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Review

Fibre properties and crashworthiness parameters of natural fibre-reinforced composite structure: A literature review

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A B S T R A C T

Several natural fibres such as hemp, flax, sisal, kenaf and jute have been used in different industrial applications. Recently, natural fibres have drawn the interest of researchers, engineers and scientists as substitute reinforcements for fibre reinforced polymer (FRP) composites tubes. Due to their fairly good mechanical properties, low cost, high specific strength, environmentally-friendliness and bio-degradability, ease of fabrication, and good structural rigidity, these materials can be used in an extensive range of applications, including aerospace and the automotive industry. Previous studies focused on how to introduce the natural fibres into industrial applications and the replacement of synthetic fibres with natural fibre materials. The tensile properties of natural fibre reinforce polymers are mainly influenced by mechanical properties such as tensile properties, flexural properties, and impact strength are strongly affected by fibre content. Furthermore, the overall tensile and flexural properties of natural fibre-reinforced polymer hybrid composites are highly dependent on the aspect ratio, moisture absorption. The geometric designs such as geometry and shapes and triggering and non-triggering and filled and non-filled was found that significantly affected the crashworthiness parameters and specific energy absorption of natural fibre reinforced polymer composite tubes. Furthermore, the compressed data, which is based on the maximum values, reported in the literature, it can be observed that the woven flax fabric circular tube exhibits high energy absorption capability and CFE. This result contributes to the increased ability to use natural fibres in vehicle manufacture and thus increases the sustainability of this industrial sector. This paper presents an overview of the developments made in the area of natural fibres reinforced composites, in terms of their physical and mechanical properties, and crashworthiness properties. Several uncertainties affecting the experimental results were discussed.

Contents

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1. Introduction

Fibre reinforced polymers (FRP) are composite materials comprised of a polymer matrix combined with high-strength fibres such as glass, aramid and carbon. Although these composite materials exhibit excellent mechanical properties, they also give rise to environmental pollution due to their non-degradability [1,2].

Currently, traditional reinforcement materials such as glass and carbon fibres are increasingly being replaced by advanced composite materials, e.g., natural fibre-reinforced polymers (NFRP). It is expected that use of fibre/polymer composites will expand in the near future due to the many advantages offered by these materials such as high strength, low weight and corrosion resistance [3]. Natural fibres such as hemp, kenaf, jute, sisal and bamboo have been studied due to their mechanical properties and their potential use in composite materials. These natural fibre-reinforced composites are finding applications in the construction industry, with a projected yearly US demand increase of as high as 60% [4–6].

Natural fibre-reinforced composites are an alternative to the ever depleted petroleum resources and have therefore received increasing attention from scientists and society. Because they are biodegradable, environmentally friendly, lightweight, inexpensive, and exhibit interesting physical and mechanical properties (high specific stiffness, low density and relatively high processing flexibility and good strength), natural fibre based composites are attractive for manufacturers and scientists. They are considered to be excellent materials for use in construction, automobiles and furniture production [7–10].

In particular, crashworthiness has attracted much attention, especially for the evaluation of crushing behaviour and the energy absorbing capability of various composite shapes. In automotive engineering, crashworthiness is defined as the capability of a vehicle to protect its occupants and passengers from serious injury and harm or death in case of accidents or sudden impacts of a specified magnitude. Crashworthiness is related to energy absorption through controlled failure modes that enable the maintenance of a gradual decay in the load profile during energy absorption [11,12].

Studies of natural fibre-reinforced plastic (NFRP) have been carried out for special geometric shapes of composite tubes that are mainly intended for automobile crashworthy applications due to their favourable strength, weight and corrosion resistance [13–16].

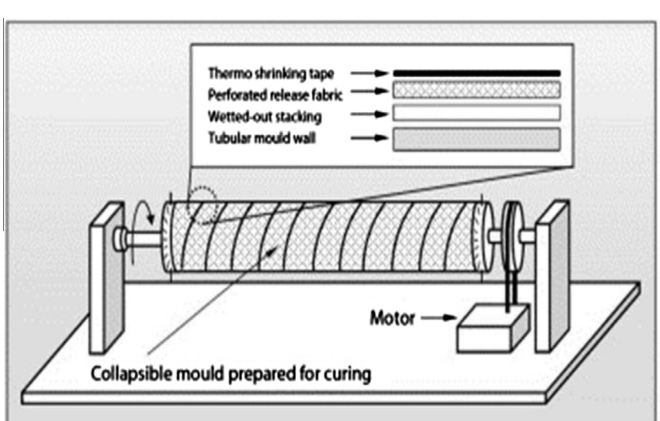

Fig. 1. Diagram of the rotating sample stand used during gelling and curing [18].

Several researchers reported that a well-designed NFRP composite can exhibit better energy absorption than metals; natural composite materials such as kenaf, silk and hemp fibre-reinforced composite tubes subjected to axial crushing will undergo fracture to obtain energy absorption rather than the fibre deformation exhibited in metal tubing [17–19]. As reported previously [20], delamination, local buckling, and bending failure modes make the largest contributions to energy absorption.

The effects of factors such as fibre orientation on axial crushing behaviour were studied experimentally in natural fibre-reinforced composite tubes. Bartosz et al. [18] carried out an experimental investigation to study the behaviour of axially crushed hemp yarns/epoxy composite tubes. Five fibre orientation angles of designed winding orientations of 10°, 30°, 45°, 60° and 90° were studied. The tube samples were prepared with the pin filament winding technique, as shown in Fig. 1. It was found that the highest stress and modulus were observed for the reinforcements oriented at 10° to the main axis. Four compression collapse modes were observed for the tested NFC tubes, namely micro-buckling, diamond shape buckling, concertina shape buckling and progressive crushing [18].

In another study, Yan et al. [15] investigated the effects of inner diameter, length-to-diameter ratio and tube thickness on flax fibre-reinforced epoxy circular tubes, and the crashworthiness characteristics of these tubes were evaluated. The energy absorption capability of flax/epoxy composite tube depends strongly on tube geometry. Specimens of considerable length with multiple composite plies exhibit a higher energy absorption capacity.

Rectangular woven natural silk/epoxy composite tubes were also used for studies of axial crushing using a trigger mechanism. Eshkoo et al. [20] investigated the effect of the trigger mechanism on axial crushing capability. They concluded that the failure mechanism proceeded in two stages, namely (i) tear onset and (ii) tear propagation, which included progressive buckling and delamination. The composite tubes exhibited only progressive, not catastrophic failure.

In this paper, several studies that were performed in order to understand the axial and lateral crushing capability of NFRP composites are described. The objective of this paper was to summarise recent research on the parameters that influence crashworthiness characteristics such as peak load, specific energy absorption and crash force efficiency.

2. Mechanical and physical properties of natural fibres

Various researchers have studied the physical and mechanical properties of natural fibre-reinforced polymer composites [21–24]. The mechanical and physical properties of natural fibres are very important for industrial applications and can contribute to the use of natural fibres in numerous applications. Lower density leads lower-weight structures in the automotive industry and aerospace applications [25–28]. Mechanical properties such as tensile properties, flexural properties, and impact strength are strongly affected by fibre content, as shown in Fig. 2 [29]. Compared with oil palm epoxy composites, the tensile properties of jute oil palm fibre hybrid composites are enhanced substantially

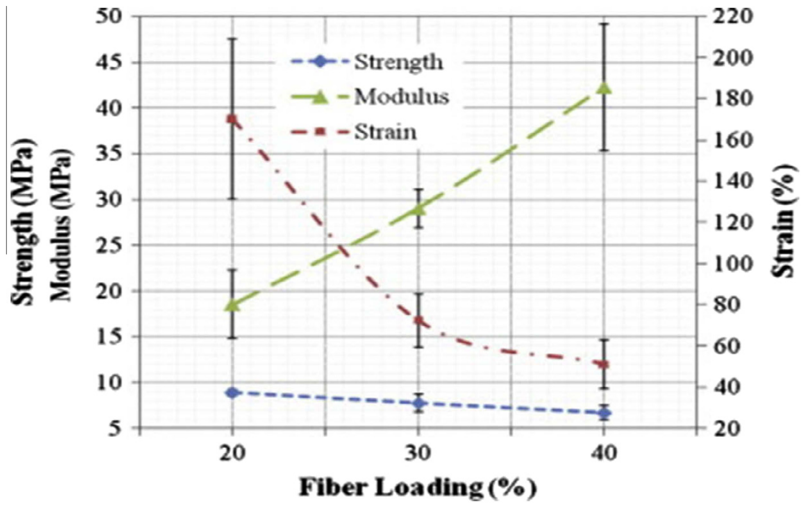

Fig. 2. Effect of fibre content on tensile properties [29].

