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A review on physico-mechanical properties of bast fibre reinforced polymer composites

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ABSTRACT

In the last two decades, the fibre reinforced composites have attracted substantial importance as a potential structural material for residential housing construction and is largely found in nonstructural housing components. Research and development efforts are being made to use bast fibres (comes under the classification of plant fibres) as reinforcement for the automotive and building industries. Bast fibres, a relatively new group of environmental friendly materials are in considerable demand in recent years by unifying technological, economical and ecological aspects. Bast fibres are receiving increasing attention as reinforcement in polymeric materials in composites due to the shortage and environmental hazardous of non-renewable resources. The use of bast fibres offer a number of advantages, since they are derived from a renewable resource, require low energy inputs in their manufacture, and can be disposed of at the end of their life-cycle by composting. Further the bast fibre reinforced polymer composites is of low density and cost as well as having satisfactory mechanical properties. The aim of this paper is to provide a consolidated report of the researches in the field of different bast fibres (banana, flax, hemp, jute, kenaf and ramie) reinforced polymer composite including the effect of chemical treatment with its physico-mechanical properties and their applications.

1. Introduction

Plant fibres often referred to as vegetable fibres, plays an increasing role in our day to day life. Mankind has been strongly dependent on plant fibres for all kinds of purposes. For example, fibrous materials such as wood and bamboo have found particular application in construction. Fibres from banana, coir, jute, pineapple and sisal have been used in aerospace, automotive [106], building [22,47,59,67] and packaging industries [6,85,102]. The most interesting aspect about plant fibres is their positive environmental impact. A wide variety of fibres has also been used for production of textiles, paper and fibre boards. The mechanical properties of plant fibres depend on their physical, chemical and morphological properties such as the fibre orientation, crystal structure and diameter/cross-sectional area of the fibre [12]. The strength of plant fibres is attributed to the rigidity and high molecular weight of cellulose chains, intermolecular and intramolecular hydrogen bonding, fibrillar and the crystalline structure of the fibres [64].

Plant fibres are widely used as reinforcements in fibre-cement building product [17]. The utilization of these fibres as reinforcement for cement products falls into two well-defined areas: Firstly, low cost, low performance materials made by labour intensive techniques and secondly, high performance materials made by conventional fibre - cement technology. The major advantages of plant fibres over traditional reinforcing materials such as glass fibres, talc and mica are: acceptable specific strength properties, light in weight, serving as an excellent reinforcing agent for plastics, less damage to processing equipment, less expensive, lower energy consumption, carbon dioxide sequestration, environmental friendly in nature, good relative mechanical properties and good thermal properties. Another important advantage of plant fibres is that they are relatively abundant in nature and therefore, can be obtained from renewable resources. They can also be recycled and it produce non-toxic fumes, when the fibres are subjected to heat. The main disadvantages of plant fibres are: their low permissible processing temperatures, their tendency to form clumps and their hydrophilic nature [53,63,85].

Plant fibres played an important role in the composite industry and it can be classified according to their origin. The types of plant fibre include bast, seed and leaf fibres. *Bast fibres* are collected from the inner bark or bast surrounding the stem of the plant. These fibres have higher tensile strength than other fibres. Therefore, these fibres are used for durable yarn, fabric, packaging and paper industries. e.g. banana, flax, hemp, jute, kenaf, ramie, etc. *Leaf fibres* are collected from leaves, e.g. sisal, banana, abaca, etc. *Seed fibres* are collected from seeds or seed cases. e.g. cotton, coir, oil palm, kapok, etc.

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1.1. Bast fibre as reinforcing material

The recent growth in environmental awareness and governmental regulations in the use of bast fibres as reinforcement by replacing the energy intensive synthetic fibre received greater attention in the composite material manufacturing industries [12,47,74]. The attractive features of the bast fibres like banana [76] and jute [84] due to their low cost, light weight and high specific modulus, attracted many scientists to use these fibres as an alternative synthetic fibres as a reinforcement material in the composite material preparation [101,113,23,28,41,50]. In the last few decades, mankind used glass fibres as reinforcement for polymer composite; however it has some disadvantages such as non-renewable and cause problems with respect to health and safety, and also cannot be thermally recycled by incineration [94]. Ecological attention has resulted in a renewed attraction in bast fibres, attracting alternative glass fibres. The use of bast fibres, derived from annually renewable resources, as reinforcing fibres in composites, provides positive environmental benefits with respect to ultimate disposability and raw material utilization [52,82]. In order to improve the properties of composites, bast reinforcing fibres can be modified by physical and chemical methods [18,100].

