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Review of kenaf fiber reinforced polymer composites

Summary — General characteristics of kenaf fibers and mechanical properties of its polymer composites (dependently on the environmental conditions) as well as applications directions of such materials have been presented.
Key words: natural fibers, kenaf, polymer composites, mechanical properties, effect of environment, applications.

KOMPOZYTY POLIMEROWE WZMACNIANE WŁÓKNAMI KENAFU — PRZEGLĄD LITERATURY

Streszczenie — Przedstawiono ogólną charakterystykę włókien kenafu, właściwości mechaniczne zawierających je kompozytów polimerowych z uwzględnieniem wpływu warunków środowiska, a także kierunki zastosowania tego rodzaju materiałów.
Słowa kluczowe: naturalne włókna, kenaf, kompozyty polimerowe, właściwości mechaniczne, wpływ środowiska, zastosowanie.

Kenaf (*Hibiscus cannabinus*), originating from Africa, has traditionally been a source of bast fiber in India and China, which together account for more than 75 percent of worldwide kenaf production. In the U. S., South Texas and Eastern North Carolina supply relatively small amounts of kenaf that shows good potential as a raw material for use in composite products. Research on kenaf first began in the United States in 1957 and has continued sporadically since that time [1]. An attractive feature of kenaf is that up to 40 percent of the stalk yields usable fiber, roughly twice that of jute, hemp or flax, which makes the fiber quite economical. Also, the plant can grow from seed to heights of 3.6 m to 4.3 m (12 ft to 14 ft) in five to six months [2].

Kenaf fibers come from the bast of the plant, and have been widely used as a jute-like material in the past. A diagram of the classification of various fibers is presented in Fig. 1 [3]. Asian kenaf is cultivated predomi-

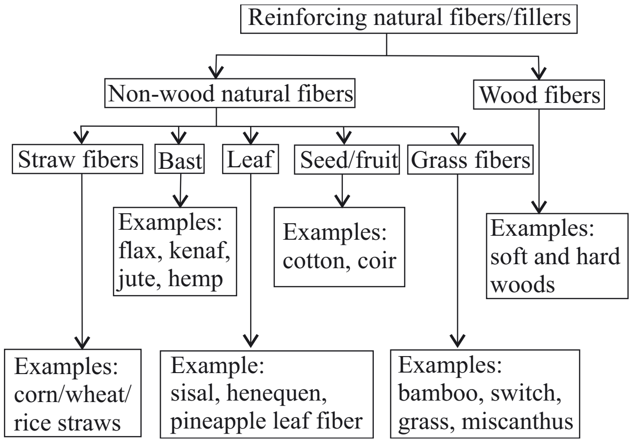

Figure 1. Classification of natural fibers [3]

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nantly for the fiber, and soaking of the stalks during the retting process, combined with manual removal of the fibers, is believed to result in superior reinforcement quality. Comparatively, U. S. kenaf producers, including Kenaf Industries of South Texas (Raymondville, Texas) and Greene Natural Fibers (Snow Hill, N. C.), use field retting and mechanical separation. The kenaf core materials, which can be used as absorbents and animal bedding, have more ready markets. While both companies supply some fiber to the composites market, they also are pursuing other applications, such as extruded plastic fencing and decking, and furniture padding [4, 5]. Today kenaf fibers as reinforcement of composite material arouse researches' interest.

GENERAL CHARACTERIZATION OF KENAF FIBERS

Raw kenaf fiber obtained from outer bark, is actually a bundle of lignocellulosic fibers. The fiber bundle size depends on the number of ultimate cells in each bundle. Most lignin is present between the ultimate cells. Kenaf contains approximately 0.7 % of cellulose, 21.6 % of lignin and pectin, and other components [6]. Lignin must be extracted to separate the fibers [7, 8]. Generally speaking, kenaf fibers are shorter at the bottom of the stalk and longer at the top. The increase in length from the bottom to the top was not gradual, but S-shaped [9]. There is more variation of the fiber length at the top of the stalk. Also, the longest fibers are located at the top. On the other hand, different parts of a plant have different chemical and physical properties. That is, the chemical compositions and fiber properties of plant tissue taken from the roots, stem, trunk and leaves are different and are also different at different stages of the growing season [10]. Fiber length increases in the early part of the growing cycle, and then decreases again for the plant matured [11]. This may be an advantage in harvesting of the fiber before the plant matures.