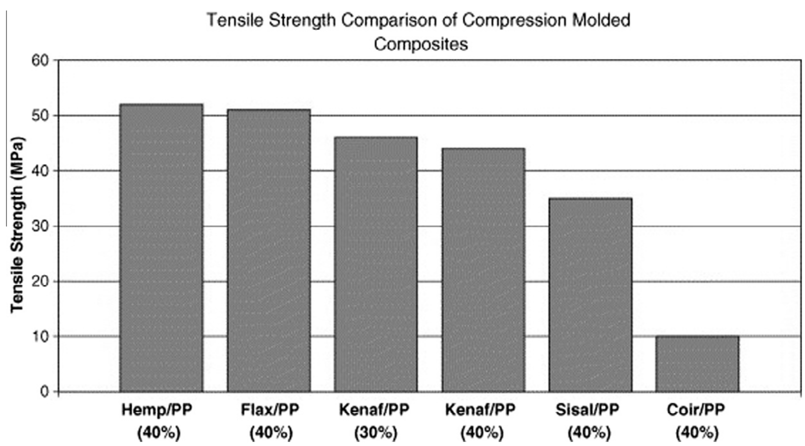

Fig. 3. Comparison of tensile strength of kenaf/PP–MAPP composites to other natural fibre composites [33].

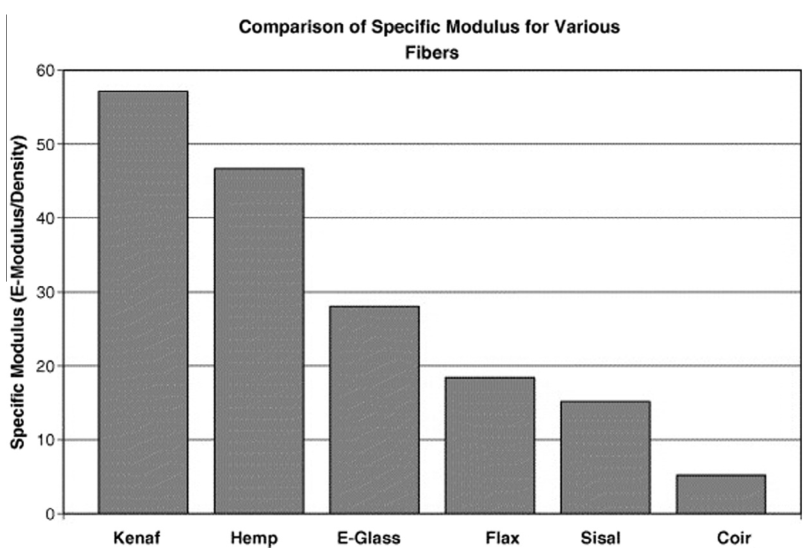

Fig. 4. Comparison of specific modulus of various fibres [33].

with increased jute. The mechanical properties of jute fibre-reinforced composites are superior to those of sisal fibre-reinforced composites [30,31].

Venkateshwaran et al. [32] studied the mechanical and water absorption properties of banana/sisal-reinforced hybrid composites using fibre length and weight percentage as the main variables.

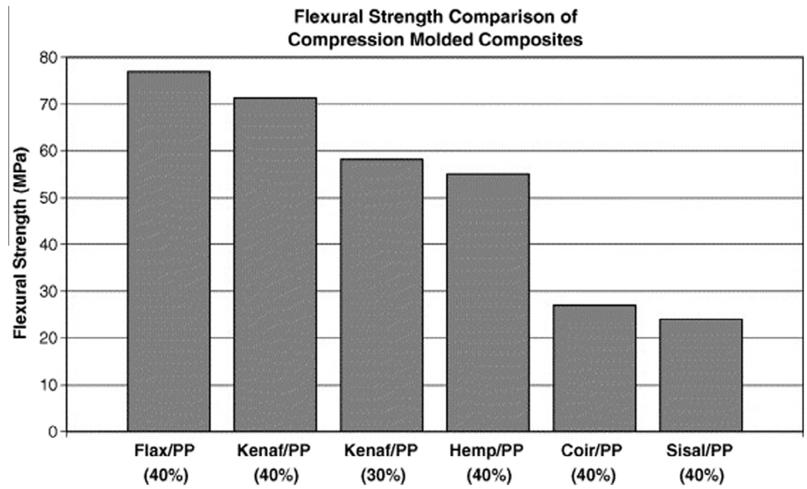

Fig. 5. Comparison of flexural strength of kenaf/PP–MAPP composites to other natural fibre composites [33].

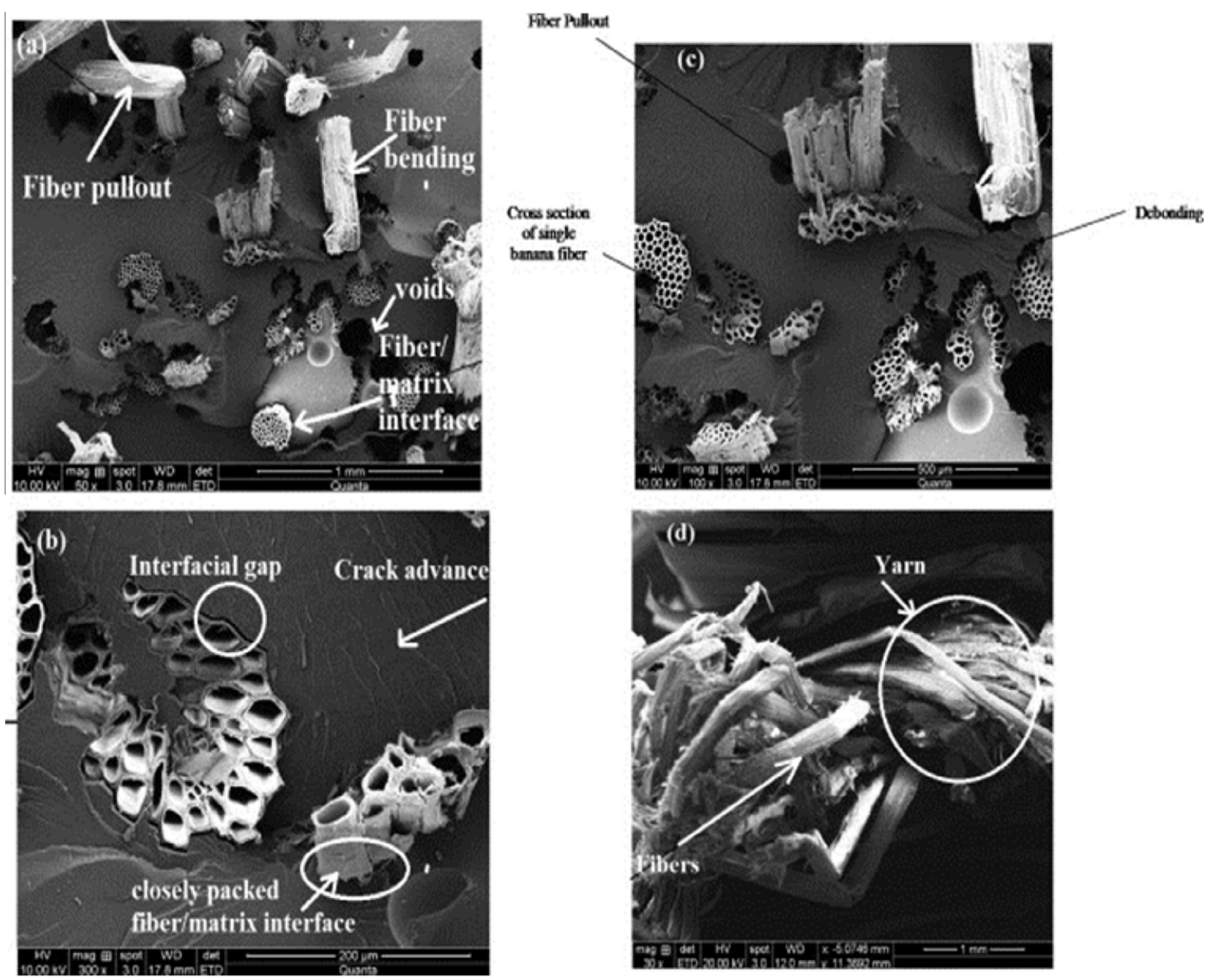

Fig. 6. Scanning electron microscopy tensile fractured specimen of randomly oriented (a) banana fibre composite, (b) kenaf fibre composite, (c) banana fibre woven fabric composite and (d) hybrid woven fabric composite [34].

