

Kenaf Fiber Composite in Automotive Industry: An Overview

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Abstract— Recently, natural fibers become attractive to automotive industry as an alternative reinforcement for glass fiber reinforced thermoplastics. Additionally, natural fiber components in the automotive industry can provide numerous advantages compared to synthetic conventional such as reduction of weight and cost, recyclability, renewability and in addition to eco-efficiency. Thus, the use of natural fibers in the automotive industry has shown increasingly stringent environmental criteria. Furthermore, amongst grouped bast fibers such as flax, hemp, jute, ramie, and kenaf; kenaf fiber is seen as a potential natural fiber with robust mechanical properties. Kenaf fiber had been explored to enhance desired mechanical properties as automotive structural components. As usual, natural fibres have some issues and disadvantages when used as reinforcements for polymeric composites. Therefore, some modification performed on fibers such as chemical treatment was carried out. In addition, the use of a coupling agent and a plasticizer can also increase fiber-matrix adhesive bonding.

Keywords— automotive; natural fibre; kenaf fibre; composite

I. INTRODUCTION

Automotive production rate has increased and estimated to reach 76 million cars annually by 2020. For that reason, utilization of bio-composite will be major leads to decrease in weight of vehicles and emissions. And yet, it is estimated that a 25% reduction in car weight would be equivalent to saving 250 million barrels of crude oil [1]. Due to its relevance, the automotive industry transforming the challenges [2] by improving recyclability of newly produced [3] and producing a bio-based product that allows domestic natural resources especially for the body of the cars so that weight reduction can be achieved [4]. For instance, natural fiber composites with thermoplastic and thermoset matrices have been embraced by European car manufacturers and suppliers for door panels, seat backs, headliners, package trays, dashboards and interior parts [5]. Natural fibers reinforced composites are primarily used as low-cost materials that have been used in applications such as automotive interior linings [6].

Natural fibers have gained renewed interest, especially as a glass fiber substitute in automotive industries [7]. Generally, natural fiber could be classified into animal, plant and mineral sources. Among the three types of classification, the natural plant fiber has more potential. According to the plant category, the fibers are extracted such as bast, leaf, seed, wood, fruit and straw (refer Fig. 1). And among that,

bast fibers have low density and higher mechanical properties, hence the possibility to reinforcements in lightweight composite for automotive parts [8].

As seen in Fig. 1, bast fibers derived from flax, hemp, jute, ramie and kenaf. Those are providing automobile part reinforcement due to such drivers as reductions in weight, cost and CO₂ yet as a “green” or ecofriendly [5]. When an eco-design is considered, information on environmental with mechanical behaviour is increasingly being requested too. A significant recent development in this area has been the appearance of bio composites (biopolymers reinforced by plant fibres), which combine good mechanical performance and low environmental impacts [9]. Due to consideration of environmentally friendly material, natural fibre reinforced polymer composites have raised up a great attentions and interests among materials scientists and engineers for their mechanical properties and potential contribution [10]. They are renewable, cheap, completely or partially recyclable and biodegradable. They are high specific strength and modulus materials, low prices, recyclable, easily available in some countries [11].

Currently, natural fibre as composites have two issues that need to be addressed a) resin compatibility, b) water absorption [12]. And for that reason, demand use of physical and chemical treatments/compatibilizer to enhance the adhesion between fibre and matrix [13].

