Thermoset Composites: Preparation, Properties and Applications

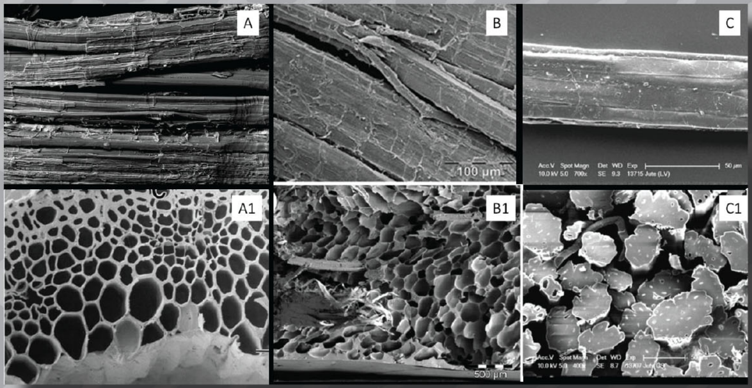

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Table of Contents

Preface

Composites are of high demand and, therefore, a field of high current research interest. The most valuable and applicable composites are thermoset composites because they have boundless adaptability in regard to design, shape and structure. They can be shaped into many-sided segments and can have extensive variety of densities and different compound details in order to meet desired properties.

The current book introduces thermoset composites and its properties and applications. The focus of the book is the preparation and applications of such thermoset composites for industrial applications. Thermoset composites are the material of the current era and are in high demand. Thermoset composites have multidisciplinary use in science and technology and that is why these composites are different from the rest of the materials currently on the market. The special characteristic of the book is that it presents unified knowledge of such thermoset composites on the basis of characterization, design, manufacture, and applications. This book will benefit lecturers, students, researchers and industrialist who are working in the field of thermoset polymers and composites for application in particular and material science in general.

We are highly thankful to contributors of different book chapters who provided us their valuable innovative ideas and knowledge in this edited book. We attempt to gather information related to thermoset composites for different application from diverse fields around the world (Malaysia, India, Korea, USA, Saudi Arabia, and South Africa) and finally complete this venture in a fruitful way. We greatly appreciate the contributor's commitment to their support to compile their ideas.

Anish Khan, Dhowkat Ahmad Bhawani,

Abdullah M. Asiri, Imran Khan

Chapter 1

Energy Absorption of Natural Fibre Reinforced Thermoset Polymer Composites Materials for Automotive Crashworthiness: A Review

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Abstract

Energy absorption capacity of composite materials is important in order to develop safety measurements for human beings in a car accident. Energy absorption, fiber type, matrix type, fiber structure, the shape of the pieces, processing conditions, are all important parameters. Changes in these parameters can cause particular subsequent changes in the energy absorption of the composite material of up to two times. Previous studies focused on how to introduce natural fibers into industrial applications and the replacement of synthetic fibres with natural fiber materials. In this paper, a detailed review of the energy absorption properties of the polymer composite material discussed. In order to understand the effects of certain parameters for the energy absorption capacity of a good composite material an attempt is made to classify the work in the field of energy absorption for composite materials that is published in the literature.

Keywords

Energy Absorption, Thermoset Polymer, Natural Fiber, Axial Crush, Composite

Contents

1.1 Introduction

Due to the advantages of polymers over conventional materials in various applications, it has substituted many of traditional materials and especially metal ones. Because they are easy to process, high productivity, low cost and versatile, they are used in many applications. However, for some specific uses, some mechanical properties, such as strength and toughness of polymer materials are inadequate. Various approaches have been developed to improve such properties. In most of these applications (crashworthiness), the properties of the polymer are modified with fillers and fibers to suit the requirements of high strength / high modulus. Fiber-reinforced polymers have better specific properties compared to conventional materials and find applications in various fields [1].

There is an important difference between penetration resistance and impact (crashworthiness) resistance. Either in passenger cars, the ability to survive by absorbing the impact energy of an occupant is called the "crashworthiness" of the structure. Impact resistance is related to the absorption of energy by a controlled fracture mechanism and modes that can maintain gradual decay of the load profile during absorption. However, penetration resistance is associated with total absorption without permeation of the projectile or fragment.

Crashworthiness is today one of the important factors in designing transportation means such as automobiles, rail cars, and aeroplanes. This is because it concerns vehicle structural integrity and its ability to absorb crash as well as providing a protective shell around the occupants. Crashworthy constructions must be designed to absorb the impact energy in a controlled manner and the passenger compartment must allow the passengers to rest without high deceleration which can cause serious injuries, especially brain injury.

In the last century, extensive studies have proven the high ability of composite materials in the field of collapsible energy absorber devices. It is also evident that composite materials meet design requirements by the vehicles manufacturers as well as customers demand for a safe vehicle with low fuel consumption and high pay load. As a consequence, more, metals parts will be replaced by composite ones for weight saving and increased reliability. However, the challenge is to find a suitable polymeric composite material with specific features for a suitable structural application.

According to the current legislation of automobiles requires, design of vehicles must have the ability to absorb an impact in the event of an impact at speeds of up to 15.5 m/sec (35 mph) with a solid, immovable object. The high efficiency of an impact energy absorber device may be defined as its ability to decelerate smoothly the occupant compartment within the allowable limit of 20 G [2]. However, optimum energy absorbed management from practical collapsible energy absorber device is characterized by having a very small elastic energy and the area under its load-displacement curve is represented in a rectangular form with long sides (i.e. a constant force). It is evident for all practical collapsible energy absorber devices that initially their resistance response records very high load till reaching its full capacity after which definitely different degrees of unstable response takes place [3]. Due to the black and white design of energy absorber device, one can define the desirable energy absorber device as the one with suppressed energy absorption during the elastic or pre-initial crush failure stage not to exceed the safe allowable limits. Moreover, its post crush stage should have a very stable response during the post-crush stage. In such design and for gross deformation, the overall stability of the energy absorber device is important as well as its energy absorbing capability and load carrying capacity.