They reported that hybridizations of sisal fibres with banana/epoxy composites of up to 50% by weight enhance the mechanical properties and degrade the water absorption properties of these fibres. The overall tensile and flexural properties of natural fibre-reinforced polymer hybrid composites are highly dependent on the aspect ratio, moisture absorption tendency, morphology and dimensional stability of the fibres used.

Zampaloni et al. [33] concluded that both tensile and flexural strength that is very similar to the 40% by weight flax and hemp polypropylene systems contrast the tensile strength is higher and

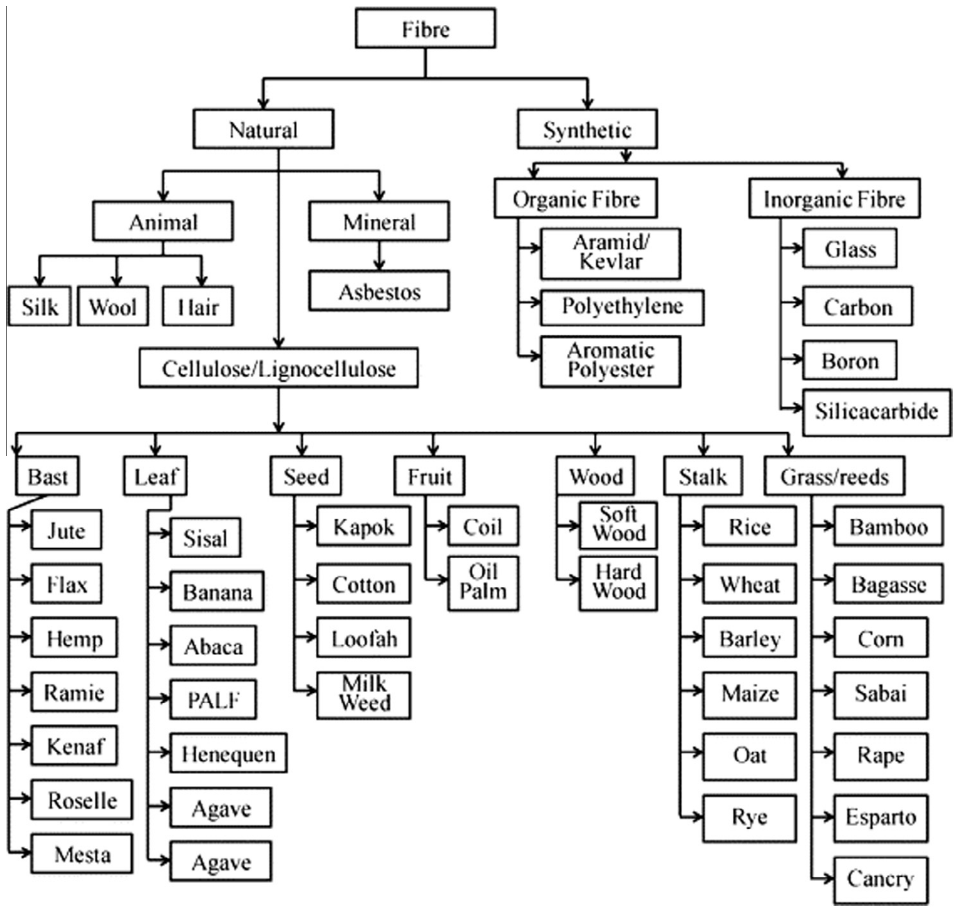

Fig. 7. Classifications of natural and synthetic fibres [43].

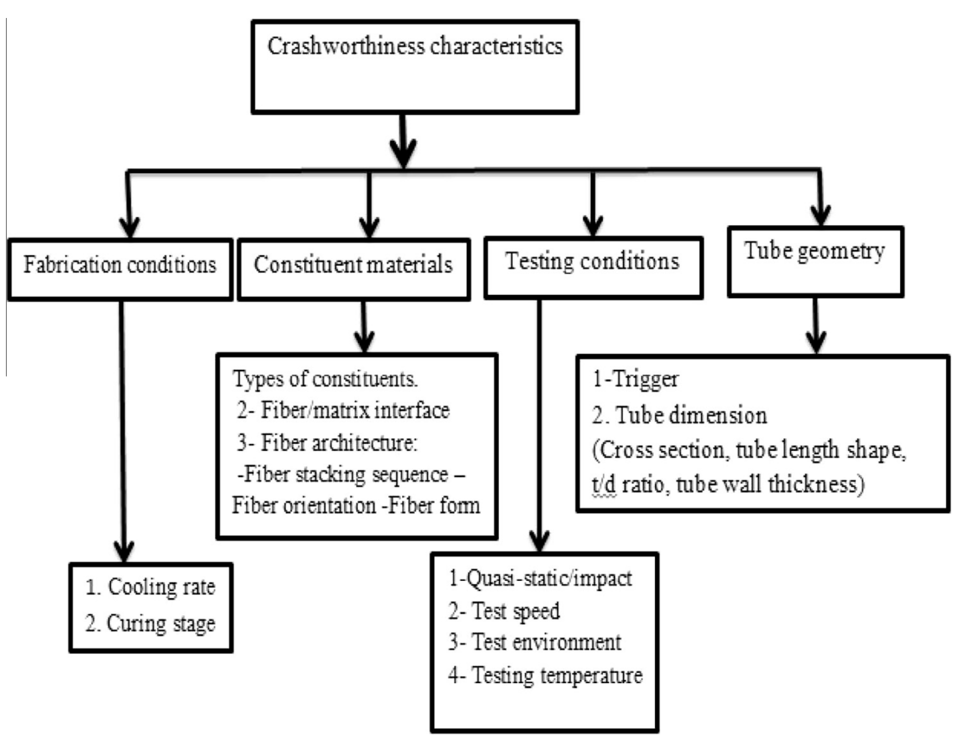

Fig. 8. Various variables that affect the crashworthiness parameters of composite materials.

Table 1
Advantages and disadvantages of natural fibres [42,43].

Advantages	Disadvantages
Low specific weight results in a higher specific strength and stiffness than glass	Lower strength, especially impact strength
Renewable resources, production requires little energy and low CO_2 emissions	Variable quality, influenced by weather
Production with low investment at low cost	Poor moisture resistance, which causes swelling of the fibres
Friendly processing, no tools and no skin irritation	Restricted maximum processing temperature
High electrical resistance	Lower durability
Good thermal and acoustic insulation properties	Poor fire resistance
Biodegradable	Poor fibre/matrix adhesion
Thermal recycling is possible	Price fluctuations due to harvest results or agricultural policies

Table 2
Mechanical and physical properties of natural fibres.

Fibres	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm^3)	References
Sisal	350–640	12.8–22	3–7	1.41–145	[44,45]
Oil palm	70.9–248	14–6.7	14–25	0.7–1.55	[46,47]
Bamboo	215–218	28–30	1.3	0.6–0.910	[48–52]
Banana	529–914	27–32	5–9	1.35	[53,54]
Coir	120–304	4–6	15–40	1.15–1.25	[45,55]
Cotton	287–800	5.5–12.6	3–10	1.51–1.6	[47,56]
Flax	345–1500	23.9–27.6	1.6–3.2	1.5	[35,57,58]
Hemp	690	60–70	1.6-4	1.4–1.5	[19,59,60]
Jute	393–780	13–30	1.9	1.3–1.45	[44,61]
Kenaf	284–1191	21–60	1.6–3.5	0.13–0.17	[54,62–64]
Pineapple	413–1627	60–82		1.07–2.4	[65]
Ramie	400–938	44–128	1.2–8	1–1.55	[40,47,54]

the flexural strength is almost doubled when compared against the coir and sisal systems.

Illustrated that these kenaf/PP composites have a higher modulus/cost and a higher specific modulus than sisal, coir, hemp, flax and E-glass as shown in Figs. 3–5.

Alavudeen et al. [34] studied the effect of weaving patterns and random orientation on the mechanical properties of banana, kenaf, and banana/kenaf fibre-reinforced hybrid polyester composites. The result reported in this study showed major improved tensile properties compared to the twill type in all the fabricated composites. Moreover, the maximum increase in mechanical strength was observed in the plain woven hybrid composites rather than in randomly oriented composites.

Fig. 6 shows the SEM images for the randomly oriented banana fibre after tested under tensile loading from the figure it is clearly observed that many hollows portions, the phenomenon occurred when pull-out in Fig. 10b, the bonding between fibre and matrix also seen in Fig. 6b. A tortuous path in crack propagation through the fibre/matrix interface is clearly evident from Fig. 6c it is evidently seen that the woven hybrid composite failure occurring under the tensile mode is by the complete removal of fibre bundles along the direction of loading.

