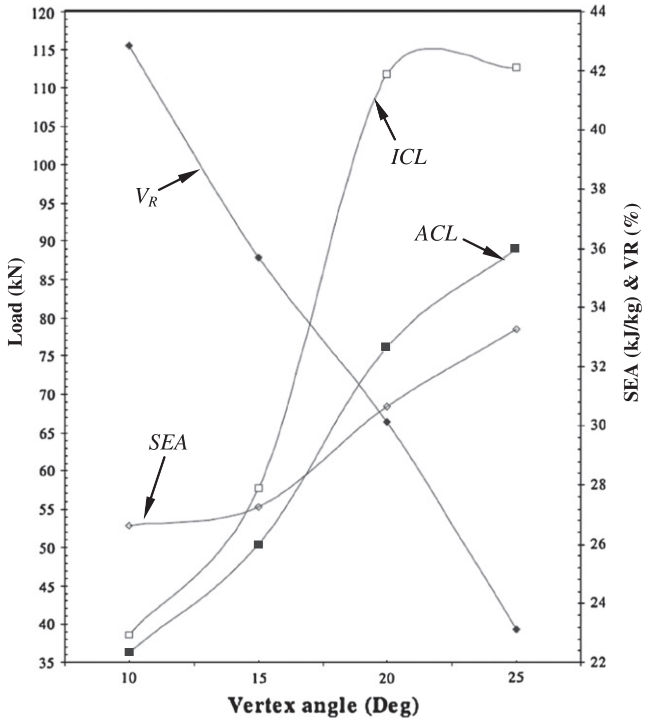
Table 1 lists the geometrical, shape, and triggers affected on peak load and Specific Energy Absorption (SEA) for non-hybrid fibre reinforced plastics (FRPs) composites. Different materials lead to different energy absorption characteristics but same material with different shape/geometry resulted in different energy absorption levels. With increasing thickness of the composite, peak load can increase by 2–3 folds as well as SEA by almost 2 folds. Accordingly, increasing in tube length yielded in different peak loads due to buckling effect [13]. On the other hand, triggering affect on peak load and SEA is significant.

4. Simulation

Mathematical simulation using numerical analysis has been carried out in order to predict composite behaviour for future applications. Often, these finite element simulation systems are having three typical processing steps. Firstly, it is being building up the model which is creating up geometry structure, input of mechanical properties and other elements (e.g. boundary condition). Secondly, non-linear dynamic analysis will be using to analyse based on the parameter set. In this step, numerical process is taking place where calculation based on the parameters and constraints assigned are running in the background. Finally will be the



(a) Carbon/epoxy composite (CFRP)



(b) Glass fibre/epoxy (GFRP)

Fig. 12. Trend of both materials (a) CFRP and (b) GFRP. Initial crushing load (ICL), average crushing load (ACL), Specific Energy Absorption (SAE) and volume reduction (V_R) [31].

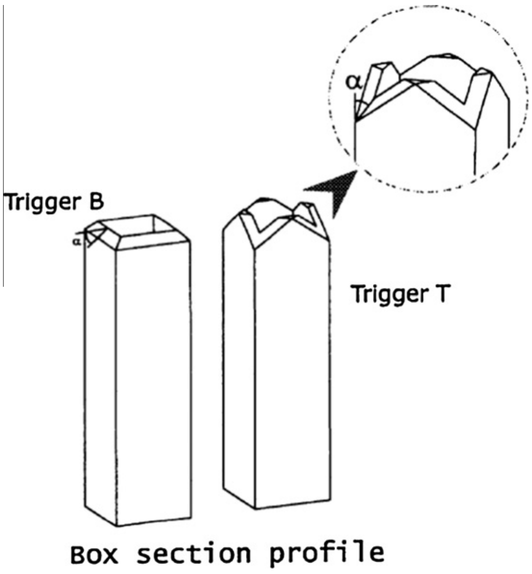


Fig. 13. Type of triggering effect that have been used [21].

post-processing analysis of results. Here, the results obtained will be the failure modes and failure patterns that will be observed and compared with the experimental data [34]. PAM-CRASH, LS-DYNA and ABAQUS [35], these non-linear finite element codes are widely used in design by industries and research institutes due to their ability to handle boundary condition parameters as tested materials collapses and other phenomena related to high deformation rate during crushing [36].