Attempts have been made to use composite materials in the development of energy dissipation devices driven by the need to overcome the negative impact of both size and mass to improve fuel economy. The size and mass of the vehicle provide certain protection but may have a negative inertial effect. In addition to the properties of stiffness-to-weight ratio and strength-to-weight ratio, fatigue resistance and corrosion resistance, the ability to condition the composite makes them very attractive in crashworthiness. The challenge is the use of specific features of geometry and material to achieve greater safety while at the same time realizing greater safety without adversely affecting the overall economics of production. Increasingly metal parts are being replaced by polymer composites to reduce the overall weight of the car and improve the fuel economy of the vehicle.

Unlike metals, especially compression, most composite materials are generally not ductile to loads but are characterized by ductile responses. Metallic structures collapse under buckling collapsing crushing or impacting in an accordion type method with a wide range of plastic deformation, but it is believed that the breakage of fibers, the cracking of the matrix, the decoupling of the fiber matrix cause separation between layers. The actual mechanism and the order of damage are highly dependent on the lamina orientation, type of trigger, geometry of the structure and crush speed, all of them can be designed appropriately to develop high energy absorption mechanisms.

1.2 Materials

Natural fibers are raw materials directly obtained and can be spun into filaments, yarns or ropes. Natural fibers are classified either on the basis of their origin, from animals, plants, or minerals. It’s increasingly popular in the automotive industry and several other industries in recent years, due to the high performance of mechanical properties, low cost, low density, and significant processing benefits compared to most synthetic fibers and availability. Table 1 illustrates natural fibers in the world and their world production. By using natural materials and modern construction technology, construction waste is reduced, energy efficiency is improved, and the concept of sustainability is promoted.

Natural fiber polymer composite (NFPC) is a composite of high-strength natural fibers embedded in a polymer matrix like oil palm, jute, kenaf, sisal and flax [5]. Usually, polymers can be divided into two categories, thermoplastic and thermoset since the structure of the thermoplastic matrix material is composed of one or two-dimensional molecules, these polymers tend to be softer in the range of elevated heat and tend to roll back its properties through cooling. On the other hand, thermosetting polymers can be defined as highly crosslinked polymers cured using heat alone or with heat and pressure and/or light irradiation. This structure gives the thermosetting polymer good properties,

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such as the high flexibility to adjust desired final properties, high strength, and modulus of elasticity [6,7].

The thermoplastic resins widely used for biofibers are polyethylene [8], polypropylene (PP) [9], and polyvinyl chloride (PVC); here's polyester, epoxy resins and phenolic are mostly utilized thermosetting matrices, different factors can affect the characteristics and performance of NFPCs. Hydrophilicity nature and loading of natural fiber [10] also effect on the composite properties [11]. Usually, high fiber loading is required to achieve good properties of NFPC [12]. Generally, increasing the fiber content improves the tensile properties of the composite [13]. Another important factor that considerably affects the properties and surface properties of the composite is the process parameter utilized.

Table 1. Natural fibers in the world and their world production [4].

Fiber source	World production (ton)
Bamboo	30.000
Sugar cane bagasse	75.000
Jute	2300
Kenaf	970
Flax	830
Grass	700
Sisal	375
Hemp	214
Coir	100
Ramie	100
Abaca	70

1.3 Thermoset and thermoplastic composites

As composite materials continue to be adopted in more industries, fiber reinforced plastics can found in products that people interact with every day such as cars and sports equipment, etc. Fiber reinforced plastics consist of reinforcing fibers surrounded by a plastic matrix. Several types of fibers can be used including industrial and natural that give the material its high tensile strength. The matrix provides compressive strength to the composite and, in the case of fiber reinforced plastics, it can be produced using thermosetting or thermoplastic.

Thermoset polymers are polymers that are cured into a solid form and cannot be returned to their original uncured form. Composites made with thermoset matrices are strong and have very good fatigue strength. They are extremely brittle and have low impact-toughness making. They are commonly used for high-heat applications because the thermoset matrix doesn't melt like thermoplastics. Thermoset composites are generally cheaper and easier to produce because the liquid resin is very easy to work with. Thermoset composites are very difficult to recycle because the thermoset cannot be remolded or reshaped; only the reinforcing fiber used can be reclaimed.

Thermoplastic polymers are a polymer that can be molded, melted, and remolded without changing its physical properties thermoplastic polymers are tougher and less brittle than thermosets, with good impact resistance and damage tolerance.

1.4 Matrix

Matrix is essential ingredients to embed fibres and provide a supporting medium for them. It is the ability of the matrix to transfer stresses which determines the degree of realization of mechanical properties of fibres and final performance of the resultant composites. Stress-strain behavior and adhesion properties are important properties, which control the ability of the matrix to transfer stresses. A lot of research is being carried out on the basic understanding of the relationship between properties and production of tough, strong, stiff, and environment resistant composite structures. This has helped in the development of composites having acceptable properties. The epoxy resins are still the work- horse of advanced polymer composites today [14].

Since the matrix can be melted the composite materials are easier to repair and can be remolded and recycled easily. Thermoplastic composites are less dense than thermosets making them a viable alternative for weight critical applications. The thermoplastic composites manufacturing process is more energy intensive due to the high temperatures and pressures needed to melt the plastic and impregnate fibers with the matrix making thermoplastic composites costlier than thermosets. These two similar materials have different properties that both will continue to be used for different applications for very different reasons, future products are likely to be a combination of both.

Previous studies have shown that thermoplastic matrix composites (Carbon/PEEK or Glass/PEEK) exhibited higher compression and compression of impact (CAI) properties with a higher strain to failure compared to thermoset composites [15,16]. One of the recent studies show that carbon fabric laminates with different thermoplastic resins (PEEK and PPS) provided smaller delaminated areas than the laminate with epoxy resin after low-speed impact testing; this result is due to the tougher matrix system of the thermoplastic composite material [17]. However, the high resin viscosity of the thermoplastic resin is a problem for impregnating the reinforcement fiber into a tightly woven or unidirectional composite [18–21]. On the other hand, thermoset composite materials are easy to process because of low viscosity of the resin, and that leads to a lower void content. Material costs and tool costs for processing thermoplastic composites are higher than in thermoset composites [22]. Diverse types of epoxy resins are generally utilized as a result of their adaptability, worthy mechanical properties, high consumption resistance, and their straightforward cure procedure and less influenced by water and warmth. Engineering fields of epoxy resins applications are the airplanes, car commercial ventures, airframe rocket applications and fiber wound structures.