Based on their origin, natural fibres can be classified as leaf fibres, bast fibres, or seed and fruit, fibres. Fig. 7 shows the classifications of natural fibres.

Natural fibres have been used to reinforce various polymer matrices. These fibres include bamboo, flax, coir [35–37] softwood, sisal, banana, coir, jute, abaca oil palm (fruit), kenaf oil palm, (empty fruit), spider silk and rice husk [38–41]. Additionally, natural fibres offers several advantages compared with glass, as shown in Table 1.

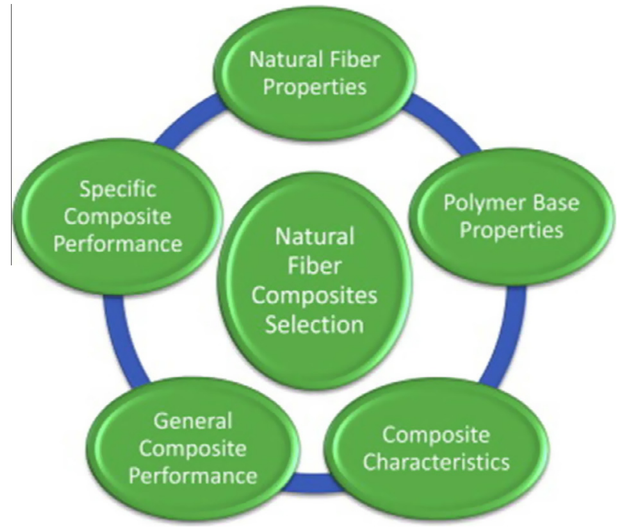

Fig. 9. Schematic diagram of criteria affecting the selection of natural fibre composite materials [59].

Some of the physical properties of natural fibres are listed in Table 2. These fibres are low-cost fibres with low densities and specific properties that are comparable with those of synthetic fibres.

3. Crashworthiness in composite structure

Crashworthiness can be defined as the capability of an automobile to shield its occupants from serious injury or death in case of accidents of a specified proportion and provides a measure of the ability of a structure to protect the occupants in survivable crashes. Crashworthiness is related to energy absorption through controlled failure modes that enable the maintenance of a gradual decay in the load profile during energy absorption. Crashworthiness characteristics depend on many parameters, as shown in Fig. 8. Various variables that affect the crashworthiness parameters of composite materials.

The general classification of such factors performed by AL-Oqla [59] Fig. 9 can assist in the selection of natural fibres and polymers to maximise the desired properties of natural fibre composite structures.

4. Energy absorption in natural reinforced composite tubes

Lateral and axial crushing tests are accomplished by quasi-static compression loading. A natural fibre reinforced composite tube is compressed at a fixed rate between two steel plates of a hydraulic press at low cross head speeds that are normally within the 1–20 mm/s range. The dimensions of each specimen were obtained based on preliminary designs and calculations to determine the tube geometry that avoids as much of a catastrophic load as possible. Different shapes and configuration were tested, as shown in Fig. 10(a–c). These included a flax (NFRP) hollow tube [15], a cone [66], a square silk/epoxy tube [19], and a silk/epoxy rectangular composite [20]. The tubes were typically 50–125 mm long with a 20–100 mm outer diameter/width and a 1–8 mm wall thickness.

The most important factor is the energy absorption capability of the fibre during the crash, which determines the energy dispersal rate for a crushing load [66]. Furthermore, the energy absorption corresponds to the energy that the structure will absorb during failure [60,67]. Fig. 11, shows the load–displacement curve for

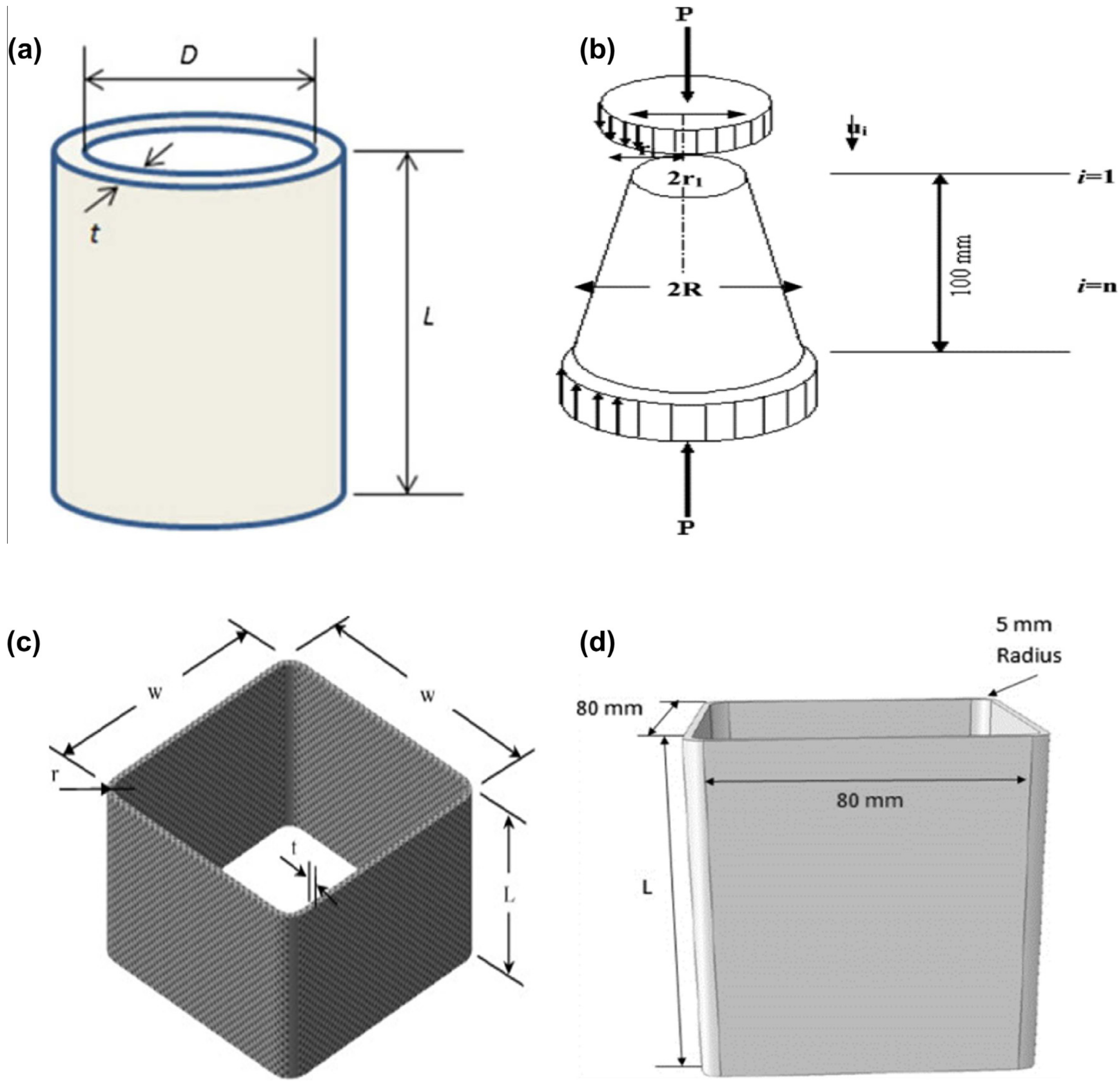

Fig. 10. (a) Flax FRP hollow tube [15]. (b) Typical cone under investigation [66]. (c) Square silk/epoxy tube [19]. (d) Silk/epoxy rectangular composite [20].

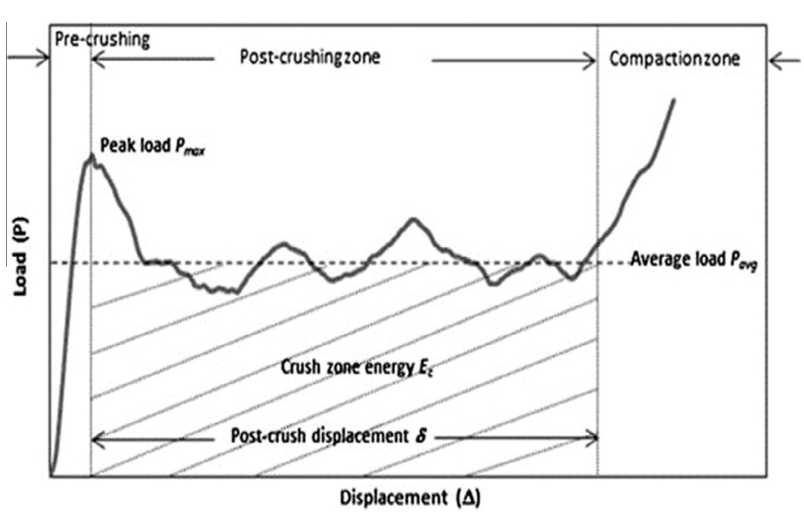

Fig. 11. Typical load–displacement response [15].

the composite tubes, demonstrating the crashworthiness parameters that are suitable for comparisons among various composite materials and structuresaccording to their load-carrying capacity and energy absorption capability [19,68].