1.2. Composition and Properties of Bast fibres

The chemical composition of bast fibres mainly comprised of cellulose, hemicellulose and lignin. Table 1 illustrates the chemical composition of some bast fibres [62]. The proportion of these chemical compositions depends on the age, conditions of growth, fibre source and method of fibre extraction. Bast fibres have 60–75% cellulose, which is the main structural component, provides the tensile strength and stability to the plant cell walls and the fibre. The remaining constituents of bast fibres are hemicellulose, lignin, pectin and ash. The amount of cellulose in a fibre influences the properties, economics of fibre production and the utility of the fibre for various applications [73]. Many research and engineering interest has been shifting from non-biodegradable synthetic fibre materials to biodegradable plant fibre-reinforced materials. The main reason for interest in these fibres is due to high specific strength, high modulus, lightweight and affordable cost of the reinforcing fibres [103]. Plant fibres are composites of hollow cellulose fibrils held together by a lignin and hemicellulose matrix. Each fibril consisting of a complex layered structure and a thin primary wall encircling, a thick secondary wall. The mechanical properties of the fibre are determined by the secondary wall, which is made up of three layers and the thick middle layer (consists of a series of helically wound cellular microfibrils formed from long chain cellulose molecules). Also the mechanical properties of these fibres are mainly dependent on the cellulose content in the fibre, the degree of polymerization of the cellulose and the microfibril angle [77,86]. The microfibril angle is the angle between the fibre axis and the microfibrils. All plant fibres are strongly hydrophilic due to the presence of hydroxyl groups in the cellulose molecules [86]. Fibres having high cellulose content and low microfibrillar angle possess high tensile strength.

Mwaikambo [61] described that the tensile strength and Young's modulus of jute fibre bundles depends on the physical characteristics of its internal structure such as the cellulose content, changes in the crystalline region content expressed in terms of crystallinity index, and micro-fibril angle. According to Bledzki and Gassan [12], the secondary wall contributes to up to 70% of the fibre Young's modulus, therefore higher cellulose content will result in higher tensile modulus.

Table 1
Chemical compositions of bast fibres [62].

Fibre type	Cellulose	Hemicellulose	Lignin	Pectin
Banana	60–65	6–19	5–10	3–5
Flax	60–81	14–19	2–3	0.9
Hemp	70–92	18–22	3–5	0.9
Jute	51–84	12–20	5–13	0.2
Kenaf	44–57	21	15–19	2
Ramie	68–76	13–15	0.6–1	1.9–2

2. Bast fibre reinforced polymer composites

In the last two decades many research scientists are concentrated on bast fibre composites, which are blended with polymer resins. The bast fibre reinforced composites have attracted substantial importance as a potential structural material for residential housing construction, packaging and furniture industries. The banana, flax, hemp, jute, kenaf and ramie fibre reinforced polymer composites are discussed in detail as follows:

2.1. Banana fibre reinforced polymer composites

Banana fibre at present is a waste product of banana cultivation. Moreover, without any additional cost input, banana fibre can be obtained in bulk quantity. The banana is extensively available throughout the tropics, which is present in the outer portion which covers the central stem region of the tree. The stem is really formed by the long stiff sheathy leaf bases which are rolled around one another forming an aerial pseudostem called shaft which is mainly used for the fibre extraction.

Gonzalez – Chi et al. [29] prepared thermoplastic composites reinforced with banana stem, leaf and pinzote fibre, and this composite are stiffer than HDPE (high density polyethylene). In addition to that, earlier studies reported that banana fibre is found to be a good reinforcement in polyester resin [76]. Due to improved fibre/matrix interaction banana fibre/eco-polyester composites showed a higher flexural strength and modulus (Lina [49]).

Ramesh et al. [80] designed the banana fibre reinforced epoxy composites with different fibre volume fractions. They found that the prepared composites have maximum mechanical strength, and suggested that it can be used as an alternate material for conventional fibre reinforced polymer composites. The alkali treatment of banana fibre has improved the mechanical properties like tensile, flexural and impact strength of both the epoxy/vinyl ester and hybrid composite when compared to the untreated one [89]. The physical properties such as tensile strengths and flexural strengths of low density polyethylene (LDPE)-banana fibre reinforced composites is increased while using LDPE 10–30% of the fibre and then started to decrease gradually [20]. Finally they concluded that banana fibre can be used as reinforced agent successfully in the composite industry as a sustainable building material.

Idicula et al. [36] analysed that chemical treatment using NaOH and polystyrene maleic anhydride (PSMA) increases both density and thermal conductivity of banana fibre composite. Also they found that, by this treatment, contact between the fibre and matrix were very high.

Pothan Laly et al. [75] found that the volume fraction of the short banana fibre influences the dynamic mechanical properties of the composites. The effect of alkali Treatment of Banana-Glass Fibre Hybrid Composites improved the mechanical properties of the composite [88].

Bhoopathi et al. [9] observed that the banana-hemp-glass fibres reinforced hybrid epoxy composites exhibited superior mechanical properties and used as an alternate for conventional materials. The interfacial characteristics, internal structures, fibre failure mode and fractured surfaces are analyzed by using scanning electron microscopy.

Pothan et al. [76] investigated the mechanical, failure and aging characteristics of short banana fibre reinforced polyester composites with reference to effect of fibre length and fibre content. According to their findings, tensile strength shows a maximum value at 30 mm fibre length, impact strength at 40 mm, flexural strength and modulus were