1.5 Test methodologies

The crash test can be performed under two conditions: quasi-static and dynamic conditions.

1.5.1 Quasi-static test

In a quasi-static test, the specimen is crushed at a constant speed. The quasi-static test may not be a true simulation of the actual collision situation because in the actual crash state, the crash speed decreases from the initial crash speed and finally to rest. Many materials used to design crashworthy structures are sensitive to speed. In other words, the energy absorption capacity depends on the speed of the crash. Therefore, determination of materials as good after quasi-static testing them does not ensure satisfactory performance as collision able structure during an actual crash.

1.5.2 Dynamic test

Dynamic test conditions can be simulated using conventional drop tower test rigs. The test specimen is mounted on the impact plate such that the axis of the tube is parallel to the direction of the travel of the dead weight. The drop weight platform is raised to a predetermined height depending on the impact energy and speed required. The dropped platform is released with a grip latch pin mechanism that is extracted with two manually activated electronic solenoids. The signals from the load cells located beneath the impact plate are fed to the analog-digital converter. From the digitized data the required load-displacement response is recorded [23].

The disadvantage of the impact test is that the crushing process takes place in a fraction of a second. Therefore, it is difficult to study crushing unless you have expensive equipment like a high-speed camera.

1.6 Crashworthiness design

Crashworthiness is the capacity of a structure and any of its segments to protect the occupants in survivable accidents. So also, in the automotive industry, crash value hints a measure of the vehicle's basic capacity to plastic-partner misshape but then keep up an adequate survival space for its occupants in accidents including sensible deceleration loads. Limitation frameworks and inhabitant bundling crash value assessment is determined by a blend of tests and explanatory strategies. Crashworthiness parameters for each specimen can be determined from the load-displacement as displayed in Figure 1.

In the past 20 years, research defines the impact resistance as the ability of the vehicle to save the crew from damage in a sudden accident. Therefore, impact resistance will be an important factor in the automatic movement and the vehicle design ethos.

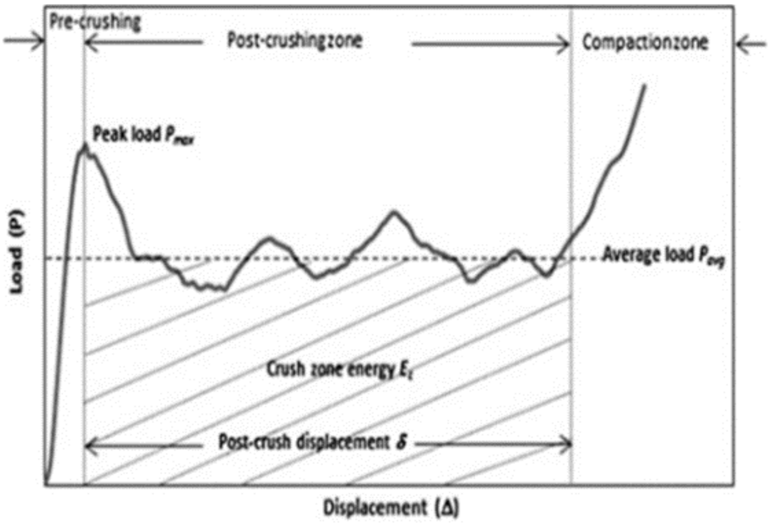

Figure 1 Typical load-displacement response [23].

To understand the absorption of energy, a few parameters like fiber type, matrix type, fiber architecture, fiber content, shape, specimen geometry, processing conditions, fiber volume fraction, and testing speed that affect the crashworthiness of a composite tube (e.g., the peak load, crash force efficiency, average crash load, and specific energy absorption) are selected. Values for some of these parameters that help the tested tubes avoid fast buckling have been determined in previous studies. Figure 2. shows the effect of the fiber content on the tensile strength and modulus. Furthermore, tubes with numerous shapes, such as circular tubes [24-26], square tubes [27], elliptical cones composite tubes [28], radial corrugated composite and composite corrugated tubes [29], hexagonal and hexagonal ring systems [30], and cone–tube–cone composite systems [31] have been designed and used in the experiments. The fiber content is a very important factor that affects a composite structure and its mechanical properties. Jawaid et al. [32] concluded that the tensile properties increased with the amount of jute fiber in hybrid composites. Davoodi et al. investigated mechanical properties of hybrid kenaf/glass reinforced epoxy composites for passenger car bumper beam. They found advantages in terms of mechanical properties compared to other common bumper beam materials [33]. El Shekeil et al. [34] investigated the effect of the fiber content (at 20, 30, 40, and 50% by mass) on the tensile, flexural, and impact properties of kenaf bast fiber-reinforced epoxy composites. The composite specimens were prepared using the melt-mixing and compression molding methods. The sample with a fiber content of 30% had the highest tensile strength, and the tensile modulus increased with the fiber content. There was an improvement in the flexural strength and modulus as the fiber content increased; increasing the fiber content caused a decrease in the impact strength. Ismail & Sahrom [35] examined the lateral crushing energy absorption of a cylindrical kenaf fiber-epoxy composite material. Two important parameters are taken into consideration when preparing the composite as a number of layers and fiber orientation. It has been found that fiber orientation is not an important factor to increase specific energy absorption rate and power factor.

A crash deceleration beat with an early peak in time and a steady rot is more advantageous for assurance of a controlled inhabitant. In this manner, the goal of crashworthiness is an advanced vehicle structure that can retain the accident vitality by controlled vehicle distortions while keeping up satisfactory space so that the leftover accident vitality can be overseen by the limitation systems to minimize crash loads exchange to the vehicle occupants, hybridization has an effect on crashworthiness goal on crushing behaviour kenaf bast fiber is suitable for hybrid natural fiber/kevlar reinforced epoxy composites with using the analytical hierarchy process(AHP) [36]. The vehicle should also be designed to possess high over strength and high retention strength for large mass components. To minimize the effects of post-crash hazards, Ataollalhi et al. [37] studied the influence of the wall lengths on the compressive response and failure mode of natural silk/epoxy composite square tubes. They found that decrease in the length of tubes leads to increase the specific energy.