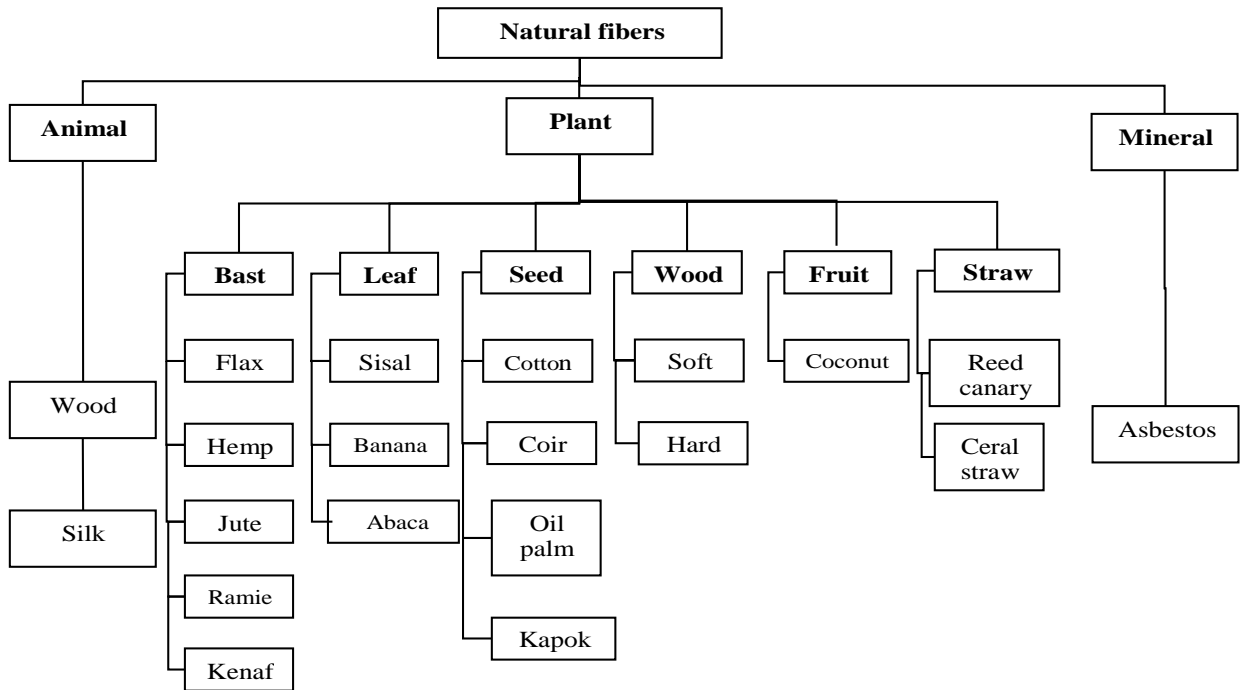


Fig 1. Classification of natural fibers [7]

Natural fibres is the hydrophilic nature of the natural fibres which may lead a fibre degradation [14]. Due to fibre degradation problems like the adhesion or interfacial bonding, treatment and coupling agents could be considered and for the improvement of the properties. The modification of fibres generally involves surface treatment of fibre is designed to facilitate a better adhesion between the fibre and the matrix. The surface treatment can be accompanied by either adding compatibilizers or by chemically treating the fibre. Effective surface treatments not only remove native surface materials and leave behind more active functional groups to promote wetting, but also roughen the surface to some degree, therefore increasing surface area and potentially enhancing mechanical interlocking [15].

Three types of chemical treatments are bleaching, acetylation, and alkali treatment aim to improve the fibre/matrix adhesion by increasing the surface roughness of the natural fibres through of clean the fibre surface from impurities and disrupting the moisture absorption process through of coat of OH groups in fibre [16]. Fibre modification through the alkalisation process can reduce the moisture absorption.

Besides, coupling agents build up chemical and hydrogen bonds which reduce fibre/matrix debonding caused by moisture thus improving the fibre/matrix adhesion and consequently. The manner in which composite materials absorb water depends upon several factors such as temperature, fibre volume fraction, the orientation of reinforcement, permeability nature of fibre, the area of exposed surfaces, diffusivity, the reaction between water and matrix and surface protection [10]. Silane treatment is used to stabilise polymer composites reinforced with natural fibres by treating the fibres to resist against water leaching.

