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ORIGINAL ARTICLE

Mechanical evaluation of hybrid natural fibre–reinforced polymeric composites for automotive bumper beam: a review

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Abstract

The use of lightweight materials in the automobile is one of the possible ways to achieve fuel efficiency demand and reduce the environmental pollution from greenhouse gases created *via* the automotive industry. The numerous advantages of natural fibre, such as low density, recyclability, biodegradability, relative ease of availability and low cost have brought it to spotlight for a variety of automotive applications. This article expounds the use of natural fibres and its hybrid as reinforcement in a synthetic polymer matrix for automotive polymer bumper beam material. The various attempts by researchers in their consideration and selection of high-performing materials for the development of automotive composite bumper beam were presented. Possible modifications employed to improve the relevance of natural fibre for this application over synthetic fibre were also considered. Lower impact properties were deduced from the mechanical evaluation of the various researches using hybrid natural fibre as a major limitation when compared with the conventional glass mat thermoplastics and the long fibre–reinforced thermoplastics used as typical bumper beam material. The use of various modifiers as tougheners has not been able to achieve comparable strength with GMT and LFRT. However, the need for nanobiocomposite should be explored for possible improvement on the impact properties in this area of application.

Keywords Hybrid · Natural fibre · Polymer composite · Automotive bumper · Bumper beam

1 Introduction

The automotive industry is continuously in the pursuit of the demand to produce vehicles with a lighter weight, which will help to achieve low-carbon emission and reduced fuel consumption in automobiles. Netravali and Chabba [1] reported that the rate of consumption of petroleum is unsustainable, which was estimated to be 100,000 times faster than what nature can create. According to Cheah [2], the transportation industry is believed to be responsible for two-third of the total petroleum consumed in the USA, which has accounted for one-third of the nation's carbon emission. The transport sector in the UK is looking into low-carbon vehicles and fuel [3]. The reports by Pandey et al. [4] and Bledski et al. [5] indicated the fact that a 25% reduction in the weights of vehicles can lead to a saving of 250 million barrels of fuel, which will translate into about 220 billion reductions in energy cost and a substantial reduction of the yearly CO_2 emission. Government legislatures in many countries have encouraged the use of recycled and biobased green products that are environmentally compatible [6]. The optimisation of the structural components and appropriate material selection are the two possible ways to achieving a reduction in the weights of the existing automobile models [7]. The utilisation of fibre-reinforced materials has the potential to bring about a further reduction in weight by an amount greater than 50% [8]. In addition, it can lead to achieving good corrosion resistance and a reduction in noise level [9]. The most commonly used fibre-reinforced material in the automobile sector is the sheet moulding compound (SMC) and the glass mat thermoplastics (GMT); however, the GMT is more preferred [7]. This is due to the better recyclability of thermoplastics matrix. Hence, weight reduction through appropriate material selection remains a possible route to reduce the consumption rate of petroleum-based products by automotive vehicles; thereby birthing a better eco-friendly environment through reduced

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CO_2 emission. Furthermore, harnessing the potentials inherent in natural fibres will also reduce the burden on petroleum-based products.

Researchers across the globe have increased their commitment to developing lightweight materials for automotive in order to address the trending issue of global climate impact and energy security. The use of light weight material for automotive will definitely lead to efficient fuel consumption. A 10% reduction in the weight of any vehicle that will bring about an increase in fuel efficiency of approximately 7% was attested [9]. According to Sadiku [10] and Sadiku et al. [11], it was estimated that the use of plastics (the majority of which are polyolefin-based materials) reduced the weight of a modern car by between 150 and 200 kg, with an estimated 800 l of fuel saving, over the average lifetime of a car. This translates to a significant reduction of carbon dioxide (CO_2) emissions. Stewart [12] estimated that polymer materials constitute between 15–20% of the total weight of vehicles. Polymers are often preferred as lightweight materials to achieve a reduction in automotive weight and for the replacement of the conventional ferrous and non-ferrous metals. Aside being lightweighted, polymers provide good thermomechanical properties, durability and superior corrosion resistance. It also has self-lubricating properties over conventional metals and metal alloys [13]. The use of polymer according to Chang et al. [14] drastically reduces noise pollution and vibration, thereby enhancing drivers and passengers comfort as well as ameliorating the consequent health hazards that can emanate from noise and vibration. Polymeric materials have been employed in several automobile components, such as bumpers, front ends, roof modules, body structures, wheel rims, interior trim component and bonnet panels [15]. However, research findings from many researchers have indicated the need for improvement in the mechanical performance of polymeric material for bumper beam. Natural fibre–reinforced polymer composites face the challenge of low-impact properties among others which are reviewed in this article. This review addresses the mechanical properties of hybrid natural fibre for a specific application (automotive bumper beam). Thereby making it novel, giving a specific, targeted and directional contribution to the body of knowledge. Most of the reviews on hybrid fibres disseminated in several papers are only for general application not specific. Many of those reviews majorly focused on manufacturing techniques while the mechanical performance was not critically reviewed or discussed. Every specific application has its unique mechanical requirements and testing to validate performance, in which this review thoroughly addressed for this specific application (automotive bumper beam).

Composite materials, according to Aramide et al. [16], have a combination of more than one property produced from two or more materials that cannot be achieved by either fibre or matrix acting alone. According to Mathew et al. [17], the engineering application of fibre-reinforced composites has transcended many decades. Polymeric materials alone could not deliver the expected mechanical properties required for the automotive application. Hence, reinforcement of different types of polymer matrix was discovered as the necessary complement in order to attain the expected properties in various structural applications. Over the last decade, synthetic fibres, as reinforcement in polymer composite, have received long-standing relevance in the aerospace and automotive application. This is due to their high strength and stiffness properties [18, 19]. However, the need for the European countries to produce vehicle parts from materials that are at least 95% reusable and recoverable by 2015 was issued in a directive 200/53/EC for end-of-life vehicles [20], hence, the rise in researches into the natural fibre.

2 The bumper system

The automotive bumper, Prabhakaran et al. [21], is a structural component, which contributes to vehicle crashworthiness and protects the occupant during a front or rear collisions. The main function of the bumper system is to reduce damage by absorbing kinetic energy on impact so that the load transmitted to the body frame is minimised [10]. The bumper systems also protect the hood, trunk, fuel, exhaust and cooling system as well as safety-related equipment, such as parking lights, headlamps and taillight in low-speed collisions. It is a shield normally made of aluminium, steel, rubber, composite or plastics and mounted on the front and the rear of a vehicle. Sapuan et al. [22] reported that the bumper system mainly comprises three components, *viz* fascia, an energy absorber and beam. Figure 1 shows the schematic diagram of a typical bumper system. The bumper beam is regarded as a structural component since it helps to absorb the kinetic energy from a high-impact collision and to provide bending resistance in a low impact collision [23]. The development of automotive bumper beam is considered to be important due to its role in absorbing bulk energy and protection during a collision [24]. The fascia is usually used for aesthetic purposes and for decreasing the aerodynamic drag force but cannot tolerate impact energy; therefore, it is considered a non-structural component. The absorber is designed to dampen a portion of the kinetic energy resulting from a collision. Steel bumper has some merit, e.g. good load bearing capacity. However, the major drawback lies in its low strength-to-weight ratio. Composite offers weight reduction with the adequate improvement of mechanical properties, which makes it a valuable replacement for steel. Composite bumpers also absorb more collision energy, has excellent corrosion resistance, high fatigue endurance limit, improved torsional stiffness, impact properties and improved appearance [25].

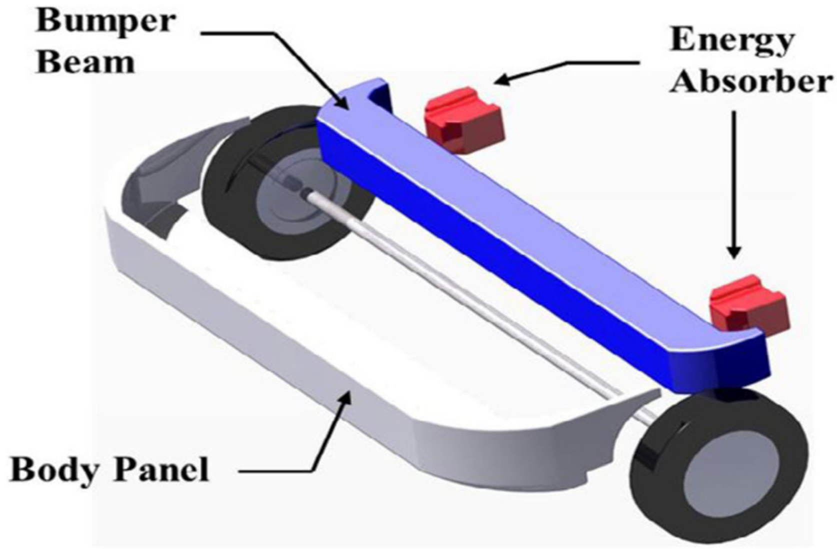


Fig. 1 Schematic of a bumper system [26]

3 Natural fibre

Fibres are broadly classified into two groups, namely natural and synthetic (man-made) fibres**.** Natural fibres encompass all class of fibres sourced from either plant or animal [27]. They are flexible materials with large aspect ratio and high strength.