MECHANICAL PROPERTIES OF KENAF FIBERS AND COMPOSITES WITH THEM

The tensile properties of kenaf single fibers have been reported in [12]. Kenaf single fibers exhibit tensile strength and tensile modulus of 11.91 GPa and 60 GPa, respectively. Kenaf fibers have been used as reinforcement in thermoplastics such as polyethylene [13], polypropylene [10, 14—17] and thermosetting resins like polyester [18] and polybenzoxazine [19]. Unidirectional (UD) composites of polyethylene and kenaf fibers have been studied. The fibers were untreated and coupling agent has been used. Tensile properties of the UD composites have been tensile tested and it was reported that kenaf fibers enhanced the tensile properties of polyethylene. Indeed, the tensile modulus of the UD composite with 57 vol. % of fibers was 7 times as much as tensile modulus of polyethylene, and its tensile strength was 4 times higher.

Many research projects have been carried out to determine the mechanical properties of kenaf fibers reinforced polypropylene [10, 14, 16, 17, 20] and described PP composities with high kenaf fiber content [21]. The purpose was to find an alternative to wood particles, and low or medium density hardboards. The plasticization is the process used to reach this high fiber content. The study reports much higher flexural properties of kenaf/PP containing 85 % or 60 % of kenaf if compared with wood fiber boards.

The effect of the maleic anhydride (MAH) as a coupling agent has been intensively investigated [15—17] and significant increase in flexural and tensile strengths was reported for maleated polypropylene (2 wt. % of MAH) [19]. However, no significant difference can be observed between kenaf fiber reinforced polypropylene and kenaf fiber reinforced maleated polypropylene (MA PP) regarding the tensile and flexural moduli. The tensile and flexural moduli increase with increasing fiber content. The positive effect of the maleic anhydride agent on the bonding of kenaf/PP has been reported. Besides, it was shown that the specific tensile and flexural moduli of kenaf/PP composite with 50 wt. % of fiber content (7.2 and 7.3 GPa, respectively) have comparable values as for the glass fiber/PP composite with 40 wt. % of fiber content (7.3 and 5 GPa, respectively). The papers [14] and [20] also reported better adhesion between kenaf fibers and PP in the presence of MAH.

Karnani [17] focused their research on the improvement of kenaf/PP interfacial adhesion. Maleic anhydride was used as a coupling agent and kenaf fibers were treated with silane (2 wt. % in water). SEM observations of kenaf/MAPP composite show better wettability of the fibers in comparison with kenaf/PP composites. At 20 wt. % of fiber content, the tensile strength and modulus increase from 26.9 MPa/2.7 GPa (PP without MAH) to 38.1 MPa/3.2 GPa (PP with 5 % of MAH). There was also reported a significant mechanical improvement after surface modification of kenaf fibers with silane (42.5 MPa/3.3 GPa at 20 wt. % of fiber content).

Selections of four different polyester resins have been used in composites containing kenaf fibers [18]. One of them was a conventional unsaturated polyester, the others have been modified to improve the adhesion to natural fibers (*e.g.* make them more polar). An alkali surface treatment of the fiber was done with use of 6 % NaOH solution. Composites with 60 vol. % fibers content have been produced and tested in bending. Modified polyester exhibited better flexural properties.

Nishino [22] investigated the mechanical properties of a composite made of kenaf fiber and poly-L-lactic acid (PLLA). Young's modulus (6.3 GPa) and tensile strength (62 MPa) of the kenaf/PLLA composite (fiber content 70 vol. %) were comparable to those of traditional composites. The effects of the molecular weight of PLLA, and orientation of the kenaf fibers in the sheet on the mechanical properties of the composite were also investigated. This composite showed superior mechanical and thermal properties based on the strong interactions between the kenaf fibers and PLLA matrix.

Both the anisotropic and quasi-isotropic composites could be obtained by lamination of kenaf sheets with preferential orientation of the fiber. Table 1 shows a comparison of literature data concerning mechanical properties of kenaf *versus E* glass (low alkali borosilicate glass), indicating that kenaf fiber can be a good reinforcement candidate for high performance biodegradable polymer composites.