- Specific energy absorption, E_S, is defined as the energy absorbed per unit mass of material. The total work done or the energy absorbed, W, during the crushing of composite specimens is the area under the load–displacement curve [69].

$$W = \int_{S_i}^{S_b} \mathrm{Pds} = \mathrm{Pm}(S_b - S_i) \quad (1)$$

where S_b and S_i are the crush distances. The specific energy absorption capability, E_S, of a composite material, which is defined as the energy absorbed per unit mass of material, is given by:

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

where m is the mass, and Pm is the average crushing load of the composite tube [66,70].

4.1. Effect of geometry on peak load

The peak load value is significant for determining tube fabrication parameters, such as thickness and length, and for the triggering of the structures.

Ataollahi et al. [19] reported that the peak load value is a non-linear function of the inner diameter thickness (t) for silk/epoxy composite square tubes. The peak load was found to decrease as the tube length (L) increased. For square tubes, the maximum peak load value was exhibited by the shortest tubes. For the shortest silk/epoxy square tube with 12 layers, a value of approximately 14.25 kN was obtained, as shown in Fig. 12.

Yan et al. [71] investigated the effect of the number of layers of laminate for flax/epoxy tubes (FFRP). They found significant increases in peak and average load values with increasing numbers of laminate layers from 2 to 6, as shown in Fig. 13. Furthermore, the average load was almost directly proportional to the increase in tube thickness.

4.2. Effect of triggered and non-triggered on specific energy and average load

Triggering is a process of stress concentration formation on the edges of the profile geometry to originate a localised failure, thus avoiding the transfer of the load to the entire structure. Therefore, triggering mechanisms in the composite profile can prevent catastrophic crushing of composite structures.

Eshkoor et al. [72] tested triggered and non-triggered processes using the woven natural silk/epoxy composite rectangular tubes cross section. This study was carried out using a plug-type trigger with a trigger mechanism of four rectangular metallic pieces, as shown in Fig. 14. It was concluded that different trigger configurations can give rise to significant differences in crashworthiness parameters [73].

Yan et al. [71] experimentally investigated the effect of triggering and polyurethane foam-filler on the axial crushing of natural flax/epoxy composite tubes, as shown in Fig. 15. It was demonstrated that the simultaneous use of triggering and foam-filler reduced the peak crush load but increased the average crush load. Furthermore, the specific absorbed energy increased for the tube with a diameter of 64 mm and a wall thickness of 4-layer laminate. The average crush load, crush force efficiency and specific absorbed energy increased from 47.1 kN to 58.2 kN, 0.51 to 0.86, and 25.5 J/g to 28.8 J/g, respectively. Furthermore, compared with flax/epoxy tubes with either triggering or foam-filler, the tubes with both triggering and foam-filler showed larger average crush loads and crush force efficiencies. The triggered and foam-filled tubes exhibited larger total absorbed energy and specific absorbed energy values than the tubes with triggering only, but the values for triggered and foam-filled tubes can be larger or smaller than those of tubes with foam-filler only.

4.3. Shape and geometry

To date, only a few studies have considered natural fibre-reinforced polymer composites for energy absorption application.

Oshkovr et al. [74] evaluated the crashworthiness characteristics of natural fibre silk/epoxy composite square tubes under axial crushing loads. They reported that the results were divided into three groups, namely short length with 50 mm, medium length with 80 mm and long length with 120 mm, with each section consisting of three layers (12, 24 and 30 layers). They concluded that the average load (Pm) and load (SAE) increase with increasing numbers of plies and increasing tube thickness.

Fig. 16 shows the SAE values of empty flax/epoxy composite tubes in axial crushing determined by the authors [15]. In the figure, the specimen codes are used, e.g., D54-N2-R1.5, indicating that the empty tube has an inner diameter (D) of 54 mm, the number of plies (N) is 2 and the length-to-diameter ratio (R) is 1.5. A comparison with the SAE values of the empty flax/epoxy tubes

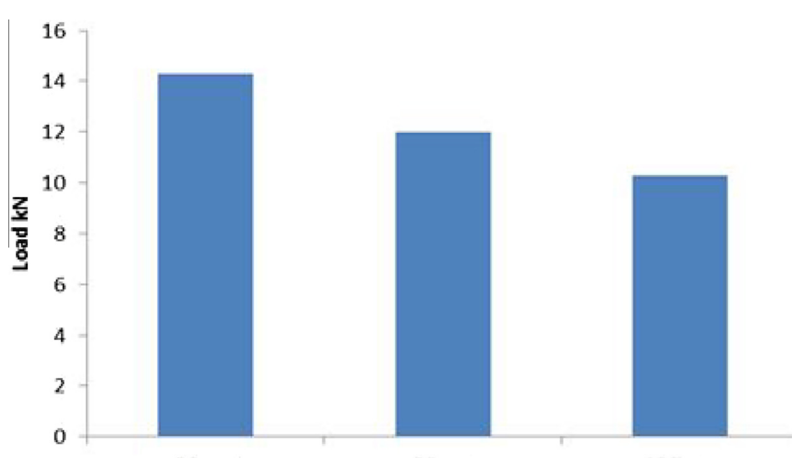

Fig. 12. Peak and average load characteristics for composite square tubes [19].

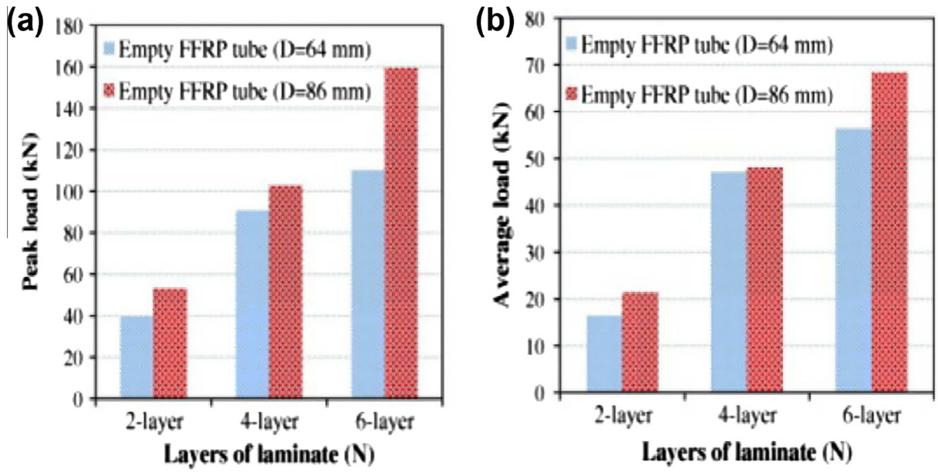

Fig. 13. Relationship between crashworthiness parameters and the number of layers for empty flax/epoxy tubes [71].

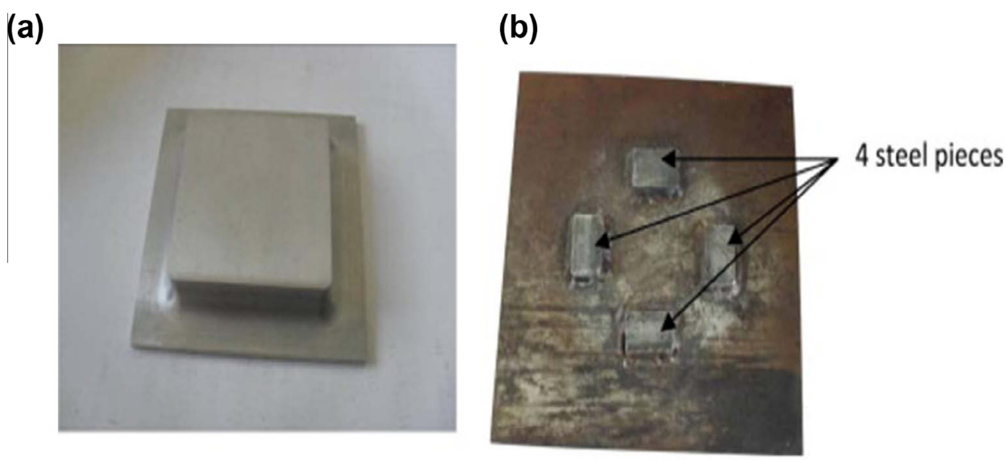

Fig. 14. (a) Plug trigger and (b) four rectangular metallic piece trigger located on the flat plate [73].