High demand has been placed on natural fibres by the automotive, construction, electrical and electronic industrial markets, making it very competitive [28, 29]. However, the largest consumers of natural fibre composites are the automotive and construction industries [30]. It has become a very attractive replacement for glass fibres as reinforcement in the automotive industry [31]. The preference for natural fibre emanated from the growing environmental concern, which has led to continuous research on natural fibres and their composite for engineering material applications in place of synthetic fibre [32]. In the automotive industry, natural fibre comes with a relatively reduced cost when compared to the glass fibre. With natural fibre, a reduction of between 10–30% in the production cost can be achieved [33] as against glass fibre. Natural fibre can also bring about a weight reduction of approximately 30% when compared to synthetic [6]. The use of natural fibre-based composite can further help to achieve a reduction in the noise level in an automobile [33].

Natural fibre–reinforced composites have received acceptance by the automotive industries, such as the German auto companies, Proton company and Cambridge industry in the USA for the development of vehicle parts [28]. However, the high mechanical performance required by the external component of the vehicle such as bumper beam has refrained the wide application of natural fibre to the automotive interior. Against all odds, car manufacturers in Germany are making efforts to having every vehicle component either as a recyclable or biodegradable material.

However, in order to explore the application of natural fibre–reinforced composite material, in-depth knowledge of the physical, chemical and mechanical properties of natural fibres are needed.

3.1 Structure of natural fibre

The main chemical constituents of natural plant fibres are cellulose, hemicellulose and lignin, which can be seen in Fig. 2. Averagely, natural fibre is composed of between 60–80% cellulose, between 5–20% lignin or (pectin) and up to 20% moisture [34]. The hemicellulose in natural fibre functions as the compatibilizer between the cellulose and the lignin. The lignin stores the water in the fibre, protects the fibre against biological attack and acts as a stiffener for the stem against the force of gravity and wind. The microfibril has between 30–100 cellulose molecules in an extended chain conformation, which confirms mechanical strength to the fibre [35].

The general properties and application of each of these fibres lie on the individual properties of each component. Increased cellulose content in natural fibres depicts a higher tensile strength and modulus to the fibre, while the hemicellulose content projects the thermal properties, biodegradability and the moisture absorption capacity of the fibre. Blast fibres in the class of plant fibres are the most important natural fibres suitable for automotive application. The blast stabilises the plant and provides the fibre with good mechanical properties. Blast fibres have high cellulose content, which makes it fit for stress-bearing applications and it is a preferred substitute for synthetic fibres in the automotive industry and other technical applications. They are readily available and have specific strength and modulus properties [37].

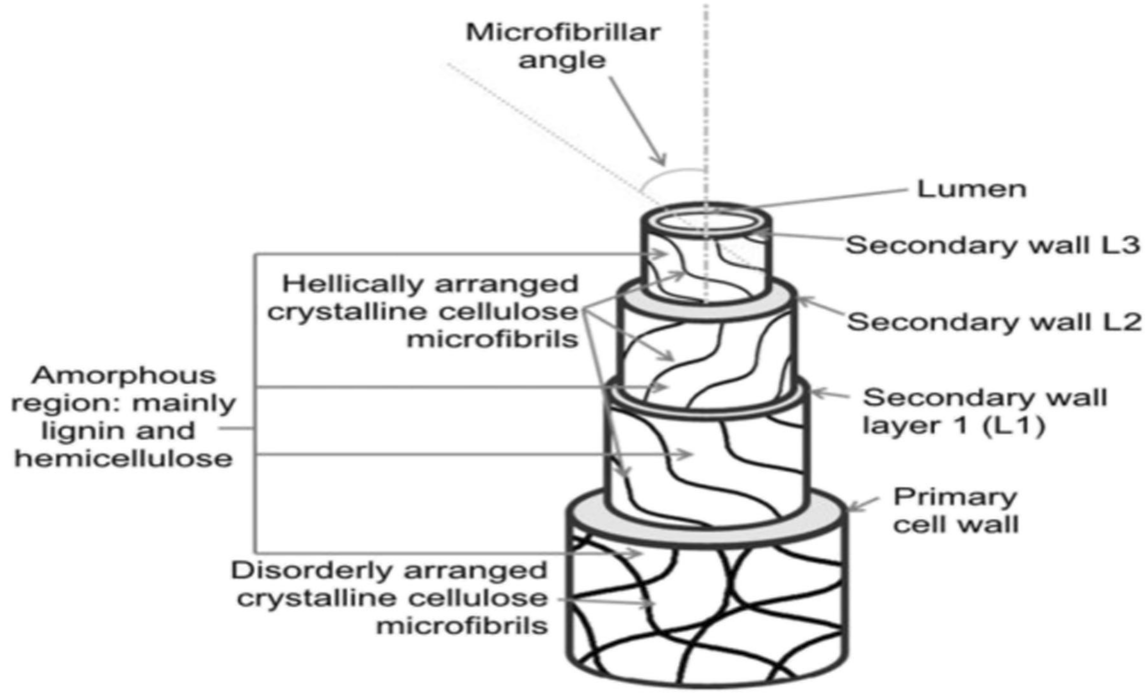


Fig. 2 Structure of natural fibre [36]

3.2 Advantages of natural fibre

A good and in-depth understanding of the properties of natural fibres is fundamental to expanding their applications in composite material development and in enhancing their performances. The performance of these fibres is a function of the chemical composition, physical properties (fibre dimensions, the extent of the defect, strength and structures) and mechanical properties. The merits of natural fibre are captioned in the following headings:

3.2.1 Environmental effect

Natural fibre is eco-friendly and biodegradable. Natural fibre originated from renewable resources; hence, it has an inexhaustible supply. The amount of carbon dioxide that the plant assimilates during the growth phase is the same as that released when decomposed. Hence, natural fibres are carbon neutral (no carbon emission). It absorbs the same amount of CO_2 as they produce [38]. The production of synthetic fibre generates extremely high gas pollutant emission when compared to natural fibre production [39].

3.2.2 Processing

Natural fibre has non-abrasive property over the screw and other metallic parts, which helps to reduce wearing of tools and damage to the machine, which often occur with the use of non-organic fillers thereby, allowing a higher volume of natural fibres in the polymer matrix. In addition, the processing is neither harmful nor results in skin irritation.

3.2.3 Mechanical properties

The lower density property of natural fibre results in their higher specific strength and stiffness when compared to synthetic fibres, as shown in Table 1. This also makes them have a lighter weight advantage over synthetic fibres [40].

Source [41]

3.3 Disadvantages of natural fibre

3.3.1 The hydrophilic nature of the natural fibre

Natural fibre is hydrophilic, while most polymers are hydrophobic. This disparity in the chemical structure of natural fibre and polymer is mainly responsible for the poor adhesion properties in the composites produced. The poor compatibility between the fibre and the matrix has an overall effect on the mechanical properties of the fibre/polymer composite. Hence, there is a need for fibre modification [42].

3.3.2 Inconsistent physical properties

The properties of natural fibres vary with respect to harvesting conditions (seasons, location, plant maturity and the type of harvesting technique), nature of the soil, climatic condition and the fibre pre-condition (mat, unwoven, chopped fibre),

Table 1 Mechanical properties of natural fibres as compared to conventional reinforcing fibres

Fibre	Density (g/cm^3)	Elongation (%)	Tensile strength (MPa)	Young modulus (GPa)
Cotton	1.5–1.6	3.0–10.0	287–597	5.0–12.6
Jute	1.3–1.46	1.5–1.8	393–800	10–30
Flax	1.4–1.5	1.2–3.2	345–1500	27.6–80
Hemp	1.48	1.6	550–900	70
Ramie	1.5	2.0–3.8	220–938	44–128
Sisal	1.33–1.5	2.0–14	400–700	9.0–38.0
Coir	1.2	15.0–30.0	175–220	4.0–6.0
Softwood kraft	1.5	–	1000	40.0
E-glass	2.5	2.5–3.0	2000–3500	70.0
S-glass	2.5	2.8	4570	86.0
Aramide (normal)	1.4	3.3–3.7	3000–3150	63.0–67.0
Carbon (standard)	1.4	1.4–1.8	4000	230–240.0

unlike the glass fibre and other synthetic fibres [43]. The growth of various types of natural fibres is also peculiar to and compatible with certain locations, as shown in Table 2, which makes their inconsistent and scare in some parts of the world [47].