Anghileri et al. [36] compared numerical results with experimental test on composite tubes made of woven carbon fibre with two different stacking sequence, firstly is four layers of (0/90) and followed by another four layers of (−45/45). In the work, "Bi-Phase" material model which allow the fibre and matrix of unidirectional plies to be given separate stiffness and strength properties had been used. The author concluded that numerical results were within 3% from experimental test but more studied are required for other geometries to be validated due to the number of parameters required in order to satisfy multi-objectives optimisation. On the other hand, Mahdi et al. reported a simulations work on corrugated composite tubes [37]. In the work, less constrains were configured (i.e. constraint completely at top section and fixed horizontal direction at the bottom part) and less parameters were focused (e.g. total compression, peak load, mean load, and energy absorbed). From the work, numerical results are quite consistent with the experimental ones where the error of the parameters tests less than 1%. However, comparing with metallic material is not applicable due to the different behaviour in material, i.e. cotton thermoplastic is having much lower strain than steel (brittle). Furthermore from the reported work [22], crushing behaviour of metallic materials (progressive crushing mode) is differed from fibre reinforced plastic (fracture crushing mode).

In other reported works [34,38], crushing on hybrid square sandwich FRP composite with corrugated and reinforced core were simulated. Although the reported simulation works out-come in both experimental and the simulation are almost same, the authors have made few assumptions on the modelling, i.e. manufacturing imperfections, modelled with-one-through thickness-thin shell element, and microscopic damage were not considered. Numerical analysis on ±45° braided pultrusion tubes [39], found that $[0]_4$ layers of pultruded tube were able to absorb highest energy amongst all tubes having the same thickness. Moreover, simulations at 6 m/s and 14 m/s crushing speed concluded that the hybrid pultruded tubes were sensitive to tube length. However from the work, no experimental data were given to be verified.

Huang and Wang [40] established a two-layer finite element based on Chang-Chang failure criterion in LS-DYNA to simulate 14-ply T700/QY8911 (carbon fibre/BMI resin) subjected to quasi-static axial crushing. In the work, crushing triggers were introduced in the numerical simulations by using four-node quadrilateral Belytschko–Tsay shell element to initiate crushing process. From the work, post-evaluation of the photo from the experimental and numerically showed good agreement but the numerical results showed higher than the experimental ones (i.e. peak load and SEA).

Palanivelu et al. [35] reported on the simulating of circular and square cross section pultruded profile made of glass–polyester using two approaches namely, single layer and two layered shell elements with solid cohesive layer as triggering effect. The results revealed that both approaches lead to higher predicted peak load than the experimental ones. This happened due to the absence of delamination contributed to inaccurate results. McGregor et al. [41,42] simulated on the comparison of using plug and without

Table 1
Non-hybrid FRP composites.

Materials	Shape (mm, outside dimensions)		Length (mm)	Thickness (mm)	Trigger	Peak Load (kN)	SEA (kJ/kg)	Ref.
Carbon/epoxy	□	100 × 100	50.7	3.73	Flat surface	219	8.2	[10]
			101.6	3.40		244	9.1	
			121.2	3.40		219	24.9	
Glass/polyester	□	20 × 20	100	1	45° edge chamfered	2.22	–	[15]
	○	Ø20				3.09	15.9	
	□	20 × 20		2		7.47	12.3	
	○	Ø20				6.97	30.4	
Glass/polyester	□	20 × 20	100	1	Tulip 90°	1.50	–	[16]
	○	Ø20				2.90	17.90	
	□	20 × 20		2		6.22	16.2	
	○	Ø20				6.35	35.2	
Glass/polyester	□	40 × 40	150	5	30° edge chamfered	61.4	38.0	[19]
					Tulip 30°	66.7	39.0	
Glass/polyester	○	Ø160	150	3.7	–	56.622	10.2	[24]
Carbon/epoxy	○	Ø100	110	3	–	156.00	29.00	[14]
Glass/epoxy						71.00	24.00	