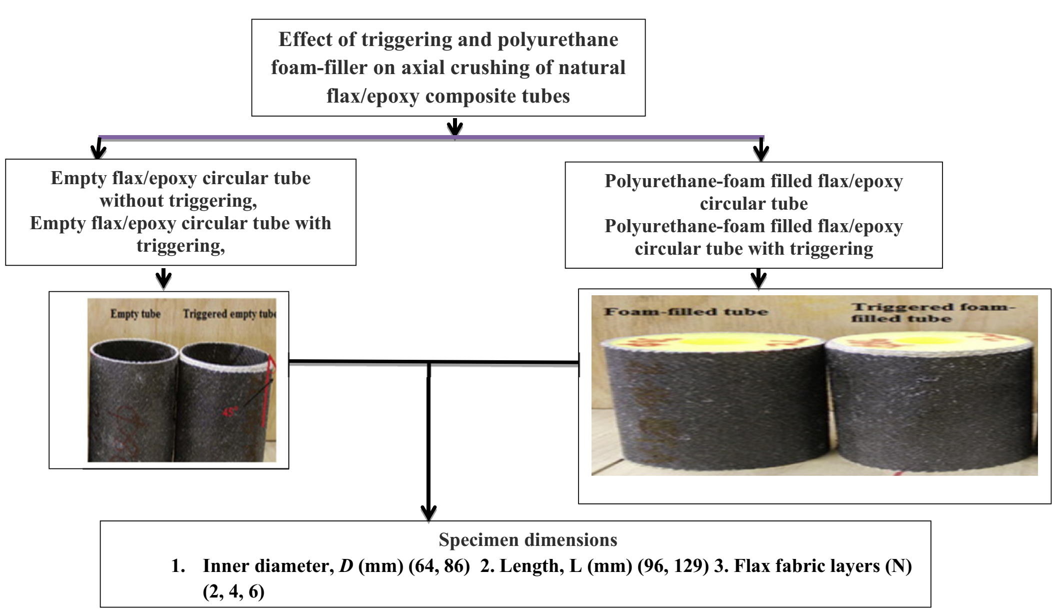

Fig. 15. Flax/epoxy composite tubes with different configurations.

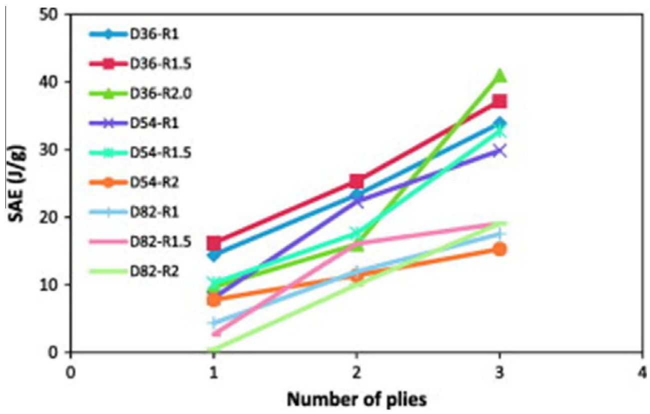

Fig. 16. Effect of the number of plies on the SAE of the specimens [15].

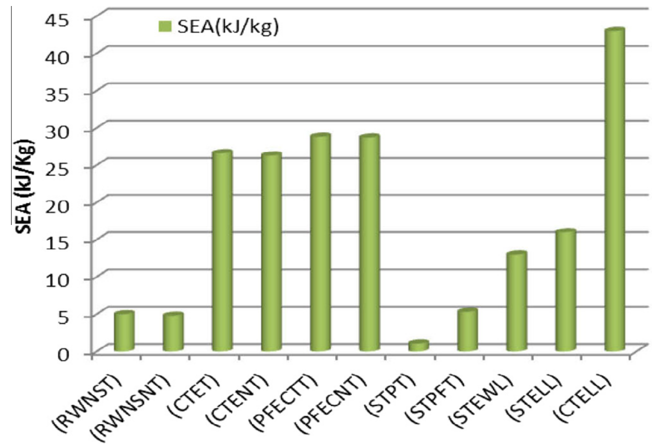

Fig. 17. Specific crushing energy data for natural fibres and shells.

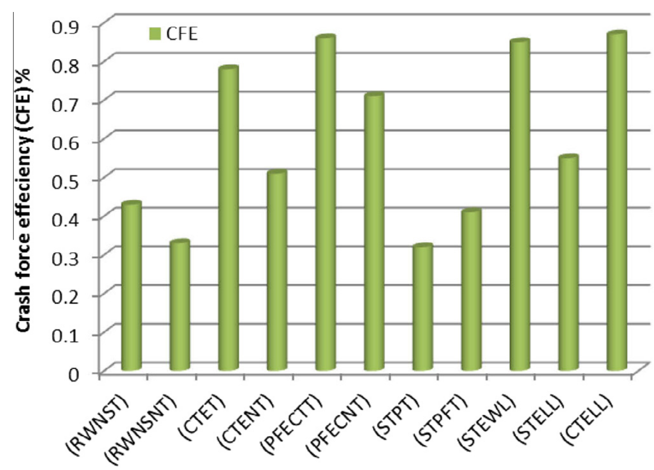

Fig. 18. Crushing force efficiency energy data for natural fibres and shells.

given in Table 3 clearly shows that the energy absorption capacities of both the empty and foam-filled flax/epoxy tubes subjected to lateral crushing are significantly lower than those subjected to axial crushing. The authors concluded that this indicates that an increase in the number of piles leads to a significant increase in specific absorbed energy, as seen from the values of SEA presented in Fig. 16; this effect is independent of the tube length-to-diameter ratio.

Improvements in the safety of the payload and optimisation of the weight have been sought. Two design parameters were used to explore the quasi-static axial crushing behaviour of a natural fibre/polyester solid cone [66].

Two types of natural fibres, namely oil palm fibre and coir fibre, were measured, and the vertex angles varied from 0° to 60°. It was concluded that an intrinsic instability in the energy absorbing process was observed for the coir fibre/polyester solid cone, whereas excellent structural integrity was exhibited by the oil palm fibre/polyester.

5. Industrial application

Industrial applications are especially concerned with the specific energy absorption of material reinforced composite polymer structures. The important characteristics of natural fibres include specific energy absorption and average load, peak load and crash force efficiency. These properties are some of the most important characteristics of natural fibre-reinforced composite tubes because they enable the protection of passengers from severe impact injuries or death; these parameters, combined with the density of the material, lead to a lower weight and also make natural fibres competitive with synthetic fibres such as glass and carbon. Furthermore, natural fibres have a lower density than synthetic fibres and also exhibit higher tensile strength and stiffness. These features make natural fibres favourable for use in energy absorption applications in the automotive industry. Comparisons of the specific energy absorption and crash force efficiency (CFE) of several types of natural fibres are shown in Figs. 17 and 18. The compression data, which are based on the maximum values reported in the literature, are shown in Table 3. It can be seen that the woven flax fabric circular tube exhibits high energy absorption capability and CFE. This result contributes to the increased ability to use natural fibres in vehicle manufacture and thus increases the sustainability of this industrial sector.

Table 3
Energy absorption capability and crash force efficiency of various natural fibres.

Configuration	Material		SAE (kJ/kg)	CFE %	References
Rectangular	Woven natural silk	Triggered (RWNST)	5	0.43	[72]
		Non-triggered (RWNSN)	4.8	0.33	
Lateral test of circular tube	Flax/epoxy	Polyurethane-foam filled natural flax	1.0	–	[75]
Circular tube	Flax/epoxy	Triggered (CTET)	26.6	0.78	[71]
		Non-triggered (CTENT)	26.3	0.51	
Polyurethane-foam filled flax/epoxy circular tube	Flax/epoxy	Triggered (PFECTT)	28.8	0.86	[71]
		Non-triggered (PFECNT)	28.7	0.71	
Square tubes	Natural silk	Plug trigger (STPT)	1.06	0.32	[73]
		Four pieces trigger (STPFT)	5.31	0.41	
Square tubes	Yarns silk	Effects of wall lengths (STEWL)	13.0	0.85	[74]
Square tubes	Woven natural silk	Effect of length and layers (STELL)	16.0	0.55	[13]
Circular tube	Woven flax fabric	Effect of length and layers (CTELL)	43.0	0.87	[15]

Fig. 19. Progressive crushing of specimens: (a) Mode I, (b) Mode II, [15].