3.3.3 Limited thermal stability

Natural fibres experience degradation and shrinkage at temperatures above 200 °C. Hence, the processing temperature is limited when compared to other synthetic fibres, thereby, affecting the performance when used in polymer composites. The physical and structural changes, such as hydrolysis, oxidation and recrystallization that occurring in natural fibres, are subject to heat and also limits their compatibility to selected resin types [44].

3.3.4 Relatively low durability

Natural fibres are prone to fungus attack and weathering, which affect their lifespans. The degradation process generates odour in the fibre.

3.4 Natural fibre in polymer-based automotive components

Natural fibre–reinforced polymer composites are composite materials, which consist of a polymer as the matrix and natural fibres, such as kenaf, jute and flax as fillers [45]. The matrix helps to transfer the load to the fibre and safeguards the fibre from the adverse environment and mechanical damage. In recent times, researchers have considered the potential of natural fibre as reinforcement in the polymer composite.

Polymeric matrices are mostly used in natural fibre–reinforced composite due to their lightweight and the ability to be processed at low temperature. Thermoplastic and thermosetting polymers are the two types of polymer used as matrices with natural fibre [46]. Thermoplastic matrix has one or two-dimensional molecular structure. It softens by the application of heat and solidifies upon cooling. The thermosetting polymer is a cross-linked structured polymer. It cures upon heating or under a combination of heat, pressure and light radiation. The lower environmental impact advantage of using thermoplastics over thermosetting is responsible for their increasing patronage in the automotive industry. Thermoplastics can be recycled, while thermosets cannot, although thermoset is able to provide better properties [47].

The common thermoplastics matrices used for biofibres are polyethylene, polypropylene and polyvinylchloride [48]. For thermosetting matrices, epoxy resins, phenolic and polyester are mostly used [45]. The degradation temperature of the choice of natural fibre is an important factor in the choice of a polymeric matrix. The natural fibre is thermally unstable above 200 °C [49]. Some natural fibres can be processed above this temperature, in rare cases, but only for a short duration. Epoxy and unsaturated polyesters are among the most researched thermosetting materials. However, polyolefins, such as polyethene and polypropylene, are used as thermoplastic matrices with natural and wood fibres [50]. A large number of natural fibres have been used as fillers in order to enhance the mechanical properties of these polymer matrices [51, 52].

Automobile manufacturers have considered natural fibre–reinforced polymer composite in some components in vehicles. Table 2 shows the list of automotive manufacturers that employ natural fibres as reinforcements in their automotive parts. Jamrichova and Akova [53] further reported that approximately 16 million cars were produced in Western Europe per year and natural fibre account for about 80,000–160,000 tons of natural fibre used.

Table 2 Automotive models, manufacturers and components using natural fibre–reinforced composite [54]

Models	Manufacturers	Components
A2, A3, A4, A4 Avant, A6, A8, Road star, Coupe	Audi	Seat back, side and back door panel, boot lining, hat rack, spare tire lining
C5	Citroen	Interior door panelling
3, 5, 7 series	BMW	Door panels, headliner panels, boot lining, seat back, noise insulation panels, moulded foot well lining
Eco Elise	Lotus	Body panels, spoiler, seats, interior carpets
Punto, Brava, Marea, Alfa, Romeo 146, 156	Fiat	Door panel
Astra, Vectra, Zafira	Opel	Instrumental panel, headliner panel, door panels, pillar cover panel
406	Peugeot	Front and rear door panels
2000 and others	Rover	Insulation, rear storage shelf/panels
Raum, Brevis, Harrier, Celsior	Toyota	Door panels, seat backs, floor mats, spare tire cover
Golf A4, Passat Variant, Bora	Volkswagen	Door panel, seat back, boot-lid finish panel, boot liner
Space star, Colt	Mitsubishi	Cargo area floor, door panels, instrumental panels
Clio, Twingo	Renault	Rear parcel shelf
Mercedes A, C, E, S class, Trucks, EvoBus (exterior)	Daimler-Benz	Door panels, windshield/dashboard, business table, pillar cover panel, glove box, instrumental panel support, insulation, moulding rod/ apertures, seat back rest panel, trunk panel, seat surface/back rest, internal engine cover, engine insulation, sun visor, bumper, wheel box, roof cover
Pilot	Honda	Cargo area
C70, V70	Volvo	Seat padding, natural foams, cargo floor tray
Cadillac Deville, Chevrolet Trail Blazer	General Motors	Seat backs, cargo area floor
L3000	Saturn	Package trays and door panel
Mondeo CD 162, Focus, Freestar	Ford	Floor trays, door panels, B-pillar, boot liner

4 Reinforcements in polymer composite bumper beam

There are different types of composite materials that have been investigated by various researchers and car manufacturers. They include carbon fibre–reinforced plastic (CFRP), glass fibre–reinforced plastic (GFRP), sheet moulding compound (SMC) and glass mat thermoplastic (GMT) for the bumper beam. The above-mentioned composite materials help achieve weight reduction and hence, reduce energy consumption [55].

4.1 Glass fibre as reinforcement in the automotive composite bumper beam

Cheon et al. [56], adopted glass fibre fabric-epoxy composite to develop and fabricate a composite bumper beam with the exception of the elbow section, which was made of carbon fibre-epoxy material. Static bending test performed on the composite bumper revealed that the weight of the composite bumper beam was 30% that of the steel bumper beam without comprising the static bending strength. The reinforcement of polypropylene with 40% glass fibre was also reported by Clark et al. [57], who worked on the stress contour design of the bumper beam. Kelman and Nelson [58] also studied the use of composite material to manufacture bumper beam. Fibre glass preform and a two-component urethane-based polyol and isocyanate were the materials used for the bumper beam. The progress on glass fibre as polymer composite reinforcement in recent times and the findings of researches are further discussed in this review.

Achema et al. [59] investigated the mechanical properties of glass fibre–reinforced composite for lightweight car bumper applications. The composite developed was fabricated *via* the hand lay-up process by using E-glass bi-directional laminate and epoxy resin. In the research, the existing steel bumper was replaced with glass fibre–reinforced composite bumper. An already existing steel bumper was used as the mould in the work. The tensile, impact and flexural strength tests were carried out according to ASTM D 3039, D256-04 and D790, respectively. From the mechanical test results, a satisfactory flexural strength at a load > 0.5 kN and a span of 80 mm, the tensile strength of 3852.8 kJ and impact strength of 100 kJ/m^2 were obtained. In addition, a 60% reduction in weight when compared to steel car bumper was observed. Higher values of tensile strength and Young modulus were observed for the composite developed when compared with the common long fibre–reinforced composite (LFRT) used for bumper beam material. Maximum impact strength of

100 KJ/m^2 was recorded for the composite developed at 40% fibre content. It was therefore concluded that it can successfully replace steel car bumper.

Prabhakaran et al. [21] , in their design and fabrication of composite bumper, utilised glass fibre–reinforced polymer instead of existing steel bumper. The fabrication of the composite bumper was carried out by hand layup process using E-glass/epoxy bi-directional laminate. From the experimental analysis performed, a weight reduction of 53.8% was achieved compared to the steel bumper without sacrificing the strength. It was also reported that the composite material enhanced the fuel economy of the vehicle.

Dakina [60] employed different percentages of glass fibres (10%, 30%, 50% and 70%) in reinforcing polypropylene for car bumper application. An increase from 85 to 498 kJ/m^2 was observed for the impact strength and the compressive strength increased from 51 to 310 MPa, for percentage reinforcement of 0% and 70%, respectively.