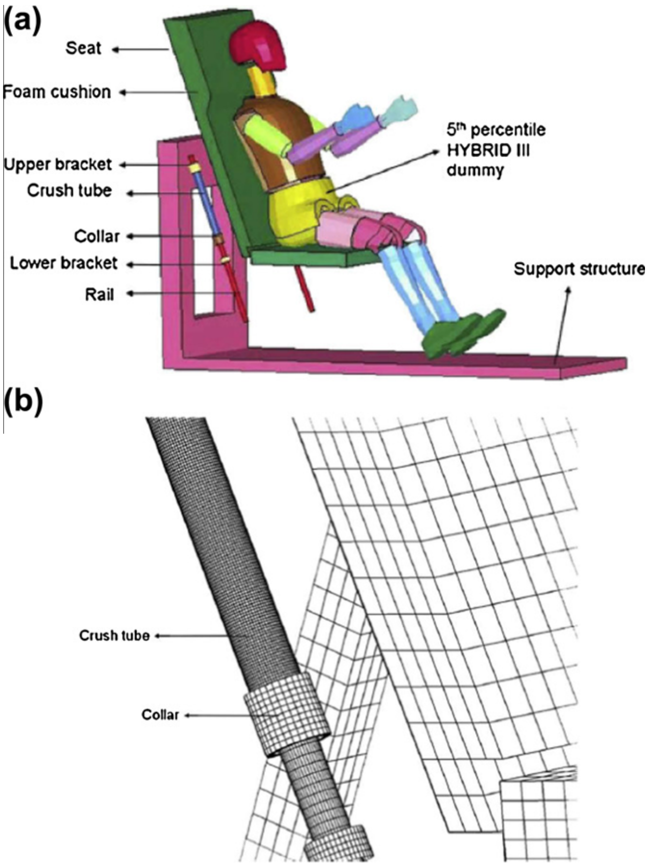


Fig. 14. (a) Design model of agriculture aircraft seat for infantry and (b) closed up of crush tube to absorb blast energy [40].

plug initiator on square hollow section carbon fibre reinforced plastic composites. In the study, modelling stability was important in minimising between experimental and numerical results, i.e. chamfering modelling.

In summary, most of the published work related to simulation of energy absorption in composite axial crushing seems to have focused on initiation of cracks due to triggering and progressive crushing failure modes. Moreover, the shape used for simulation mostly circular or square cross section due to ease in calculation and simulation on energy absorption.

5. Application of axial crushing for safety purpose

In the event of collision or blast, total energy absorbed by a material used is very crucial. Therefore, developed materials and design must be able to perform well for the safety of mankind, structures as well as other components on machine or equipment used.

An experiment [43] had been conducted on the axial crushing of tubes on agriculture aircraft seat shown in Fig. 14a. In the figure, the crush tube was placed at an inclination angle to neutralise the moments between the weight of occupants, seat structures and the bending moment of the rail. A closed up of a steel collar that was used to fix at rail so that the tube will crush coaxially shows in Fig. 14b. Using simple energy method, crashworthiness of the tubes parameter could be estimated for occupant survivability studies.

Barnet et al. [44] presented application of composite material in energy absorption capability in a certain military and civilian field. The author demonstrated that composite material was able to absorb blast as good as metallic materials. On top of that, using composite material as car safety barrier simulated in LS-DYNA, showed that a car weight about 1000 kg able to stop after hitting composite barrier at speed of 80 km/h as compare to metallic material which the same car had overcame it.

In marine application [45], a study had been carried out on crushing of web girder in ship collision and grounding under in-plane loading. In ship grounding, primary bulkheads, deep frame and floors in bottom ship will suffer large in-plane forces. Meanwhile, in collision, decks, side stringer stiffeners may also suffer torrential damage. The structural components mentioned are called as web girders. This is well presented in Fig. 15 to show the different type of girders used. The authors [45] proposed a new theoretical model for crushing of web girders under localised in plane loads. By using plastically method of analysis (compressed two folds with second partly folding), existing methods were improvised whereby crushing factor plays a significant role in predicting the mean crushing resistance.