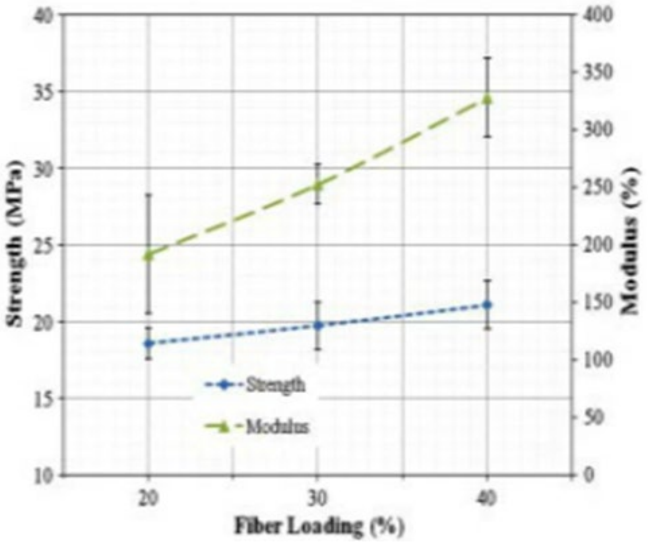

Figure 2 The effect of the fiber content on the modulus and tensile strength of epoxy composites [34].

1.7 Crashworthiness prerequisites

The structure should yield a deceleration pulse that satisfies the following requirements for a range of occupant sizes, ages, and crash speeds for both. It should minimize high-frequency fore-aft vibrations that give rise to harshness. In addition, the vehicle structure should be sufficiently stiff in bending and torsion for proper ride and handling [38].

Crashworthiness features are required to prevent excessive and injurious acceleration forces from being transmitted to the occupants under crash impact conditions. The forward vehicle structure should be designed to absorb energy during the incident. Anyway, energy-absorbing equipment should be provided for survivability and minimize the severity of injuries. In order, to satisfy the crashworthiness design criteria discussed a total system approach is needed which includes a strong protective shell to protect the occupants from crushing as well as energy-absorbing components to minimize the severity of injuries. It is important to demonstrate that in replacing metals with composite materials in crashworthiness structures, the capability to absorb energy and to maintain post-crash integrity is not compromised. The load-displacement relationship for epoxy composite tubes, which includes the essential factors and the primary regions, is shown in Figure 3.

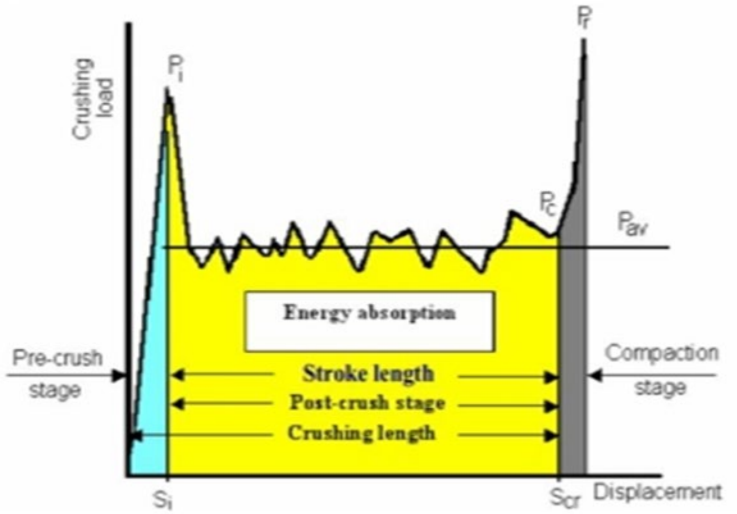

Figure 3. A schematic of the load-displacement relationship for after 40 mm [39].

1.8 Energy-absorbing thermoset composite structures

Polymer-based fiber composite materials offer significant benefits over metallic structures in reducing weight and cost as well as improving fatigue and corrosion resistance. However, these materials exhibit lower rate and behaviour of collapse compared to such metals as aluminium, a ductile metal that can tolerate rather large strains, deform plastically, and absorb a considerable amount of energy in the nonlinear region without fracture. Because of this difference between metals and composites, crash energy absorption with composites must come from innovative designs to enhance stress-strain behaviour.

Assembly operations such as mechanical joining, adhesive bonding, other kinds of attachments contribute and there are other parameters affecting (e.g., specimen geometry, processing conditions, fiber volume fraction) to crashworthiness. Effects of fiber volume fraction on absorbed energy and impact toughness of kenaf/epoxy composite, is shown in Figure 4. For crashworthiness considerations, the empirical relationship between these parameters and energy absorption are also required. Thermoplastic/thermoset multilayer composites can improve the impact damage tolerance of thermosetting resin matrix composites and thus will contribute to the ability to absorb most of the energy. A further enhancement in energy absorption and post-crash integrity can be achieved by optimizing the design of parameters.

High energy absorption, high strength, and rigidity are obtained primarily due to the property of mass reduction by the composite materials widely used in the automotive and motor sports industry [41]. The potential of NFPCs for application in providing sustainable energy absorption was investigated by Meredith et al. while focusing on motor sports. The used vacuum assisted resin transfer molding technology, test conical specimens of jute, hemp and flax fabric reinforced polypropylene composites for their properties and features and recorded various values by different kinds of materials to analyze specific energy absorption (SEA). Improvement in energy absorption is evident from the increase in volume fraction that is possible only in the presence of low speed such as 2.5 m/s [42]. On the other hand, at high speeds such as 300 m/s, similar performance is shown with jute, hemp, and flax, but jute showed the low strength of fibers and brittleness [43]. The use of NFPCs has expanded considerably in products developing industry fields in recent years. As indicated by current pointers are that interest NFPCs in the industry will continue to growing quickly around the world. Over 5 years (2011–2016), the NFPCs industry is estimated to grow 10% worldwide [44].