4.2 Carbon fibre as reinforcement in the automotive composite bumper beam

Wang and Li [61] worked on the design and analysis of automotive carbon fibre composite bumper beam, based on finite element analysis. The material and thickness of the bumper beam were modified in order to improve the crashworthiness performance in a low-velocity impact test. The low-velocity impact simulation was carried out according to the E.C.E. United Nations Agreement, Regulation no. 42. A bumper beam analysis was carried out for carbon fibre composite and steel materials in order to analyse their deformation, weight, impact force, energy absorption and acceleration of the impactor. Better impact behaviour was observed for carbon fibre composite. Different bumper beam thicknesses were also examined for the purpose of lightweight. The impact behaviour of different bumper thicknesses was analysed, among which a 5.4 mm thick bumper beam was the best choice, without sacrificing the impact performance and a weight reduction of about 53.2% was achieved.

Hu et al. [62], conducted research on carbon fibre–reinforced plastic bumper beam that was subjected to a low-velocity frontal impact. The issue of lightweight and crashworthiness (safety performance) was considered in their work. The research focused on replacing the traditional high strength steel used in bumper beam application with carbon fibre–reinforced plastic bumper beam. Low-velocity impact finite element simulations were performed for the two bumper beams under consideration by using LS-DYNA. LS-DYNA is an advanced general-purpose multi-physics stimulation software, developed by Livermore Software Technology Corporation (LSTC). It is used by the automobile, aerospace and other engineering industries for modelling parts and components. In comparison, they found out that the energy absorption capacities and the dynamic response characteristics of the carbon fibre–reinforced plastic bumper beam were found to be better than that of steel. In addition, a 50% reduction in weight was experienced using carbon fibre–reinforced composite.

4.3 Nanoparticle as reinforcement in polymeric bumper beam

The exceptional properties of nanoparticle, such as large surface area, relatively low cost and high surface reactivity, have stirred the interest of researchers to harness it in various applications.

Hasanzadeh et al. [63] studied the effect of carbon nanotube reinforced polymeric nanocomposite material selection for the automotive bumper beam. Six alternative samples of polymeric material were produced in their study. In this experiment, three samples of polyamide-6 nanocomposites foams blended with 0.5, 1.0 and 1.5 wt% multi-walled carbon nanotube (MWCNTs) and three samples of polycarbonate nanocomposites blend with 0.5, 1.0 and 1.5 wt% of nanoalumina were injections moulded. The melt compounding of the composite component was done with a twin-screw extruder. The impact strength, tensile strength, cost and the manufacturing process were considered in the different multi-criteria decision-making to select the proper polymeric material for the bumper beam. Tensile and the Charpy impact tests were carried out according to ASTM-D638 and ASTM-D6110, respectively. According to the procedures used, polycarbonate with 0.5 wt% of MWCNTs nanocomposite had higher impact and tensile strengths and involved the lowest cost and therefore, it was considered to be a suitable polymeric nanocomposite material for bumper beam.

4.4 Natural fibre as reinforcement in automotive bumper beam

A few numbers of natural fibres have used as reinforcing material in polymer composite for bumper beam and their mechanical properties were evaluated. The aim is to substitute the conventional glass mat thermoplastics (GMT) and other synthetic fibre with either partially or fully eco-friendly material.

Witayakran et al. [64] fully replaced the conventional glass fibre used as reinforcement in the automotive bumper beam with oil palm fruit bunch (EFB), which is a kind of natural fibre. EFB fibres were prepared through chemical (NaOH) and mechanical (steam explosion) means. Chemical extraction route with 30% NaOH gave the optimum properties of the EFB. The matrix contains a mixture of epoxy resin and hardener of 100:33 weight ratio. The glass fibre and the EFB reinforcement were at 0–10% *w/w* fibre content. The

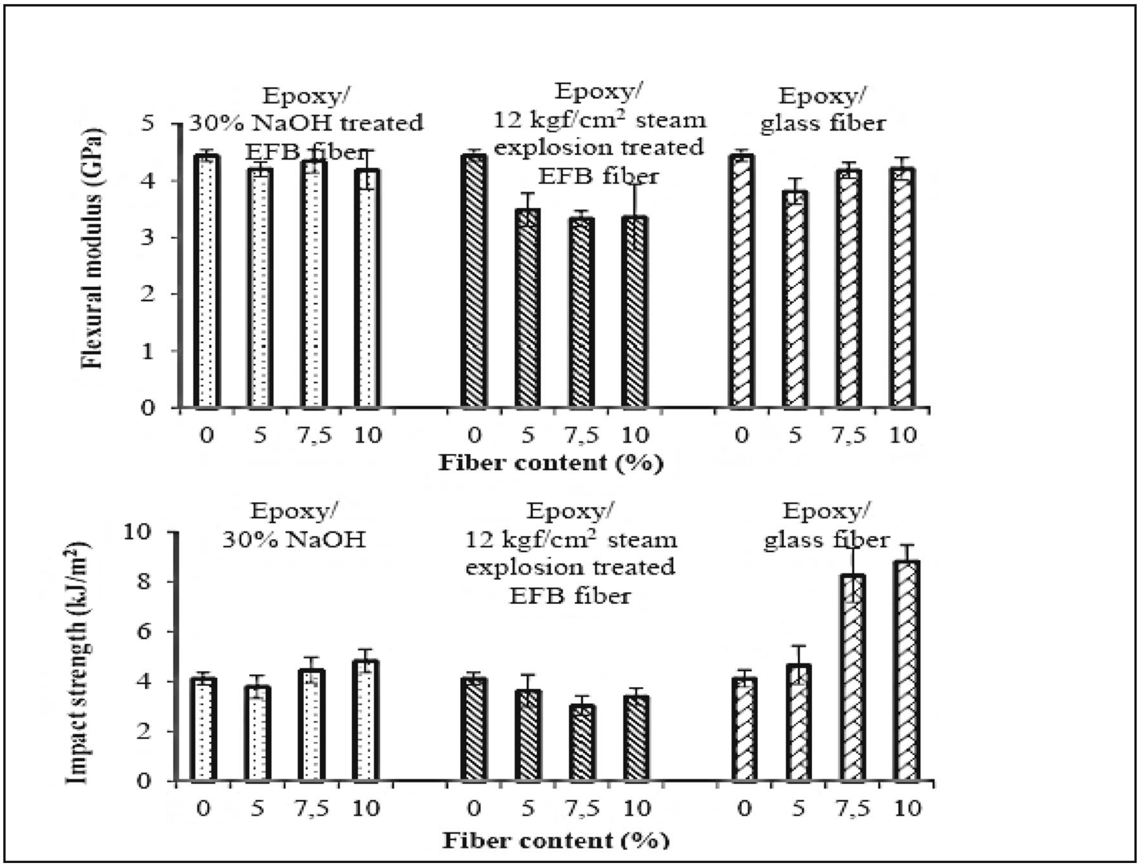


Fig. 3 Flexural modulus and impact strength of epoxy composite reinforcement with 30% NaOH-treated EFB fibre, 12 kgf/cm^3 steam-treated and glass fibre [64]

mechanical test results obtained were compared with that of the glass fibre–reinforced composite of the same fibre weight ratio. The flexural modulus and thermal properties of the epoxy composite reinforced with EFB fibres at 7.5–10% *w*/*w* yielded similar results with that of glass fibre reinforcement of same fibre weight, as shown in Fig. 3 and Table 3, respectively. The results from the differential scanning calorimetry (DSC) and dynamic mechanical thermal analysis (DMTA) showed that the glass transition temperature of the composite increased as the fibre content increased. However, EFB still displayed lower impact strength property when compared to that of the glass fibre–reinforced composite, which is also shown in Fig. 3. The reason is due to the higher aspect ratio of glass fibre when compared to EFB.