II. MATERIAL AND METHOD

Natural fibre represents an opportunity to partially the environmental impacts by integrating biodegradable filler material [17]. And classified natural fibres into 6 types as follows: bast fibres (flax, hemp, jute, ramie and kenaf) [10], leaf fibres (sisal, banana, abaca), seed fibres (cotton, coir, oil palm and kapok), core fibres (kenaf, hemp and jute), grass and reed fibres (wheat, corn and rice) and all other types (wood and roots) [18]. Amongst them, kenaf (*Hibiscus cannabinus* L. family Malvacea) is one of the strong and stiff agro based fibres and has sufficient potential to reinforce polymers.

Kenaf fibre consists of main cellulose (45-57%) as well as hemicelluloses (21.5%), lignin (8-13 wt%), pectin (3-5 wt%) and waxy substances [19], [4]. Kenaf is a new type of economic crop which currently being grown in Mississippi, Texas, Florida, Arizona and North Carolina. Its excellent fiber strength, kenaf fiber has great potential for use in industrial nonwoven materials and for competing with flax and hemp fibers on the global market [3]. Fig. 2 showed the parts of kenaf stem (core, bast and innerbast). The kenaf bast fiber is known to have the potential as a reinforcing fiber in thermoplastic composites because of its superior toughness and high aspect ratio in comparison to other fibre [19].

The sustainable properties of kenaf include [19], [22]:

- Kenaf plant absorbs carbon dioxide from the air at a significantly high rate
- Kenaf plant absorbs nitrogen and phosphorous from the soil
- It is easily recycled

Due to the light weight of kenaf fiber composites, the fuel consumption and emission are improved especially in automotive industries.

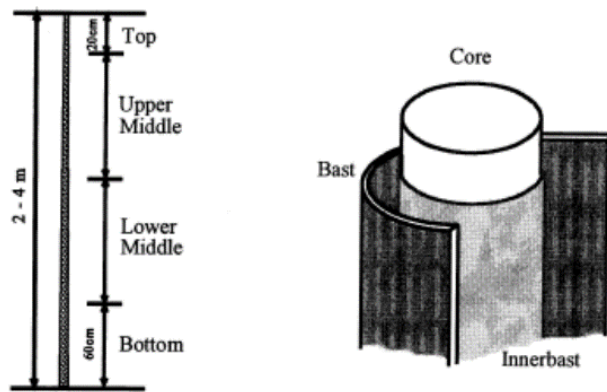


Fig. 2 Sampling positions and parts of kenaf stems [20], [21]



Fig. 3 (a) Kenaf core (b) Kenaf bast

TABLE I
FIBRE DIMENSIONS OF KENAF FIBRE

Kenaf Fibre	Length (mm)	Diameter (μm)	Lumen Diameter (μm)	Cell Wall Thickness (μm)
Bast fibre	2.32	21.9 ± 4.6	11.9 ± 3.4	4.2 ± 0.8
Core fibre	0.74	22.2 ± 4.5	13.2 ± 3.6	4.3 ± 0.7

Table 1 showed the dimension of kenaf fiber for the outer part (bast fiber) and an inner part (core fiber). Both parts showed good mechanical properties even with a different dimension. Comparing with other types of plant fiber, kenaf fiber becomes more potential because of both part of kenaf; bast and core give a good mechanical performance. Different with certain fiber, only the outer part give a good performance and some fibers only the inner part that can be used. Considering this advantages, kenaf tends to be growth as another potential natural fiber that can be substitute glass fiber in the automotive industry.

TABLE III
COMPARISON PROPERTIES KENAF AND GLASS FIBER [4]

Properties	Kenaf Fiber	Glass Fiber
Density	1.4	2.5
Strength	284-800	2000-3000
Modulus (GPa)	21-60	70
Elongation at break	1.6	2.5

Table 2 showed the comparative properties of density, strength, modulus and elongation at break between kenaf fiber and glass fiber. Despite this, glass fiber showed a dominant value for each property yet extensively applied in the automotive component. Apparently, kenaf fiber has some advantages over glass fiber in terms of cost, density, renewability, recyclability, abrasiveness and

biodegradability. To enhance the properties of composites, it depends on fiber matrix interface, and this contributes to transfer stress from the matrix to the fiber.