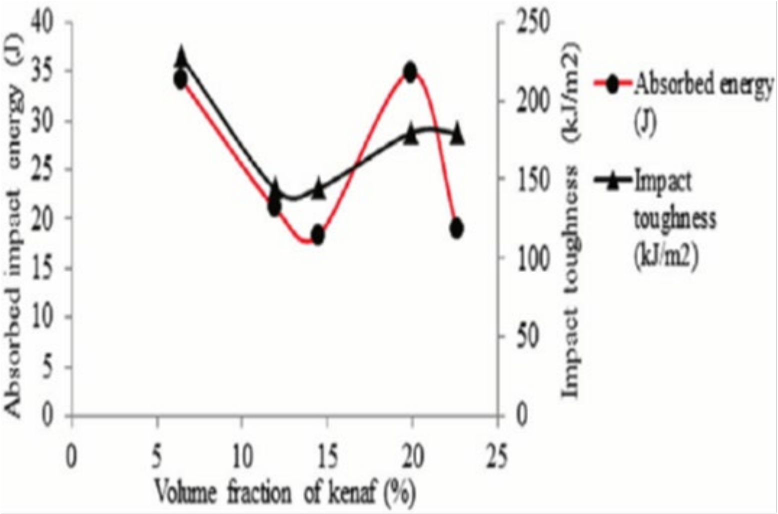

Figure 4 Shows the effects of volume fraction on absorbed energy and impact toughness of epoxy composite[40].

1.9 Assessing factors of energy absorption capability

1.9.1 Crush force efficiency (CFE)

Crush force efficiency is the ratio between the average crush load and the initial crush failure load. It is useful in measuring the performance of an absorber. It is calculated as Eq. (1).

$$P_m \tag{1}$$

where, P_i and P_m are the initial and the average crushing loads, respectively. This ratio should be as close to 100% as possible, which is difficult to achieve in practice, but an ideal absorber is said to exhibit a crush force efficiency of 100%.

1.9.2 Stroke efficiency (SE)

The relative deformation of the absorber is referred to as the stroke efficiency (SE) of the absorber. This can be calculated as:

$$SE = \frac{u}{H} \tag{2}$$

where *u* and *H* represent the stroke and the total height of the structure, respectively.

1.9.3 Initial failure indictor (IFI)

The ratio between initial crush load and critical crush load are calculated as:

$$IFI = \frac{P_i}{P_{cr}} \tag{3}$$

where P_i is the initial crushing load, and P_{cr} is the critical crushing load.

1.9.4 Specific energy absorption E_S

Specific energy absorption (E_s) is defined as the energy absorbed per unit mass of material. Figure 5 shows a typical load-displacement curve obtained from the progressive crushing of a composite tube specimen(Alkateb et al [45]). The total work is done, or energy absorbed W_t, in the crushing of composite specimens for the area under the load-displacement curve is:

$$W_t = \int_{S_i}^{S_b} pds \tag{4}$$

where W_t is the total energy absorbed in the crushing of the composite tube specimen, and the more characteristic property of progressive crushing mode is:

$$W_t = \int_{si}^{sb} P_m ds = P_m (S_b - S_i) \tag{5}$$

where S_b and S_i are the crush distances, and P_m is the mean crush load as indicated.

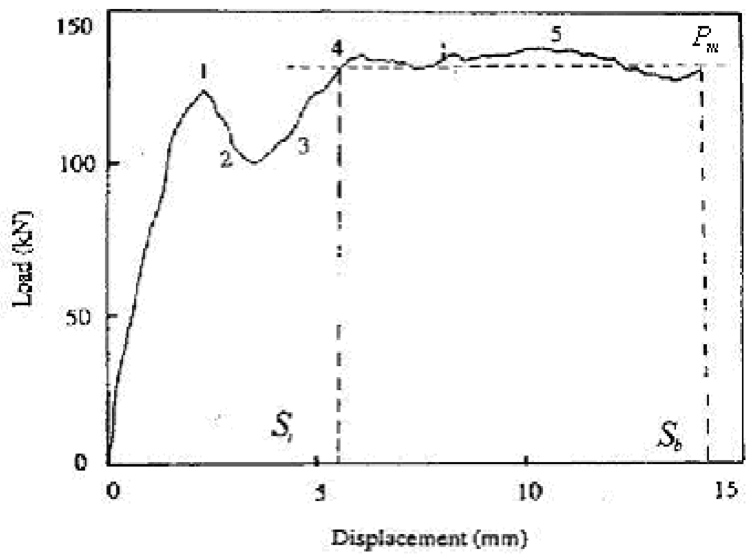

Figure 5 Typical Load-displacement curves for a progressively crushed epoxy composite tube [45].

1.10 Volumetric Energy absorption capability

The volumetric energy absorption capability (i.e., energy absorbed per unit volume) is also an essential parameter for an energy absorbing system design, where space is a restraint factor. The volume occupied by kenaf fiber reinforced elliptical epoxy composite cones before crushing can be calculated as:

$$V = \pi \times a \times b \times \frac{h}{3} \tag{6}$$

The energy absorbed per unit volume E_V can be calculated as:

$$E_V = \frac{E}{V} = \frac{1}{V}\sum_{i=1}^{N} P_i \bullet \frac{(s_{i+1} - s_{i-1})}{2} = \frac{3}{\pi \times a \times b \times h}\sum_{i=1}^{N} P_i \bullet \frac{(s_{i+1} - s_{i-1})}{2} \tag{7}$$

1.11 Energy absorption

The energy absorption capability of a composite material is critical to developing improved human safety in an automotive crash. The capacity of energy absorption is considered one of the general characteristics of thermoset epoxy composites such as biodegradability, mechanical properties, viscoelastic behavior and flame retardant.

The energy absorption capacity of epoxy composite materials is important for improving the safety of human beings at the time of an automotive crash. Energy absorption depends on many parameters such as sample shape, fiber type, fiber structure, matrix type, fiber volume fraction, processing conditions, test speed etc. When designing energy absorption composite structures, one of the aims, at absorbing most of the kinetic energy of impact within the device itself in an irreversible manner, this contributed towards a better understanding of the modes of failure and the energy dissipation patterns during impact in such safer structures and in evaluating existing ones for specific uses. Energy absorption is the concept of absorbing energy by converting the kinetic energy into another form of energy, therefore reduce losses in human and material resources [46]. The conversion of kinetic energy into plastic deformation depends on the method and magnitude of application of loads, material properties, displacement patterns or the deformation and transmission rates [47]. On the other hand, the total energy absorbed (E) is the area under the load/displacement curve, which is a function of the specimen cross-sectional area and the material density and is a load-displacement curve obtainable by numerical integration.