Onyedum et al. [65] worked on comparative mechanical analysis of okra fibre and banana fibre composite used in manufacturing automotive car bumper. Okra and banana serve as the reinforcement while vinyl ester resin is the matrix. The composites were prepared by hand layup technique in a mould, impregnated with the epoxy resin and then cured. The fibre length considered for this study is 10 mm, 30 mm and 50 mm. The percentage weights of fibre used were 10 wt%, 30 wt% and 50 wt%. The effect of varying fibre length and percentage composition on tensile strength of okra and banana fibre–reinforced composite were examined for automobile application. The moisture content of the fibre was removed by NaOH treatment and also to enhance the tensile strength. The optimum tensile strength value was found for

Table 3 Glass transition temperature (T_g) of epoxy composite analysed by DSC and DMTA [64]

Epoxy composite reinforced with		% fibre	30% NaOH-treated EFB fibre		12 kg/cm^3 steam explosion–treated EFB fibre		Glass fibre	
		0%	5%	10%	5%	10%	5%	10%
T_g (°C)	DMA	61.50	68.50	70.10	69.30	69.20	68.50	73.00
	DSC	61.74	66.06	66.40	65.85	65.85	66.87	65.76

Table 4 Summary of density and mechanical properties of natural fibre (NF-PP), hybrid PP and long glass fibre–filled composite (GF-PP) [76]

Property	Units	NF-PP	Hybrid PP	GF-PP
Density	g/cc	1.04 (0.01)	1.17 (0.02)	1.21 (0.01)
Tensile strength	MPa	56.4 (1.20)	75.3 (0.80)	101.3 (2.60)
Tensile modulus	GPa	3.43 (0.04)	4.36 (0.08)	4.97 (0.08)
Flexural strength	MPa	88.5 (1.70)	123.7 (4.10)	160.7 (5.20)
Flexural modulus	GPa	3.79 (0.04)	5.54 (0.21)	6.25 (0.18)
Izod impact strength	J/M	154 (14.0)	240 (42.0)	560 (30.0)

length percentage composition is (50 mm; 30%) for banana and (10 mm; 30%) for okra fibre.

Ragupathi et al. [66] worked on the enhancement of impact strength of a car bumper using natural fibre composite made of Jute. This study considered the impact strength, cost and weight of jute fibre–reinforced composite for bumper beam with existing steel bumper. The composite bumper was developed via hand layup technique in which jute fibre were laid and followed by liquid resin in succession. The composite bumper has an impact strength of 7.14 J/mm^2, achieving a reduction in weight of 56.1% and a 58% less in cost.

Vemuri Lakshminarayana [67] studied the effect and analysis of natural fibre polymer composite plates used for passenger vehicle bumper. Composite plates of Sisal fibre mat reinforced epoxy and Sisal fibre mat reinforced polyester resin were fabricated via hand lay-up technique. The tensile, flexural and impact properties were conducted over these two composite plates. It is intended to find a possible replacement to the conventional steel bumper. A 35.69% weight reduction was achieved with sisal natural fibre composite compared to steel bumper without compromising the mechanical strength of bumper impact beam. The natural fibre is also seen to have a cost advantage over the steel bumper impact beam.

4.5 Hybrid natural fibre as reinforcement in automotive bumper beam

Hybrid composites are materials in which two or more different types of fibre are combined in a common matrix [68]. Sanjay et al.[69] also defined a hybrid composite as a combination of two or more different types of fibres in which one type of fibre balances the deficiency of another fibre(s). Dong [68] reported that the general purpose of bringing two different fibres together is to retain the merit of both fibres and alleviate their limitations. Hybridised composite of high strength synthetic fibres, such as glass fibre and carbon fibre with natural fibre in a composite, yielded superior mechanical properties when compared to hybridising natural fibre with natural fibre composite.[70] Synthetic fibres help to compensate for the limitation of natural fibres when used in a hybrid in order to improve the mechanical properties of the polymer composite.[71] The hybridisation route is a channel for enhancing the modulus, strength and moisture resistance characteristics of polymeric composites [72]. It will also help to lower the water uptake in natural fibre and enhance thermal stability. Rout et al. [72] compared the water absorption property of polyester composite reinforced with glass and coir with that of coir fibre alone. The hybrid reinforcement shows less water absorption. Kim et al. [26], conducted research on the design optimization and manufacture of hybrid glass/carbon fibre–reinforced composite bumper beam for automotive vehicles.

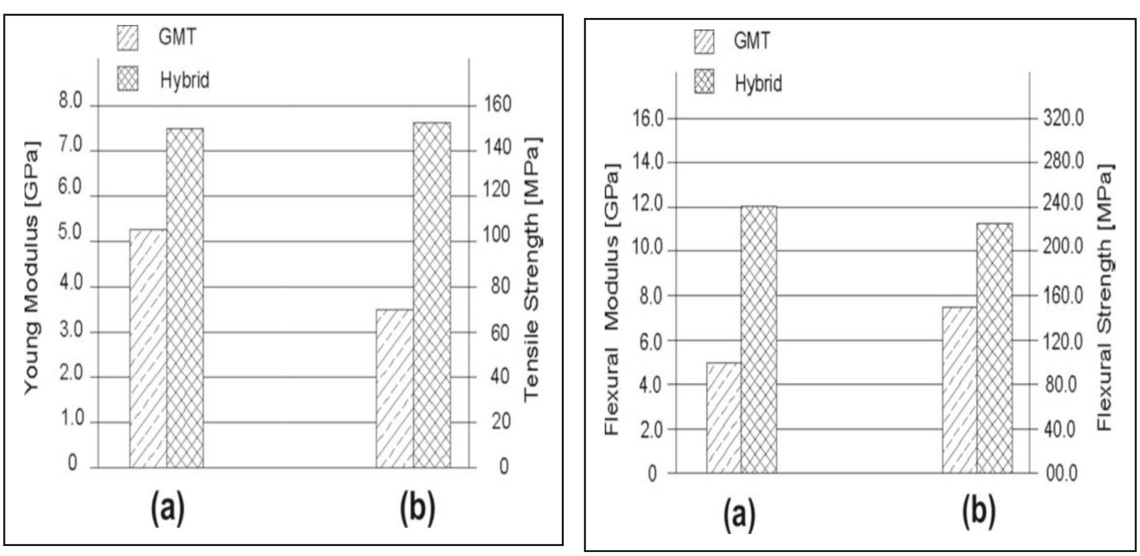


Fig. 4 Mechanical properties: (**a**) Young modulus, (**b**) tensile strength; (**a**) flexural modulus and (**b**) flexural strength of fibre-reinforced composites [24]

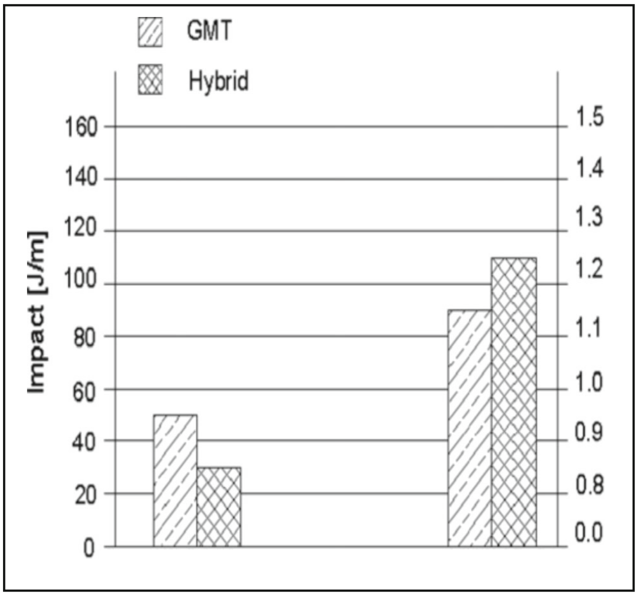


Fig. 5 Mechanical properties: (**a**) impact strength and (**b**) density of fibre-reinforced composites. [24]

Khalil et al. [73] investigated the mechanical and physical properties of an agro-hybrid composite made of oil palm fibre (EFB)/glass hybrid–reinforced polyester composites. Different ratios of glass, EFB fibres, *viz* 3:7, 5:5, 7:3 and 9:1, were prepared and EFB/polyester composite was made as the control sample. The technique used in impregnating the fibre mat was resin transfer moulding. The mould used has a thickness of 1 mm and a pressure of 5 bar. Tensile and flexural tests were performed according to ASTM D-638 and ASTM D-790, respectively by using the Instron Universal testing machine. Charpy impact test, ASTM D-256, was also carried out by using the pendulum impact tester CS 1370. The total fibre loading was varied from 15 to 55 wt%. From the mechanical analysis, composite with 35% fibre loading displayed the overall best mechanical performance. This is due to the excellent dispersion of the fibre and the good load transfer capability of this composition. However, the high strength and modulus values of glass fibre were responsible for the improvement, rather than EFB. This can be further explained as the composition with the lowest percentage of EFB gave the best properties, while the control sample with the highest EFB percentage gave the lowest properties and reduction in resistance to water absorption. A different case was witnessed as the elongation-at-break increased with increasing EFB content. This is due to fact that EFB had high strain-to-failure of between (8–18%), while glass fibre recorded a strain-to-failure of 3%.