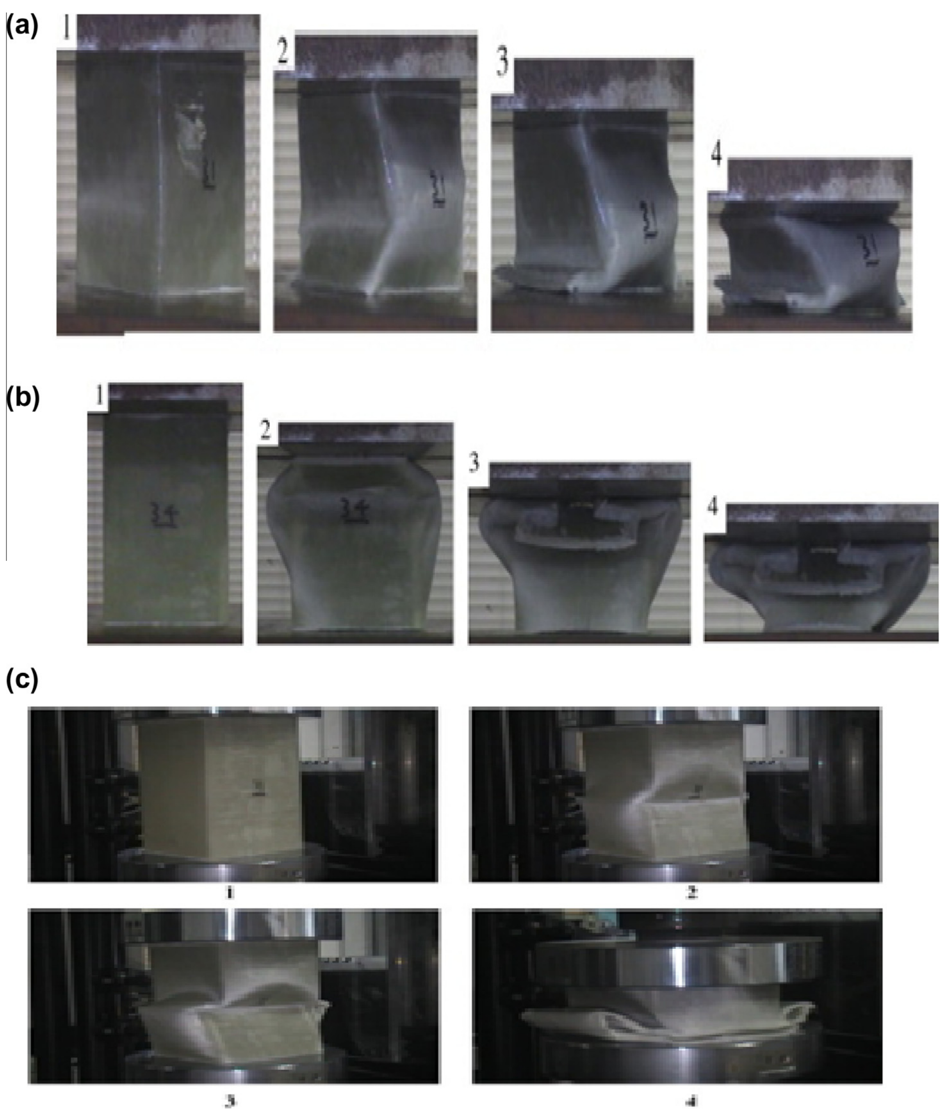

Fig. 20. Local buckling or mid-length buckling [76,77].

The data presented Table 3 clearly show that flax fibre is competitive for use in automotive applications. An examination of Fig. 18 shows that the crash force efficiency for flax fibre is higher than that of woven natural silk and is comparable with that of yarn. This fact makes natural fibre suitable for absorbing energy in the automotive field.

6. Failure mode

As mentioned earlier a crashworthy structure should be designed to absorb crushing energy in a controlled manner and this can be achieved by progressive crushing of the composite tubes. The failure mechanism is an important parameter to evaluate the crashworthiness of the composite tubes as energy absorber. For specimens failed in a stable progressive manner as shown in Fig. 19, the variations of the force as a function of displacement will be small and hence provide a stable deceleration [15].

To date, only a limited studies have attended to study the failure mechanism in natural fibre reinforced polymer composites tubes. The studies by Oshkovr et al. [76] and Eshkoor et al. [77] on silk/epoxy tubes showed that generally buckling (either local buckling or mid-length buckling) and hinge formation are the two main characteristics of woven silk/epoxy tubes, displaying a catastrophic failure. The study by Yan and Chouw [15] showed that flax/epoxy composite tubes crushed in a brittle manner with a progressive crushing pattern with favourable specific energy absorption capability.

Failure map of the 24-layer woven natural silk/epoxy composite square tube Figs. 20 and 21, Failure map of the 24-layer woven natural silk/epoxy composite square tube Figs. 20 and 21, presents the morphological failure of 24 layers woven natural silk epoxy composite tube, three mechanisms; buckling, tear and delamination were contributing in a failure of a tube. The mechanisms which happened in each side were repeated in the opposite side. Numbers on terminal view photo of a tube are linked with images of those special spots [78].

Mahdi et al. [79] studied experimentally the crushing behaviour of hybrid and non-hybrid natural fibre composite solid cones, this study showed a stable load–displacement behaviour characterised by high load level was observed and resulted in superior energy absorption capability. Moreover, brittle fracturing failure progressive failure mode was reported.

7. Uncertainties affecting the experimental results

7.1. Void content

The existence of voids in a composite can degrade its mechanical and physical properties. Air or other volatile materials become trapped in the composites during the impregnation of the fibres into the matrix or during the fabrication of fibre-reinforced composites. The most general cause of voids is the inability of the matrix to oust the air that is contained within the kenaf or chopped fibres as it passes into the matrix [30,80] To prevent the occurrence of the voids in the hand lay-up process, the wet composite can be rolled using hand rollers to facilitate uniform resin distribution and the removal of air pockets. This process is repeated until a smooth surface is obtained.

Several studied were Focus to study the void content formatting of fibre reinforced the composite structure [80,81], they concluded that the void content was initially formed as a result of few factors such as mechanical air set-up in the laminate in the fabrication process. Storing materials also affected by moisture and humidity.

Li et al. [82] studied the location of void content formatting through manufacturing of flax unidirectional fibre reinforced the composite structure. Hot press method was used with different parameters. As shown in Fig. 22, the voids trapped between the

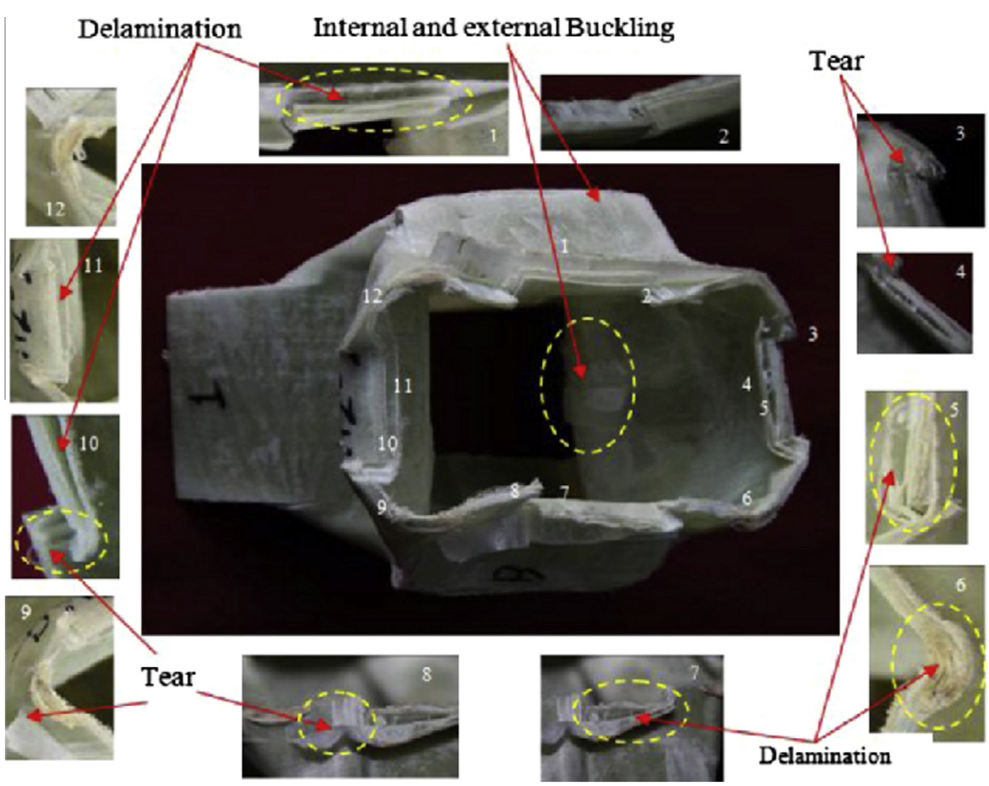

Fig. 21. Delamination, tear and buckling [78].