An attempt in this chapter is made to display some related works completed in the field of epoxy composite energy capability absorption that has been published in the literature to better understand the effect of parameters on the energy absorption capability of composite materials. In the following section, the review is focused on the research activities in the development of energy-absorbing composite structures which demonstrate compliance with the crashworthiness design criteria.

1.12 Literature survey

Many researchers have done many studies on the energy absorption capability of composite materials. Axially symmetric tubes have been used to perform many experimental studies on the energy absorption of composites because they are easy to manufacture and close to the geometry of the actual impact structure. In addition, composite tubes can be easily designed for stable crushing.

Several studies on the energy absorption capability of epoxy composite materials carried out by many researchers. Axially symmetric tubes have been used to perform many experimental studies on the energy absorption of composites because they are easy to manufacture and close to the geometry of the actual impact structure. In addition, composite tubes can be easily designed for stable crushing.

Alkbir et al. [48] study the energy absorption performances of hexagonal shaped tubes fabricated using non-woven kenaf fiber reinforced epoxy composites. Their work investigated the effect of hexagonal geometries on the crushing performances. It was found that the values of the specific energy absorption depend on the tube geometry.

Eshkoor et al. [49] found similar values of the SEA for non- triggered and triggered woven natural silk/epoxy composites. Oshkovr et al. [50] reported that the specific energy in short and mid-lengths of silk/epoxy composite square tubes was increased as the number of specimen's layers increases. On the other hand, the specific energy of the silk/epoxy composite square tube with 30 layers decreased due to the increasing of the specimen's weight. Yan et al. [51] concluded that the specific absorbed energy of the natural flax/epoxy composite tube with triggered and foam-filled tubes had greater value than that of the triggering tubes. But these energy absorption values of triggered and foam-filled tubes can be higher or smaller than that of foam-filler tubes. Ataollahi et al. [52] manufactured and tested square tubes based on silk fiber reinforced epoxy resins and studied the effect of tube lengthen SEA. The authors found that decrease in the length of tubes leads to increase of the specific energy. Mahdi et al. [53] investigated experimentally the crushing behavior of hybrid and non-hybrid natural fiber/polyester composite solid cones. Two types of natural fiber used oil palm and coir fiber to fabricate solid cones with vertex angles varied from 0° to 60°. They pointed out that solid cones greatly affects the crashworthiness for the natural fiber. Yan et al. [54] concluded that the specific absorbed energy of the natural flax/epoxy composite tube with triggered and foam-filled tubes had greater value than that of the triggering tube as depicted in Figures 6 and 7. But these energy absorption values of triggered and foam-filled tubes can be higher or smaller than that of triggering tube as depicted in figures 8 and 9 also the figures indicate that the presence of triggering on the total absorbed energy and the specific absorbed energy is insignificant. Yan and Chouw [55] studied woven flax/epoxy composite tubes with different tube inner diameters, cell wall thickness, and length to diameter ratios under quasi-static axial crushing were tested. The study showed the clear majority of empty flax/epoxy composite tubes were crushed in a brittle manner and commented in a progressive crushing pattern with advantageous specific energy absorption capability. Therefore, these subsequent studies (e.g. [56]) indicate that the natural fiber-reinforced polymer composite has potential to be an energy absorber in axial crushing. Eshkoor, et al, [57], studies investigate the energy absorption response of rectangular woven natural silk/epoxy composite tubes when subjected to an axial quasi-static crushing test using a trigger mechanism. Results showed the specific energy absorption values decreased with increased length of the composite specimen, whereas total energy absorption increased with the increased length of the epoxy composite specimen.

Hamada and Ramakrishna [58], shows the epoxy composite tubes with t/D ratios of less than 0.015 fail by brittle fracture whereas tubes with t/D ratios in the range 0.015–0.25 crush progressively. Specific energy absorption capability is dependent on the absolute value of t, rather than the t/D ratio, and it increases with increasing t up to a certain value above which it decreases. Highest energy absorption capability was displayed by tubes with values of t in the range of 2–3 nm. This variation in specific energy is attributed to changes in the crush zone morphology. Also, the changes in fiber orientation for a single layer fiber do not significantly affect energy absorption performance. As expected, as the number of layers increases, the energy absorbed also increases [59]. Warrior et al. [60] studied the effect of tube geometry on the crashworthiness performances of kenaf reinforced epoxy composite tubes under quasi-static uniaxial compressive load. In their study, the randomly oriented non-woven kenaf fibers were cured into hexagonal tubes. They found that hexagonal tube angle changes affect (as depicted in Figure 9) crashworthiness parameters with different distinct failure modes.

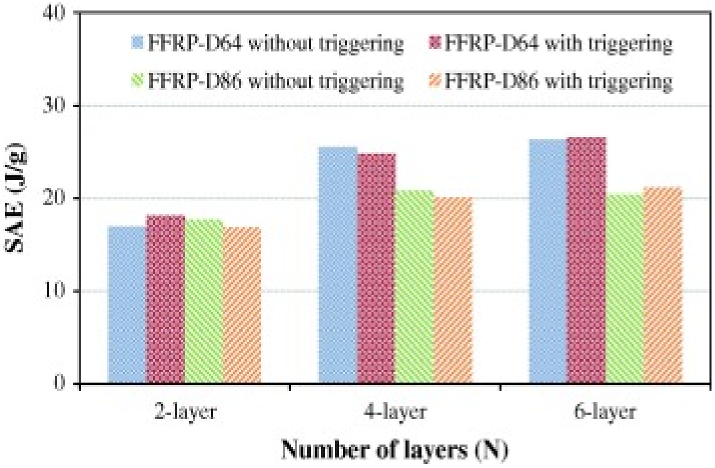

Figure 6 Effect of triggering on the specific absorbed energy of all the empty flax/epoxy composite tubes [37].