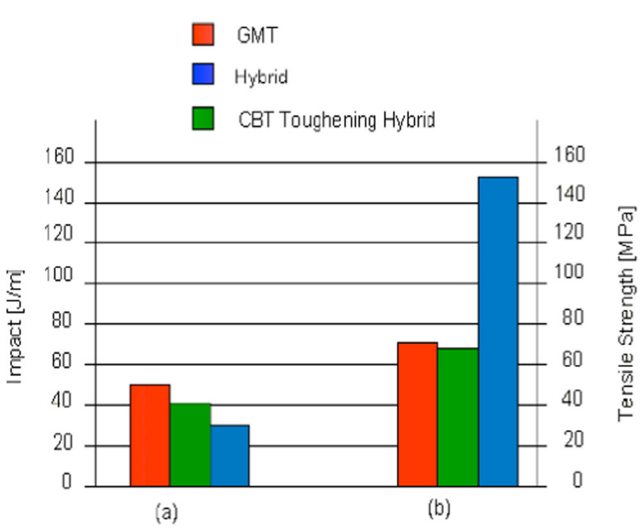


Fig. 6 Comparison chart: (**a**) impact (**b**) tensile strength [77]

Olorunishola and Adubi [74] performed a comparative analysis of a blend of natural jute and glass fibres with synthetic glass fibre composite for car bumper materials. The structure of the material, hardness and impact properties were examined in the analysis for bumper beam material. Samples of hybrid Cs (30 wt% jute, 10 wt% glass fibre), PNFC (40 wt% natural twisted jute fibre) and GF-C (40 wt% glass fibre) in a polypropylene matrix were produced using hand layup technique and mechanically characterised. From the result obtained, it can be deduced that superior hardness strength of 65.5 HRB and impact strength of 11.61 J was found with Hybrid Cs. This implies that hybrid Cs has the potential of possibly replacing the commercial GF-C as automobile structural application such as bumper beam.

Mishra et al. [75] investigated the mechanical performance of biofibre/glass-reinforced polyester hybrid composite. In the study, sisal fibre was chemically modified by using various treatments, which were later used as hybrid with glass fibre for reinforcing a polyester matrix. The effect of the different types of modifying solutions, lengths of time of treatment and their concentrations on surface treatment, were examined. The hybrid composite with 5% alkali concentration produced the highest tensile strength when compare to other chemicals, such as cynaoethylated and acetylated treatments. The tensile strength was about 28% higher when compared to the untreated. However, at higher concentration of alkali, a reduction in the tensile strength of the composite was observed. Furthermore, alkali-treated natural fibres used in hybrid composite, revealed the superior impact strength. The alkali-treated biofibre polyester glass hybrid composite showed better matrix adhesion when compared to the untreated glass hybrid. It can be deduced that the developed hybrid developed had good encouraging mechanical properties, with strong relevance in automotive and building structures.

Panthapulakkal et al. [76] examined the performance of injection moulded natural fibre hybrid thermoplastics composite for automobile structural applications. The research was directed at evaluating the thermal properties, creep properties and the recyclability of the natural fibre. The properties

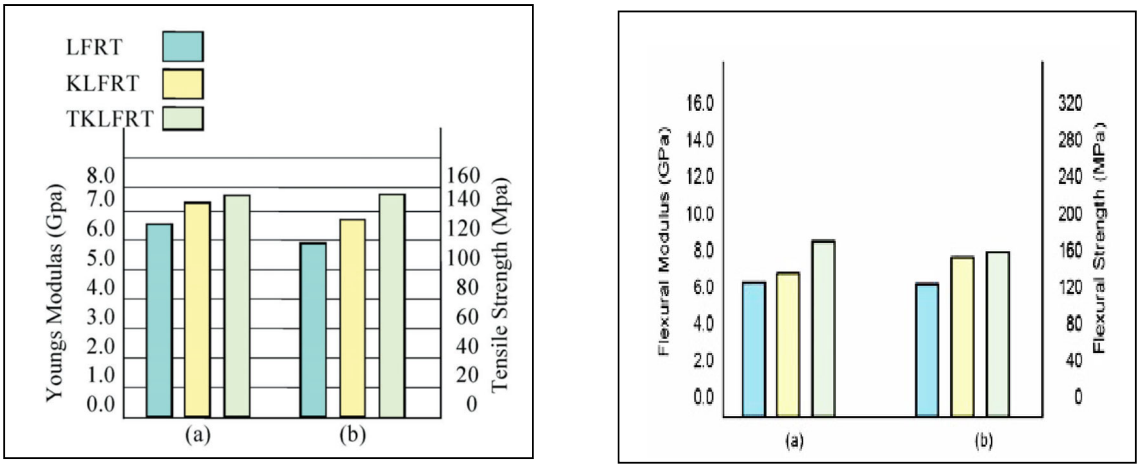


Fig. 7 Mechanical properties: (**a**) Young modulus, (**b**) tensile strength; (**a**) flexural modulus and (**b**) flexural strength of fibre-reinforced composites [79]

of the natural fibre hybrid were then compared with that of long glass fibre–filled thermoplastics, thereafter. The samples prepared were 40 wt% of natural fibre with 55 wt% of PP and 5 wt% compatibilizer, 40 wt% of natural fibre with 45 wt% of PP and 5 wt% and 40 wt% long glass fibre that was chemically coupled with heat stabilised PP. From the result of the mechanical test conducted, the densities of the natural fibre hybrid composite was less when compared to the glass fibre filled PP. Although, a tangible improvement was observed in the hybridisation of natural fibre with 10 wt% glass fibre, the mechanical strength of the hybrid composite still could not measure up with that of glass-filled PP in applications such as bumper beam. However, it was still superior to that of the engineering plastics, such as polycarbonates and polycarbonate/ABS alloy. The hybridised composite has comparable modulus (tensile and flexural) with glass-filled PP, but the impact strength should be greatly improved. Hence, they can only be used in engineering structural applications where

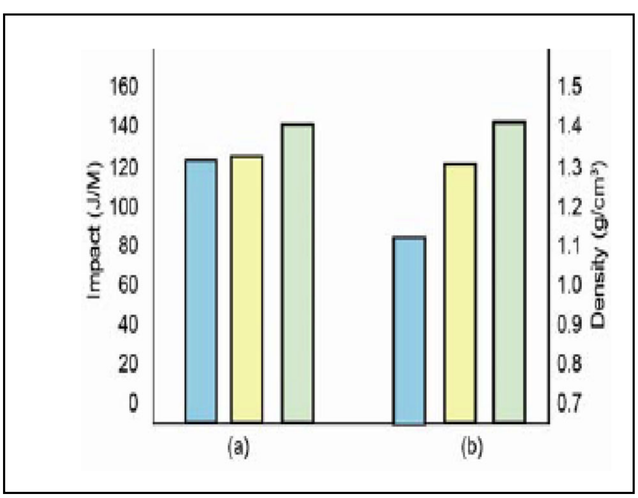


Fig. 8 Mechanical properties: (**a**) impact strength and (**b**) density of fibre-reinforced composites [79]

tensile and flexural properties are prioritised over impact properties. The heat deflection temperature of hybrid PP is comparable with that GF-PP (Table 4).

Davoodi et al. [23] studied the mechanical properties of hybrid Kenaf/glass fibre–reinforced epoxy composite for passenger car bumper beam. The composites were prepared through sheet moulding compound, which was thereafter compression moulded. The samples without any modifier were tested and compared with a typical bumper beam material of glass mat thermoplastics (GMT). The hybrid materials were heated under a controlled pressure of 80 bar at 85 °C for 1 h. The result of tensile strength and the Young modulus of the specimen were higher than the common bumper beam materials, e.g. GMT as shown in Fig. 4. It can also be seen from the figure that the flexural strength and modulus were higher than the typical GMT, but the impact strength of the hybrid composite was still low, as shown in Fig. 5. The improved mechanical properties were reported to be due to the pressure applied to the sample that made it denser. The adhesion between the fibres and the epoxy was also observed to be significantly better than that of polypropylene and fibre in GMT.

Further studies were conducted by Davoodi et al. [77], in which an attempt was made to enhance the thermoplastic impact property in hybrid natural fibre composite bumper beam by employing CBT 160 thermoplastic toughening. The commonly desired bumper thickness of the sample was made as the previous work by using hybrid kenaf/glass fibre–reinforced epoxy composite without any modifier [24]. The sample was prepared as a sheet moulding compound and moulded through the hot press machine. The toughness and the impact properties of the CBT-toughened hybrid material were significantly increased. However, it still could not completely fulfil the requirements desired of the GMT impact properties as shown in Fig. 6. Hence, there is a need for further improvement.

