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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 maximum at 20 mm of fibre length. Silane treatment of banana fibre composite showed 28% and 13% increase of tensile strength and flexural strength respectively. The improvement in flexural strength is noticed of about 13% with a fibre content of 10% and increase of impact strength about 341% with a fibre content of 40%. The composite specimens are subjected to thermal aging, water aging and exposed to sun is about 6%, 32% and 9% respectively.

Zain et al. [112] evaluated the effect of aging and nonaging characteristics on mechanical properties of banana pseudostem fibre reinforced polymer composites. After applying the aging treatment, the flexural and impact test results showed that the prepared composite material's strength was improved and tensile test result showed a reverse effect of the composites.

2.2. Flax fibre reinforced polymer composites

Flax (Linen) fibre is obtained from the stalk of a plant which is from 80 to 120 cm high and contains 70% of cellulose. The influence of retting on the properties of single flax fibres and short flax fibres/ polypropylene composites has been studied. The tensile properties of single fibres increased with the degree of retting for both Young's modulus and strength at break. The mechanical properties of short fibres reinforced composites were increased with a high degree of retting (Nicolas Martin et al. [65]).

Xue Li et al. [108] prepared the flax fibre high density polyethylene (HDPE) composites by using injection moulding techniques. The study showed that when increasing the fibre content of flax fibre in the prepared composite material results an increase in the tensile and flexural strength, as well as flexural modulus. Influence of various fibre parameters such as lignin content, pectin content and degree of polymerisation on the Flax fibre reinforced epoxy composite properties was investigated. Surface modifications of fibre by alkali, silane and isocyanate treatment leads to significant influence on the mechanical properties of the composites. The modified fibre surface was characterised by SEM, AFM, TGA and DSC measurements [27].

Daohong Zhang et al. [19] investigated the influence of relative humidity (RH) in composite fabrication on the interfacial shear strength and flexural properties of flax/unsaturated polyester composites. The interfacial shear strength of the flax/unsaturated polyester composite started to drop sharply at 70% RH and ended up with a more than six fold reduction at 90% RH. The results highlighted the importance for air conditioning and dehumidification in natural fibre composite fabrication facilities.

Cantero et al. [15] studied the effects of fibre treatment on wettability and mechanical properties of flax/polypropylene composites. Before the preparation of composite material, the three different treatments (such as maleic anhydride MA, maleic unhydride – polypropylene copolymer MAPP and vinyl trimethoxysilane VTMO) were applied to the fibre to reduce the polar component of the surface energy of the fibre. Resulting composite containing MAPP (10 wt%) treated fibre showed the highest flexural and tensile strength compared with the MA and VTMO treated fibre.

Oksman [68] prepared the high quality Arctic flax fibre epoxy composites by means of resin transfer moulding processing techniques and these composite's mechanical properties were compared to glass fibre composites, traditionally retted VD flax fibre composites and pure epoxy composites. The results showed that high quality Arctic flax epoxy has higher stiffness (40 GPa) and tensile strength (280 MPa) when compared to pure epoxy composites (stiffness 3.2 GPa and tensile strength 80 MPa).

Van de Weyenberg et al. [105] investigated the consequences of optimizing parameters (time and NaOH conc.) for the fabrication of unidirectional flax fibre epoxy composites. They measured the transverse Strength and transverse modulus of about 250% and 300% respectively by the chemical treatment of fibre. Also the longitudinal properties of unidirectional composites showed (both modulus and strength) improvement with 40% or more.

Munoz and Garcia [56] studied the effect of water absorption on the mechanical properties of flax fibre reinforced bioepoxy composites by the immersion of sample in water at room temperature. The authors observed that swelling of flax fibres in the composite material has higher tensile strength compared to dried sample. Flexural modulus and tensile modulus was found to decrease with increase of water absorption characteristics. These composites have potential use in outdoor application due to exposure of water absorption not affecting negatively their mechanical properties.

Xia et al. [107] modified the flax fibre surface by alkali treatment, corona discharge, maleic anhydride grafting and amino propyl triethoxysilane treatment. Also the authors fabricated the high toughness polylactic acid (PLA) flax treated fibre composites. The mechanical properties of this composites were higher than PLA untreated flax fibre composites. The results indicated that the chemical treatment gave a roughness to fibre surface and give more contacting points to improve the mechanical interlocking between PLA and fibre.