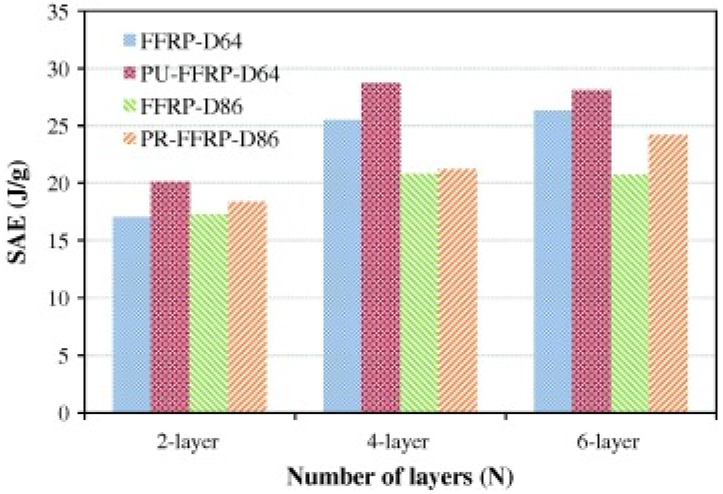

Figure 7 Effect of triggering on the total absorbed energy of all the empty flax/epoxy composite tubes [37].

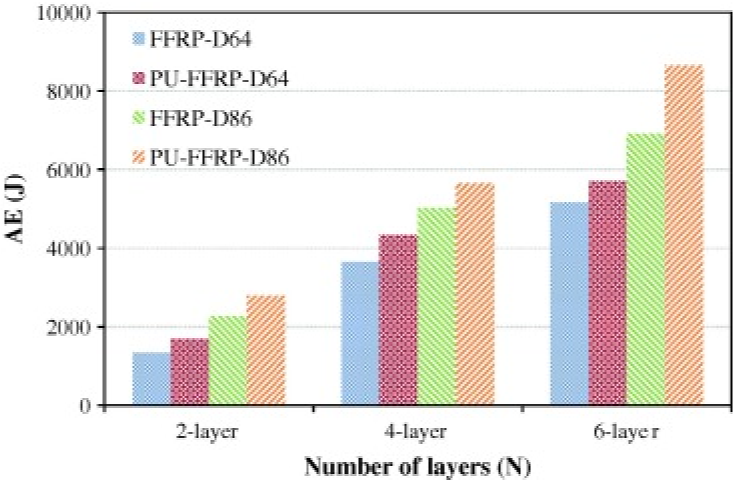

Figure 8 Effect of foam-filled on the total absorbed energy of all the empty flax/epoxy composite tubes [37].

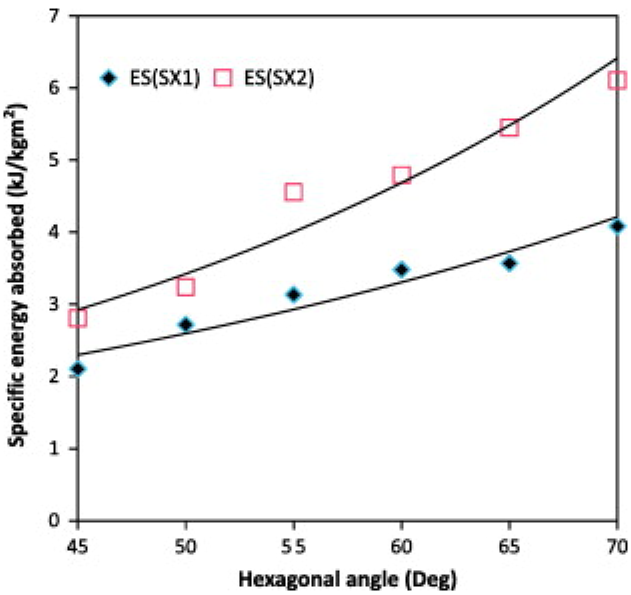

Figure 9 The effect of hexagonal angle on energy absorption capability of epoxy composite [60].

Research also took care of the use of thermoset polymer resins composites because they have a role in improving performance and the mechanical characteristics of natural fibers such as stiffness, toughness, and impact resistant.

Jeyanthi, et al, [61], focused on partially eco-friendly hybrid long fiber reinforced thermo plastics with natural kenaf fiber to enhance the desired mechanical properties for car bumper beams as automotive structural components. A specimen without any modifier is tested and compared with a typical bumper beam material called LFRT, the results indicate that some mechanical properties such as tensile strength, Young's modulus, flexural strength of a flexural modulus are more advantageous to LFRT, the new material also must improve the ability to absorb more impact load and increase the protection of the front car component. Saijad et el. [62] manufactured and tested a range of tubes with different shapes and geometric design in an axial crushing of epoxy composite materials, progressive failure absorbs more energy due to the presence of multiple failure modes and geometric design can improve energy absorption capability. On the other hand, using natural fiber reinforced a plastic composite material (NFPCs), since the ratio of the volume of the tube due to the natural fiber is lower density, environmentally friendly, bio degradable and lower the cost. Ataollahi et al. [63] manufactured and tested square tubes based on silk fiber reinforced epoxy resins and studied the effect of tube lengthen SEA. The authors reported relatively low values of the SEA, typically in the range of 4 to 5 kJ/kg. Energy Absorption of the NFPCs. Each contribution of the energy absorption mechanisms depending upon the overall toughness and the properties of the composite varies.

RĤžiþka el at. [64] presented experimental investigation and numerical prediction of the deformation behavior of several types of composite deformation elements. Experiments were conducted on two types of samples. First, on filament wound composite tubes with thermoset polymer matrix and on moulded thermoplastic corrugated plates. Second, deformation elements made from moulded thermoplastic carbon sheets are also promising for parts of composite absorbers. The authors found that the absorbed deformation energy of elements made from filament wound thermoset composite tubes depends on a laminate layup. Accordingly, simulation tests showed that the deformation boxes applied to the front bumper can effectively absorb most of the impact energy at the initial stage of the crash.