III. RESULTS AND DISCUSSION

The automotive industry uses of natural fiber reinforcement, which proven that viable in a number of automotive parts. Currently, flax, sisal, and hemp are processed into door cladding, seatback linings and floor panels [5] (refer Fig. 5). Prior to this, proper material selection of natural fibers and careful design should be count into in order to achieve good impact behavior especially the main structure like bumper beam for absorbing the energy of collisions [4].

Several well-known compositions of kenaf fiber with matrix and some additive can meet the automotive requirement for interior and exterior parts as long as non-structural and semi-structural applications. Refer Table 4, twisted kenaf fiber [4] showed the performance of beams increased with hybrid kenaf/glass reinforced material. This proved that it could be utilized in automotive structural components. A twisted kenaf hybrid material could be improved by optimizing the structural parameters such as thickness, beam curvature and strengthening ribs. The application in automotive parts as bumper beams and front end modules.



Fig. 4 Flax, hemp, sisal, wool and other natural fibers are used to make 50 Mercedes-Benz E-Class components [5]

TABLE III
TYPES OF FIBER AND CURRENT APPLICATION [5]

Types of Fiber	Application
Coconut fiber	Seat bottoms, back cushions and head restraints
Cotton	Sound proofing
Wood fiber	Seatback cushion, sliding door inserts for the Ford Freestar
Abaca	Underfloor body panels
Kenaf and flax mixture	Package trays and door panel inserts for Saturn L300s European-market Opel Vectras
Wood fiber	Seatbacks for the Cadillac DeVille and in the cargo area floor of the GMC Envoy and Chevrolet TrailBlazer
Corn	Ford mounts Goodyear tires
Kenaf	Lexus package shelves



Fig. 5 Modern door inner trim panels are molded using mats of 60% natural fiber in a Baypreg® polyurethane resin (Courtesy of Bayer Polymers) [23]

TABLE IVV
KENAF FIBER COMPOSITION

Composition	Findings
Twisted kenaf fiber LFRT (TKLFRT) and LFRT	Performance of beams increased
Kenaf with PFA poly(furfuryl alcohol) bio-resin	Good damping behavior
Kenaf and ramie fiber nonwovens. With binder: PVA and Acrylic copolymer	Enhance the performance composite thermal and mechanical properties
Kenaf with PLA	Good aesthetics and strength

The composite of bast kenaf with PFA poly(furfuryl alcohol) bio-resin [24] possess good damping behavior as shown by the DMA analysis [28], which shows the ability of the green composites to use in automotive industry. This ability proved that natural fiber been utilized in the automotive industry.

There is not only kenaf with the matrix, but there's also a nonwoven kenaf and ramie fiber been utilize with a binder so-called PVA and the acrylic copolymer [19]. This composition had been enhancing the performance and the composite thermal-mechanical properties. Acrylic copolymer binder well-known be able to cross-link at high temperatures. Besides that, from the padding times, it

showed significantly influenced the tensile properties of the acrylic-copolymer bonded composite. The example in the automotive interior or exterior application is a headliner.

Another lightweight application in the automotive industry by kenaf which is the matrix with PLA [25]. Biopolymer PLA provides good aesthetics and strength and easy process ability in most equipment. PLA is brittle, and it needs modification to improve the mechanical and thermal properties to achieve a better adhesion between the fiber and the matrix. It was found that standard PLA resins are suitable for the manufacture of kenaf fiber reinforced laminated bio-composites with useful engineering properties.