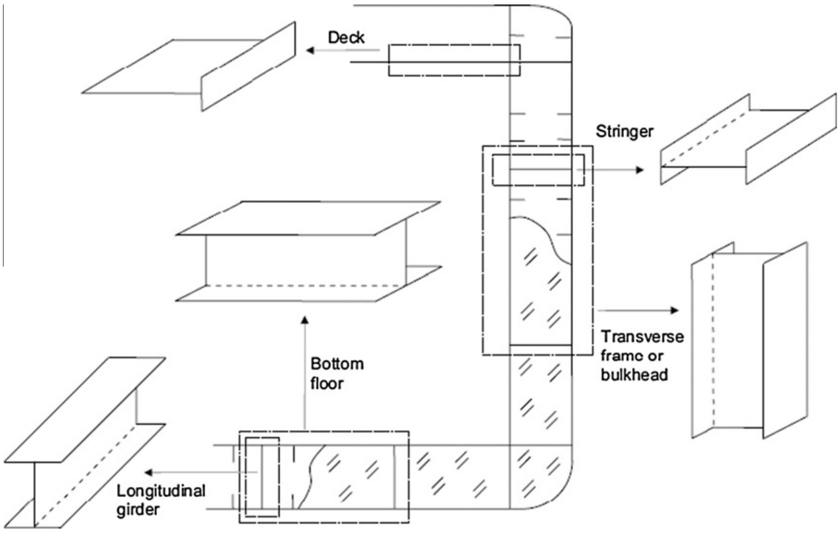


Fig. 15. Type of girders used in ship to resist crushing during collision and grounding [42].

6. Conclusion

Numerous experiments have been carried out to study FRP composites. Having advantageous of good lightweight energy absorption capability, FRP composites could be the next generation of metal substitution. Furthermore, improvisation on the energy absorption capability had been extensively studied. Accordingly, this paper summarises the recent researches on the factors that affected peak load and energy absorption capabilities.

In composite axial crushing, fracture failure contributed high energy absorption. Two types of fracture failure which had been categorised namely, catastrophic failure and progressive failure. Progressive failure absorbed more energy due to presence of multi-failure modes which lead to different characteristics of energy absorption. Mode I and Mode II failure absorbed more energy due to friction between laminates and bending. However Mode III (mid-plane crushing), energy absorption was lower. Shapes and geometrical design factors in composite were studied. Shape such as square and circular with the same t/W or t/D aspect ratio showed different energy absorption levels. In axial crushing, 0.045 ratio of square cross section showed catastrophic crushing while circular cross section crushed progressively. Geometrical designs could improve energy absorption capability. Studies showed that hour glass shape would absorb less energy due to delamination. In order to improve composite materials to crush progressively, triggering effect had been carried out. It is learnt that triggering affect on peak load, and SEA. Different type of triggers (edge chamfering and tulip trigger) lead to different energy absorption capabilities. Studies on axial crushing had been extended to simulation and numerical analysis to predict their failure characteristics. However, this mode requires further improvisation due to assumptions made which, the composite material have equal volume fraction, and stress distributions are equal and so on but in real life these control parameters are difficulty to obtain.

After due research, effect of the manufacturing process onto the axial crushing should be study. From the past research, hand-lay up technique and filament winding have been concentrated and the axial crushing have been experimented. However, in the simulation works, one of the most assumptions made was imperfection of manufacturing. Therefore, new technique (i.e. resin transfer moulding, etc.) should be adopted in order to minimised the assumptions made during simulation. Hence, this will lead to a better result. On the other hand, using natural fibres (e.g. cotton, oil palm and coir) as reinforcement in plastic composite is potential study in the future due to the natural fibre are lower in density, environmental friendly, bio-degradable and most of all it is low in cost [46].

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