Salman S.D., et al, [65], discussed the influence of resin system on the energy absorption capability and morphological properties of plain woven kenaf composites. The results show that a significant increase in energy absorption, strength, and toughness of the kenaf/PVB composite was found at different energy levels. The impact strength and toughness of the kenaf/PVB film was 6 times that of the kenaf/epoxy composite material, which was particularly at different energy levels. The SEM examinations of the Charpy impact test specimens show that there is no delamination between the layers and the interfacial bond between kenaf fiber and the two resins but the PVB film is the highest. kenaf/PVB composite failed by fiber fracture while kenaf/epoxy composite failed by a combination of fiber pull-out and although the kenaf/PVB composite material failed due to fiber fracture while the kenaf/epoxy composite material was failed by a combination of fiber pull-out and fiber fracture as well as crack propagations through the matrix.

Bakar el at. [66] investigated the tensile properties and low-velocity impact behavior of long kenaf with two different thermosetting polymer resins (epoxy and polyester) Tensile properties of kenaf/epoxy and kenaf/polyester composites were studied experimentally. Tensile tests of kenaf fibers were carried out by different fiber weight percentages (10, 15, 20 and 25%) and the impact test was conducted using an instrumented drop tower device. The results of this study indicated that kenaf/polyester composites have better impact absorption energy than kenaf/epoxy composite material. However, kenaf/epoxy composites have higher tensile properties than kenaf/polyester composites. This is a good indication that epoxy bonding is superior to other thermoset polymer resins. For that reason, appropriate process techniques and parameters should be rigorously chosen in order to get the best characteristics of producing a composite. Dehkordi et al. [67] evaluated the damage tolerance is assessed through compression after Impact (CAI) tests and response of thermoset composites containing basalt/Nylon hybrid yarns. Their results indicated that hybrid laminates have 41–82% lower compressive strength than the basalt laminates. However, hybrid laminates had higher residual strength with increasing impact energy level.

A similar finding was also observed in the average impact strength of the two types of composites. It was clear that for the composite specimens fabricated using plain woven kenaf/PVB composite recorded the higher values of impact strength compared with the composite specimens fabricated using epoxy resin, at different energy levels. This may be explained by that PVB film has higher elongation properties compared to epoxy resin due to its low viscosity which helps in penetrating fabrics easily. High strength and viscosity of the epoxy resin have increased the specimen stiffness and decreased from its ability to absorb impacts. Furthermore, using a hot press technique to fabricate the kenaf/PVB composite has affected the impact properties of the composites which lead to good resin/fabrics penetration. As research studies have reported, the type of polymer is a critical factor which has an important influence on the impact strength of the natural fibers composites [68-70].

Main practice of natural fiber thermoplastic resin was limited because it cannot withstand high temperatures during processing and moisture absorption. These limitations can be controlled by some of the components such as proper selection of natural fibers, selection of fillers, methods of separating fibers from bast, fiber processing techniques, fiber-matrix bonding, injection molding, extrusion, compression molding, etc. [71].

Thermal composite materials are easier to recycle than mineral-based fibers. Thermoplastic is more recyclable than thermoset plastics composite. Grinding reprocessing is a common method for recycling thermoplastic composite materials. This recycling process is more efficient and more economical than other recycling methods such as chemical recycling, particle recycling, energy recycling [72].

Natural fiber reinforced composite efficiency depends on the fiber to the matrix interface and the capability of adhesion over the matrix to the fiber. This can be maximized by increasing the bond between the fibers and the matrix and changes the length of the short fibers to the length of the long fibers. Influence of fiber length and fiber distribution give greater impact while developing natural fiber thermal composite using extrusion process or injection moulding [73]. Efficiency and performance are less for using short fibers compared with long fiber composites due to fiber distribution and fiber orientation while using short fibers for the composite. Through previous studies carried out to investigate the potential use of natural fibers as reinforcing agents in polymers. Table 2 shows the application of natural fiber composite applications in the industry. Finally, most of the results show that natural fibers can be used as a reinforcing tool for plastics. However, its mechanical strength is relatively lower than that of synthetic fiber epoxy composite material [74].

Table 2 Natural fiber composite applications in industry [75, 76–78].

Fiber	Application in building, construction, and others
Hemp fiber	Construction products, textiles, cordage, geotextiles, paper & packaging, furniture, electrical, manufacture bank notes, and manufacture of pipes
Oil palm fiber	Building materials such as windows, door frames, structural insulated panel building systems, siding, fencing, roofing, decking, and other building materials [14]
Wood fiber	Window frame, panels, door shutters, decking, railing systems, and fencing
Flax fiber	Window frame, panels, decking, railing systems, fencing, tennis racket, bicycle frame, fork, seat post, snowboarding, and laptop cases
Rice husk fiber	Building materials such as building panels, bricks, window frame, panels, decking, railing systems, and fencing
Bagasse fiber	Window frame, panels, decking, railing systems, and fencing
Sisal fiber	In construction industry such as panels, doors, shutting plate, and roofing sheets; also, manufacturing of paper and pulp
Stalk	Building panel, furniture panels, bricks, and constructing drains and

fiber	pipelines
Kenaf fiber	Packing material, mobile cases, bags, insulations, clothing-grade cloth, soilless potting mixes, animal bedding, and material that absorbs oil and liquids
Cotton fiber	The furniture industry, textile and yarn, goods, and cordage
Coir fibers	Building panels, flush door shutters, roofing sheets, storage tank, packing material, helmets and postboxes, mirror casing, paper weights, projector cover, voltage stabilizer cover, a filling material for the seat upholstery, brushes and brooms, ropes and yarns for nets, bags, and mats, as well as padding for mattresses, seat cushions
Ramie fiber	Use in products as industrial sewing thread, packing materials, fishing nets, and filter cloths. It is also made into fabrics for household furnishings (upholstery, canvas) and clothing, paper manufacture.
Jute fiber	Building panels, roofing sheets, door frames, door shutters, transport, packaging, geotextiles, and chip boards.

1.13 Conclusions

The use of natural fibers as reinforcement for polymer and thermoset polymer composites has a positive effect on the mechanical behavior of the polymer. High strength, energy absorption, and rigidity are obtained by the composite materials, which are widely used in automobiles.

In recent years, applied research on natural fiber composite materials specifically on energy absorbing has grown rapidly considering encouragement from many researchers who emphasize sustainability and the commercial industry and using green materials. Natural fiber composite has good properties and potential to be developed as a component of engineering.