TABLE V
PROPERTIES OF TYPICAL THERMOSET POLYMERS FOR NATURAL FIBER COMPOSITES [7]

Property	Polyester Resin	Vinylester Resin	Epoxy
Density (g/cc)	1.2-1.5	1.2-1.4	1.1-1.4
Elastic Modulus (GPa)	2-4.5	3.1-3.8	3-6
Tensile Strength (MPa)	40-90	69-83	35-100
Compressive Strength (MPa)	90-250	100	100-200
Elongation (%)	2	4-7	1-6
Cure Shrinkage (%)	4-8	-	1-2
Water Absorption (24 h @ 20°C)	0.1-0.3	0.1	0.1-0.4
Izod Impact, Notched (J/cm)	0.15-3.2	2.5	0.3

TABLE VI
PROPERTIES OF TYPICAL THERMOPLASTIC POLYMERS USED IN NATURAL FIBER COMPOSITE FABRICATION*

Property	PP	LDPE	HDPE	PS	Nylon 6	Nylon 6,6
Density (g/cm ³)	0.899-0.920	0.910-0.925	0.94-0.96	1.04-1.06	1.12-1.14	1.13-1.15
Water Absorption -24 hours (%)	0.01-0.02	< 0.015	0.01-0.2	0.03-0.10	1.3-1.8	1.0-1.6
T _g (°C)	-10 to -23	-125	-133 to -100	-	48	80
T _m (°C)	160-176	105-116	120-140	110-135	215	250-269
Heat Deflectionm Temp (°C)	50-63	32-50	43-60	Max. 220	56-80	75-90
Coefficient of Thermal Expansion (mm/mm/ °C × 10 ⁵)	6.8-13.5	10	12-13	6-8	8-8.6	7.2-9
Tensile Strength (MPa)	26-41.4	40-78	14.5-38	25-69	43-79	12.4-94
Elastic Modulus (GPa)	0.95-1.77	0.055-0.38	0.4-1.5	4-5	2.9	2.5-3.9
Elongation (%)	15-700	90-800	2.0-130	1-2.5	20-150	35-> 300
Izod Impact Strength (J/m)	21.4-267	> 854	26.7-1,068	1.1	42.7-160	16-654

*Selected data obtained from [26]; LDPE = low-density polyethylene; HDPE = high-density polyethylene; PP = polypropylene; PS = polystyrene

There are two types of blending with natural fiber composite matrix that been used to enhance the properties of the fiber. Refer to Table 5 and 6, thermoset matrix been used has a good mechanical performance. Contrast to the thermoplastic matrix showed advantages in weight reduction and importantly recyclability. Both matrices have pros and cons depends on application requirement because each natural fiber has different properties. Hence, the different fibers need different blending type to achieve the needed properties. For example, to fullfill automotive application that needs higher tensile strength so we should blend fiber with thermoset matrix because it performs high tensile strength rather than a thermoplastic matrix. But, it showed a contrast izod impact strength between thermoset and thermoplastic matrix.

Fig. 6 shows natural fiber mat that been processed into a door inner panel blending with thermoplastic matrix (PP). The composition of the part consist of material specifics:

1,600 g/m², 50% kenaf and blend with 50% polypropylene. The mats are heated to melt the thermoplastic fibres and pressed into the desired shape in a cold press, and the parts are sensitive to temperature. Alternatively, non-wovens based on natural fibres are coated with thermosets such as epoxy or polyurethane resins is generated by curing the resin under heat in a hot press (Fig. 7). The mats have to be moulded immediately after impregnation because of the high reactivity of the thermoset.

IV. CONCLUSION

In conclusion, annual production of the automotive industry will increase constantly. Therefore, apparently, there is a critical issue for our next decade with the biodegradable or recyclability materials. For that reason, the automotive industry is growing rapidly due to natural fiber reinforced composites. Compared to natural fiber, glass fiber had good performance in terms of physical and mechanical

properties but the low cost, processing advantages and low density becoming as a value added to the natural fiber's performance for automotive parts. Over glass fiber, natural fiber consuming less energy during the natural fiber manufacture and had been potential in lower mass structures. The availability of natural fibers like kenaf have some advantages over traditional reinforcement materials such as glass fiber and have a potential to meet requirement new automobile design. In order to fulfill application in automotive structures [27], a few modification in design, fiber treatment, the use of the additive, material selection and method for production are necessary.



(b)



(a)

Fig. 6 (a) Natural fiber mat (b) Door inner panel



Fig. 7 Heated and molded mat into door panel

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