T a b l e 1. Kenaf fibers and E-glass fibers properties [23]

Fibers	Properties						
	Density g/cm^3	Tensile strength, MPa	*E*-modulus GPa	Specific (*E*/density)	Elongation at failure, %	Cellulose/ Lignin, %	Microfibril angle*), deg.
E-glass	2.6	2000	76	29	2.6	—	—
Kenaf	1.5	350—600	40	27	0.33—0.88	75—90	9—15

*) The term microfibril angle (MFA) in wood science refers to the angle between the direction of the helical windings of cellulose microfibrils in the secondary cell wall of fibers and tracheids and the long axis of cell. Technologically, it is usually applied to the orientation of cellulose microfibrils in the S2 layer that makes up the greatest proportion of the wall thickness, since it is this factor which most affects the physical properties of wood (see Barnett J. R., Bonham V. A.: "Cellulose microfibril angle in the cell wall of wood fibers" Biological Reviews 2004, Cambridge University Press, p. 461—471).

Unsaturated four different polyester resin formulations A, B, C and D were used for kenaf fibers composites [18]. The molecular structure of polyester B was based on polyester A, modified to make it more polar in nature to better react with the surface of natural fibers. Polyester resin A was a conventional unsaturated polyester resin in styrene monomer, Crystic 2-406PA. Composite with 60 vol. % fibers content have been produced and tested in bending. One of the composites, reinforced with 56 vol. % of fiber content, had respectively almost 2 and 3 times higher flexural modulus and strength in comparison to an unmodified composite with higher fiber content (63 vol. %). A moisture absorption test showed a weight increase divided by 3 if compared unmodified (±60 %) and modified polyester composites (±20 %). The biodegradable polymer poly-L-lactic (PLLA) was used to produce kenaf fiber reinforced composites with a 70 vol. % of fiber content [19]. Interesting tensile properties were reported and were attributed to the strong bonding among kenaf fibers and PLLA.

UD composites with 20 wt. % of kenaf fiber using polybenzoxazine (PBZX) resin matrix produced and investigated by authors of [19] were tested in bending and it was shown that they had lower flexural strength but higher flexural modulus if compared to the composites made of unsaturated polyester resin.

USE OF KENAF

Today, one of the major values of kenaf is its use in some countries in a limited scale, in the production of pulp and paper as substitute of wood [2]. Kenaf offers many significant advantages in this application, including a short harvest period and no chlorine bleaching. Kenaf paper is stronger, whiter, longer lasting, more resistant to yellowing, and it has better ink adherence than wood pulp paper [24]. Kenaf leaves and stems have a potential as livestock feed. The breakthroughs and advances in environmental technology have resulted, among others, from intensive research in the kenaf industry. Here are some examples: natural fiber/plastic compounds, construction and housing industry, food packaging, automotive industry, oil and chemical absorbents, animal bedding and poultry litter and soil-free potting mix.

With the increasing applications of composites with kenaf fibers more and more assessment is needed to get a better understanding of interfacial bonding of the materials. The environmental conditions, such as high moisture and high temperature, can limit the usefulness of polymer composites by deterioration of their mechanical properties during service.

Modiboo [25] investigated the moisture imbibition by alkalized kenaf fiber using moisture sorption method and he found that these fibers had excellent specific properties and had the potential of being outstanding reinforcing fillers in plastics industry. Alkalized fiber composites have higher elastic storage modulus E′ and lower damping tan (Aziz [26]), and the standard laminating polyester resins are suitable for manufacturing of natural fiber composites with useful engineering properties. Huda [27] evaluated the mechanical and thermal properties of alkalized or silane treated kenaf fibers reinforced polylactic acid. It was found that treated fiber composite offered superior mechanical properties.

CONCLUSIONS

Kenaf fibers have been investigated and very good mechanical properties have been reported. The specific stiffness is comparable to the glass fiber ones, and the price is 3 to 2 times lower than of the glass fibers; the elongation at failure is also comparable to that one of glass fibers. Thermoplastic and thermosetting matrices have been used to produce kenaf fibers reinforced composites. A positive effect of MAH on the bonding and the wettability of kenaf fibers/polypropylene was reported. The pre-treatment of the fibers improves the mechanical properties of the composite. The standard laminating polyester resins are suitable for manufacturing of kenaf fiber reinforced laminated bio-composites with useful engineering properties. An information concerning specific combinations of environmental effects (RH and temperature) on mechanical properties of kenaf fibers is very difficult to be found in literature.

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