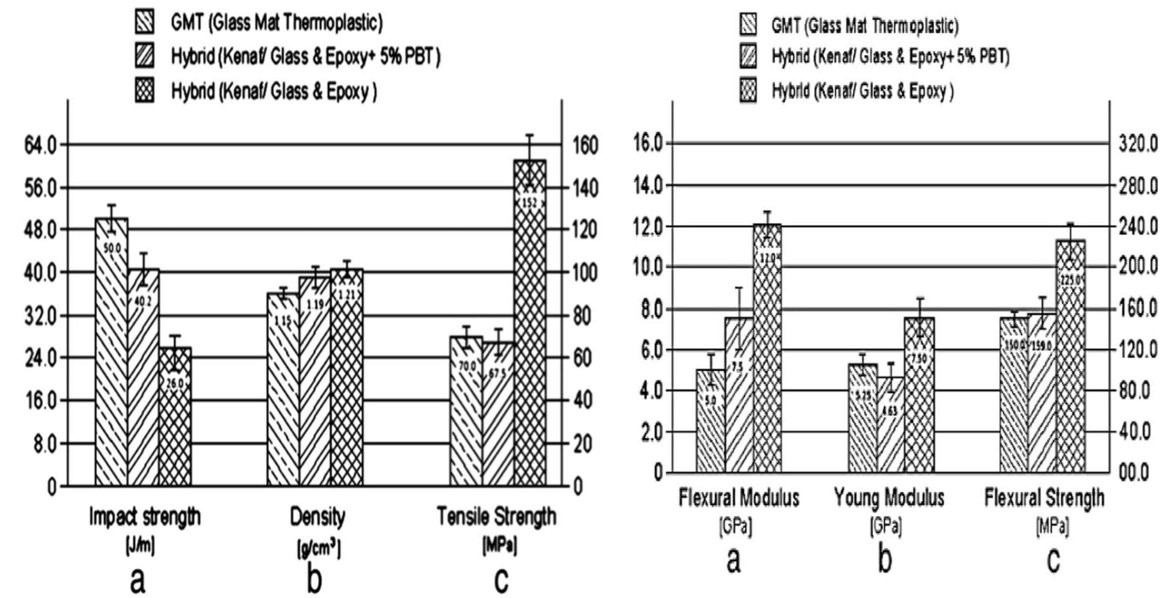
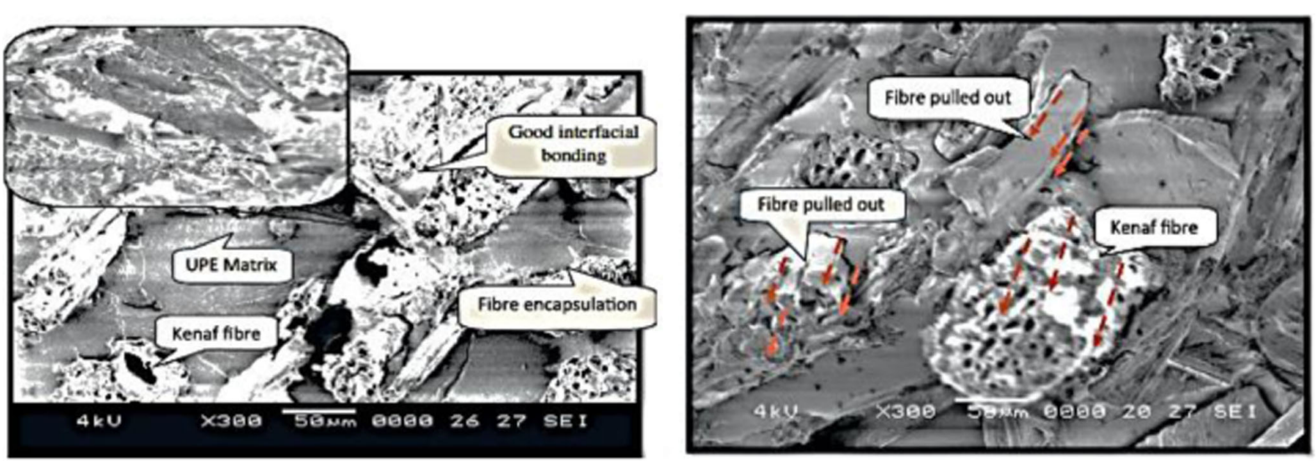


Fig. 9 Mechanical properties comparison: (**a**) impact strength, (**b**) density, (**c**) tensile strength; (**a**) flexural modulus, (**b**) Young modulus, (**c**) flexural strength [80]

In order to expand the application of hybrid kenaf/glass fibre epoxy composite for structural applications, Davoodi et al.[78] carried out further investigation using 5% (*w*/*w*) polybutylene terephthalate (PBT) with the sheet moulding process. It was intended to enhance the toughness performance of the epoxy, which will bring about an improvement in the impact property of the hybrid for automotive structural application, e.g. the car bumper beam. Tensile, flexural and impact tests, according to the American Society of Testing and Materials ASTM D-3039, D790-3 and D253-04, respectively, were carried out on the hybrid composite developed and the results were compared with the untreated epoxy and the GMT. The outcome of the impact test for the PBT-toughened hybrid revealed an improvement of 54% when compared to the untoughened hybrid. However, the impact value of GMT still remained higher. The optimisation of the design parameters was suggested as a possible means to further improve the impact property of the material.

According to ASTM standards 08:01, the long fibre was reported to offer better impact resistance and rigidity property by up to five times that of short fibre.

Natural long fibre–reinforced thermoplastic composite was, however, developed by Jeyanthi and Janci [79], for automotive frontal beams. The objective was to produce a partially eco-friendly injection moulded long hybrid composite with improved properties. Kenaf fibre was treated with caustic soda (NaOH) in order to enhance its strength and flexural rigidity. Three different compositions of the fibre materials



(a) (b)

Fig. 10 SEM fractography of kenaf/glass-reinforced UPE hybrid (**a**) treated (15/15 *v*/*v* KG) and (**b**) untreated (15/15 *v*/*v* KG) [80]

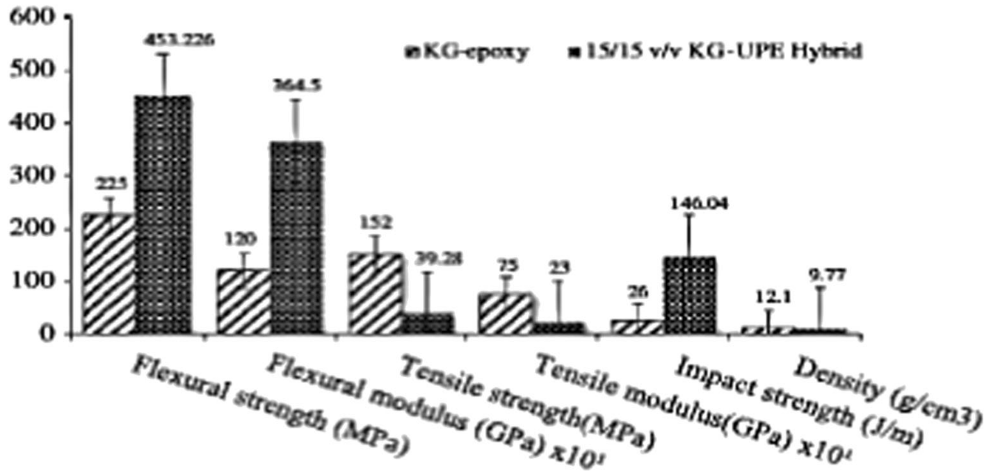


Fig. 11 Mechanical properties: (**a**) Young modulus, (**b**) tensile strength, (**c**) flexural modulus and (**d**) flexural strength of fibre-reinforced composites [80]

were cut into pallet, which was later fabricated through hot impregnation process. Long kenaf fibre–reinforced thermoplastics (LFRT) were prepared. 40 wt% of twisted kenaf fibre, PP and compatibilizer, hybrid (30 wt% of twisted Kenaf fibre plus 10% glass fibres plus PP and compatibilizer and commercial LFRT (40% long glass fibre) was prepared. The specimen was injection moulded, tested and the results were compared with a typical bumper beam material (LFRT). It was observed from experimental results, shown in Fig. 7 that long and twisted kenaf fibre–reinforced thermoplastics (TKLFRT) specimen had higher tensile strength and Young modulus than the common bumper beam material, e.g. LFRT. LFRT recorded a yield strength of 101.3 MPa and Young modulus of 5.5 GPa. KLFRT material also recorded higher values than LFRT. In addition, the flexural strength, conducted according to ASTM D790, showed that hybrid PP had comparable flexural strength and modulus with the commercial LFRT. The result of the Izod impact test (ASTM D256-04) conducted on the samples was compared with LFRT material. However, it can be observed that the impact strength of the hybrid is lower to that of typical LFRT used for the bumper beam as shown in Fig. 8. Hybrid PP also showed the comparable value of heat deflection temperature with LFRT, which confirms its dimensional stability.