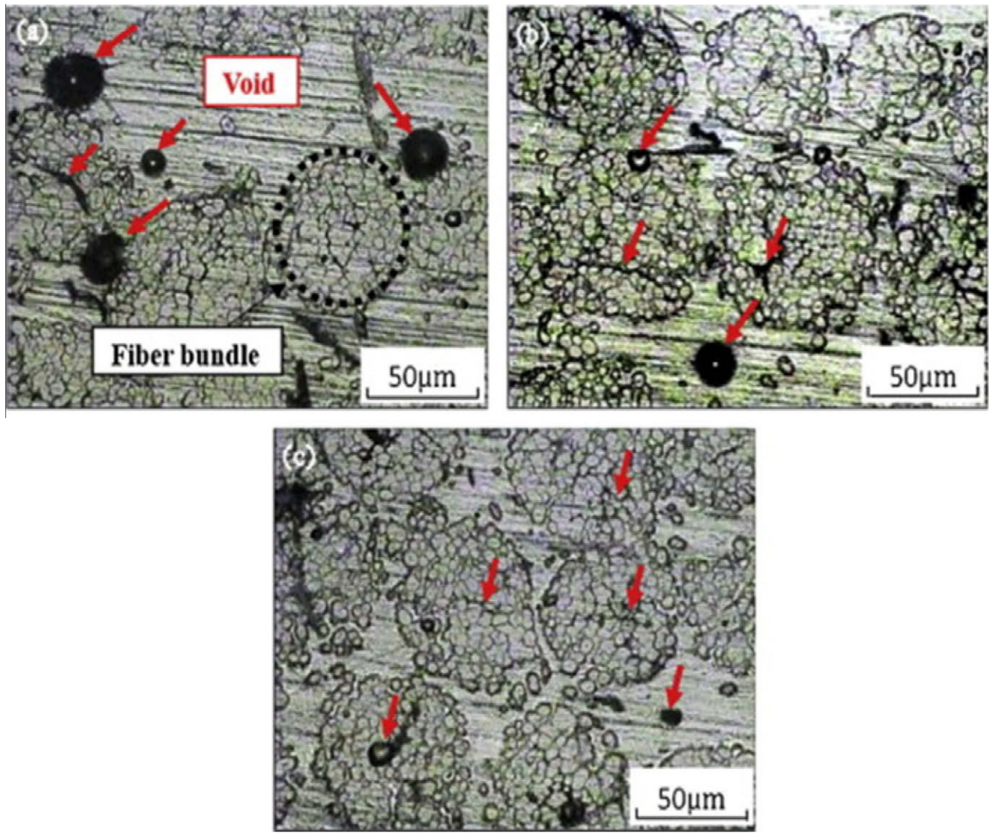

Fig. 22. Microscopic photos of the typical voids inside (a) laminate 1, (b) laminate 2 and (c) laminate 3 [82].

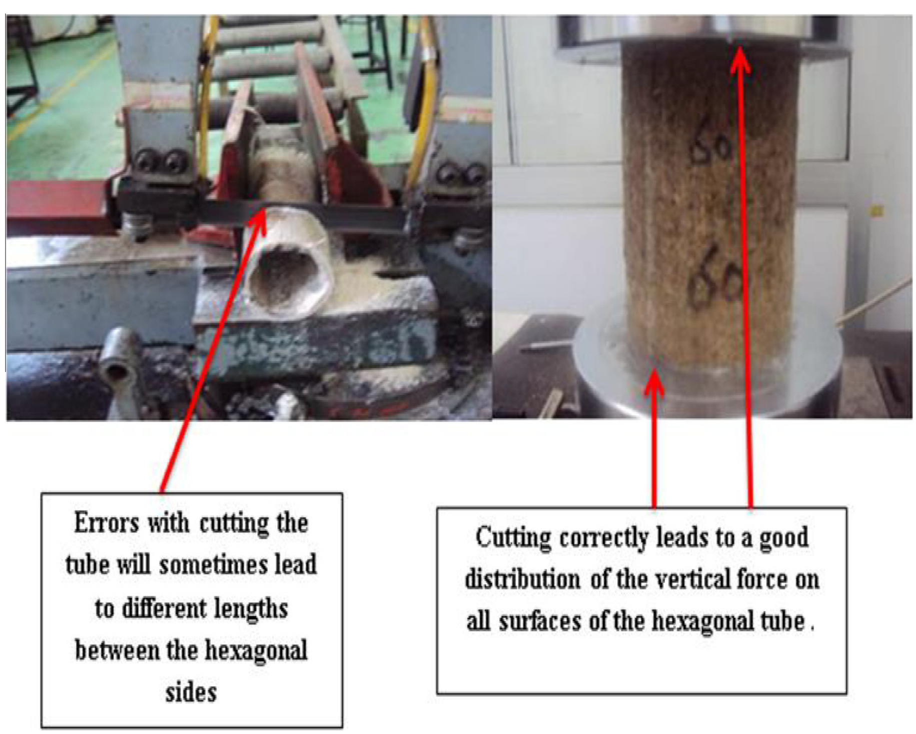

Fig. 23. Demonstration of how the cutting point and length measuring affected the test results.

interface of (fibre and matrix) also could be trapped between the flax yarns. If the pressure adding early influence on the tensile strength, on the other hand, when the pressure added late the located void will be found between the interface of composites, which leads to affect the mechanical properties of flax fibre reinforced composite more pointedly.

7.2. Calibration of the testing machine

Calibration of universal testing machines using calibrated force transducers (load cells) is very important for industry and for research institutions. The calibration process has an impact that can be either positive or negative. The machines must be calibrated to obtain accurate results. To ensure that the machine is calibrated, three specimens with the same specification are tested to examine whether identical results were obtained or not. Additionally, if the machine is not calibrated, the speed will be different within the crash time; this affects the load displacement relationship.

7.3. Reading error

Almost all direct measurements involve reading a scale (ruler, calliper) or a digital display the reading error refers to the uncertainties caused by the limitations of the measuring equipment. A reading error affects the precision of the experiment. The uncertainty associated with the reading of the scale and the need to interpolate between the scale markings is relatively easy to estimate. Fig. 23 demonstrates how the cutting point and length measuring affected the test results.

7.4. Maxing up the mixture and adhesion between layers

If the surface of the moulded part is smooth, high adhesion between the layers of the structure sometimes cannot be obtained. This leads to a decrease in the resistance of the tube to compression loading. The mixing of the mixture can affect the results if the mixture was not mixed well during the time recommended.

The mixture is carefully applied on the surface of the wooden mandrel. A necessary at the end of the process is that the composite must be compacted to remove trapped bubbles because these strongly affect the results.

8. Conclusion and future work

- Hemp-reinforced composite is an important area in which little work has been done [18] Hemp fibre can be woven (mat) preforms and impregnated with resins by resin transfer moulding (RTM) to make greater result but more economical composites.
- The future of natural fibre composites appears to be bright because they are cheaper, lighter and environmentally superior to synthetic fibre in general. Future research should hence focus on achieving equivalent or superior technical performance and component life.
- Void content of the interface between natural fibre and matrix need more studies and to be investigated using variety types of natural fibre. The void content between interface and bulk composite properties should be minimised by using stable manufacturing process.
- Since there is no experimental data available on the response of several configuration such as like corrugated composite, honey combes and safety head helmet using natural fibres, therefore, more investigations and data are needed to understand the crushing response, failure mechanisms and modes and to address the unknowns of scale effects.
- The failure mechanisms show the major role in the energy absorption but the failure modes, damage mechanisms and damage sequence of reinforced composite tubes is still not well understood.

Several experiments have been carried out to study natural fibre-reinforced composite polymer tubes. These exhibit the advantage of good energy absorption capability. Natural fibre polymers can be the next generation of synthetics fibres. Furthermore, improvements in energy absorption have been extensively studied.

This paper summarises the recent research on the parameters that influence crashworthiness characteristics such as peak load, specific energy absorption and crash force efficiency.

Natural fibres such as kenaf, oil palm, coir, flaks, and silk are promising for future use in polymer composites due to their lower density, low cost, and good environmental and mechanical properties.

Finally, several factors can affect experimental results such as void content, curing time, calibration of the testing machine, reading error, adhesion between layers, and mixture composition.

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