Atiquah et al.[80], also employed a surface treatment process known as mercerization; using 6% caustic soda (NaOH) diluted solution, in an attempt to enhance the properties of kenaf fibre (KF) before developing the hybrid composites. The formulations were prepared with varying percentages of natural (kenaf fibre) and synthetic fibre (glass fibre) as reinforcements in an unsaturated polyester matrix. The hybrid composites were consolidated as a sheet moulding compound, having a total reinforcement of 30%. In this experiment, the mechanical properties of the treated kenaf hybrid composite and the untreated natural fibre composite were compared, as shown in Fig. 9. The untreated glass fibre UPE hybrid has the highest tensile strength, and this was accorded to the higher strength and modulus of glass fibre (GF) rather than that of kenaf fibre (KF). As the percentage composition of GF decreased, the value for the tensile strength decreased. However, for the treated kenaf fibre, a different trend was witnessed. The treated kenaf hybrid showed higher value in its tensile strength and modulus giving the optimum material performance when compared to the untreated hybrid. This was attributed to the better bonding between the fibre and the matrix due to the mercerisation treatment. Figure 10 shows the SEM of the treated and untreated of 15/15 *v*/*v* hybrid formulations. Furthermore, the treated hybrid composite showed an increase

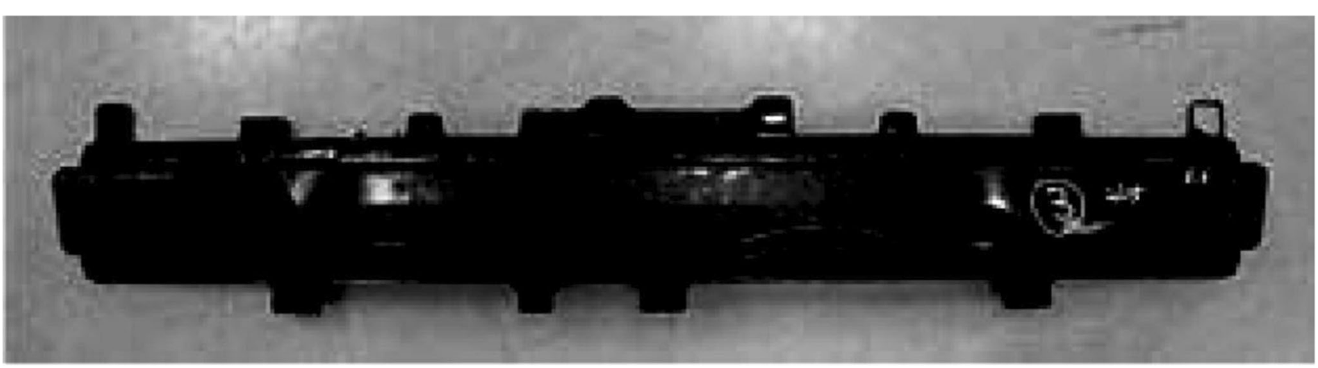


Fig. 12 Bumper beam made from hybrid composite of glass fibre and carbon fibre [27]

Table 5 Summary of findings on hybrid natural fibre as reinforcement in polymeric bumper beam compare to GMT/GF-PP

Author	Composition	Application	Preparation	Modifier	Mechanical findings
Davoodi et al. [24]	Hybrid kenaf/glass fibre–reinforced epoxy composite	Bumper beam	Sheet moulding/compression moulding	No modifier	Flexural strength and modulus higher than GMT Lower impact strength compare to GMT
Davoodi et al. [71]	Hybrid kenaf/glass fibre–reinforced epoxy composite	Bumper beam	Sheet moulding/hot pressing	CBT-160-toughened thermoplastic	The toughness and the impact properties were improved significantly Lower impact strength compare to GMT
Davoodi et al.[72]	Hybrid kenaf/glass fibre–reinforced epoxy composite	Bumper beam	Sheet moulding process	PBT-toughened hybrid	54% improvement compared to untoughened hybrid but lower impact value compare to GMT
Jeyanthi and Janci [73]	Hybrid natural Kenaf long fibre–reinforced thermoplastics (LFRT)	Automotive frontal bumper beam	Injection moulded	Fibre treated with NaOH	Has higher tensile strength and Young modulus properties compare to common bumper beam, material (LFRT) Impact strength lower than typical LFRT
Kim et al.[27]	Hybrid glass/carbon fibre–reinforced composite	Bumper beam		No modifier	Enhanced impact performance with 33% less weight compare to metallic bumper beam
Olorunisola And Adubi [72]	Natural Jute and glass fibre	Bumper beam	Hand lay-up technique	No modifier	Superior hardness and impact strength Suitable for automobile structural application such as bumper beam.
Panthapulakkal et al. [75]	Natural fibre hybrid thermoplastic composite	Automobile structural application	Injection moulded		Comparable modulus (tensile and flexural) with glass-filled PP but the impact strength is lower compared to GF- PP. Has lower density compared to glass fibre
Mishra [73]	Biofibre/glass-reinforced polyester hybrid composite	Automobile structural and building application		Treated and untreated	5% alkali concentration showed superior tensile properties and good adhesion. Alkali-treated natural fibre in hybrid showed superior impact strength.

of 11% in the impact resistance above the untreated kenaf-glass of the same KG composition. It was concluded that kenaf alone, whether treated or untreated in the hybrid formulation, cannot withstand higher impact load due to its reduced toughness and high brittleness. The orientation of the fibre mat was also reported to have contributed to the ability of the composite to withstand impact forces.

The mechanical properties of a 15/15 *v*/*v* treated Kenaf/glass unsaturated polyester resin (KG-UPE) developed by Atiquah et al.[80] were compared with that of KG-epoxy hybrid composite, which was developed by Davoodi et al., and shown in Fig. 11. A higher value of the tensile, including flexural properties, was obtained for the treated KG-UPE when compared with the KG-epoxy hybrid material developed for use as an automotive bumper beam. However, it was concluded, from the work of Atiquah et al. [64] that kenaf fibre alone, either treated or untreated cannot withstand the high impact loading in a non-hybrid formulation.

Kim et al. [26] worked on the design optimization and manufacture of hybrid glass/carbon fibre–reinforced composite bumper beam for automotive vehicles. In this study, the design of the glass/carbon hybrid composite bumper beam was carried out. The hybrid glass/carbon mat thermoplastics (GCMT) were used to replace the conventional GMT composites. The mechanical properties of GCMT were predicted using classical laminate plate theory (CLPT) and finite element analysis (FEA). The optimal design of the bumper beam was performed with impact stimulation. The result obtained showed enhanced impact performance with glass-carbon hybrid composite bumper beam when tested for automotive bumper application with 33% less weight when compared to the commonly metallic bumper beam. Figure 12 shows the hybrid composite of glass fibre and carbon fibre (Table 5).

5 Conclusion

This paper has explored the mechanical strength of polymer-based bumper beam containing natural fibre in their reinforcement. The effect of natural fibre reinforcement in synthetic polymeric matric composite as bumper beam application was revealed through mechanical testing of the developed composite material. Most of the polymer composites developed for bumper beam materials investigated the mechanical performance under the tensile properties (strength and modulus), flexural properties (strength and modulus) and the impact properties. The assessment from the reviewed articles revealed that natural fibre in itself, cannot deliver the expected mechanical properties needed in the automotive industry (as bumper beam material). Although it satisfies the condition of light weightiness, delivers minimal negative effect on the environment owing to its eco-friendliness, biodegradability and carbon neutrality. The hybridisation of natural fibre (either treated or non-treated) with synthetic fibre produce a synergy to helps improve the mechanical properties, such as the tensile and flexural properties of the polymer composite when compared to using natural fibre alone as reinforcement. However, it still leaves the challenge of inadequate impact properties unresolved. Future research should still focus on the optimising the parameters of importance for better mechanical performance. In addition, the use of natural fibre–reinforced hybrid nanocomposite should be explored for further improvement in the interfacial adhesion of the fibre with the polymer matrix.

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