Karsli and Aytac [43] characterized the properties of alkali treated flax fibre reinforced poly(lactic acid)/poly carbonate (PLA/PC) composites by conducting tensile test, dynamic mechanical analysis(DMA), differential scanning calorimetry(DSC) and scanning electron microscopy(SEM) analysis. The result revealed that superior tensile strength, maximum crystallinity value and good interfacial bonding (by SEM analysis) with PLA/PC matrix was obtained at 2%NaOH treated flax fibres. DMA also supported the results of tensile test.

Zhang et al. [114] studied the influence of flax polypropylene (PP) fibre blending ratio, moulding temperature, moulding time on the mechanical properties of flax fibre PP composites. From the experimental observations, the flax fibres reinforced PP bond has maximum tensile and bending strength, with 50% weight of flax fibres at moulding temperature, of 181 °C and moulding time for about 48 min.

2.3. Hemp fibre polymer composites

Hemp fibres are more suitable for making reinforcement in composite material. Investigation of tensile fractured surface reveals that the fibre delamination, fibre tensile fracture and poor interfacial adhesion between hemp fibre and HDPE matrix are mainly responsible for poor tensile and flexural strength of the hemp fibre reinforced virgin recycled HDPE matrix composites [97].

Asim Shahzad [5] evaluated the various physical and mechanical properties of hemp fibres to assess their suitability for use as reinforcement in composite materials. In his study he found that the decomposition of hemicelluloses and pectin occurred at around 260 °C and that of cellulose occurred at around 360 °C. The treatment of hemp fibres with isocyanatoethyl methacrylate, using dibutyltin dilaurate as a catalyst significantly increased the tensile, flexural strength, and flexural modulus of the resulting hemp – unsaturated polyester composites and yet decreased the impact strength of the composites [99].

Bhoopathi et al. [8] fabricated and investigated the mechanical properties of NaOH treated and hemp-banana-glass fibres reinforced hybrid composites. From their experimental results, it has been noted that the treated hemp-banana-glass fibres reinforced hybrid epoxy composites exhibited superior properties and used as an alternate material for synthetic fibre reinforced composite materials. Morphological studies are carried out to analyze the interfacial characteristics, internal structures, fibre failure mode and fractured surfaces by using scanning electron microscopy (SEM) analysis. From the SEM micrographs the interfacial characteristics describe the adhesion between the fibre and the matrix. The fibre failure mode explained that the matrix fracture and fracture at the edges of the fibre.

Thielemens et al. [98] observed an enhancement in tensile strength of composites using lignin to modify hemp fibres for the preparation of polyester composites. The increment of tensile modulus (10%), flexural modulus (22.5%) and flexural strength (7%) is noted. The mechanical properties found were related to amount of lignin covering the fibre. Mutje et al., [58] investigated the effect of maleated polypropylene as polymer matrix and hemp fibre as reinforcement material by injection moulding technique. The addition of 4% maleated polypropylene as coupling agent for polypropylene composites modified with 40 wt% of hemp strands enhanced the tensile and flexural strength up to 49% and 38% respectively. The obtained results were compared with the composites without using the coupling agent.

Sebe et al. [90] prepared a hemp fibre reinforced polyester composites using RTM techniques. Due to chemical modification of fibres, a good interfacial adhesion between hemp fibres and polyester is noticed. The authors accounted for a strong interfacial adhesion is because of radical copolymerization between vinylic group and the unsaturated bonds of resin occurred.

Park et al. [72] investigated the interfacial evaluation of jute and hemp fibres/polypropylene (PP) – maleic anhydride PP copolymer (PPMAPP) composites by micromechanical technique and nondestructive acoustic emission. The interfacial shear strength is increased because of the modification of the fibre by alkaline and silane coupling agent. Using the uni and Bimodal Weibull distribution, the authors also evaluated the mechanical properties of single jute and hemp fibres with the effects of alkaline, silane and thermally treated conditions. The effects of alkaline and silane treatments showed increase in mechanical properties of single jute and hemp fibres whereas the thermally treated fibre showed decrease in mechanical properties, this is because of, the chemical structures were seriously damaged during the time of heating.

Mwaikambo and Ansell [60] studied the physical and mechanical properties of unidirectional hemp fibre reinforced cashew nut shell liquid composites. A sharp increase in porosity with respect to the moulding pressure is noted in untreated unidirectional hemp fibre CNSL composites. At a moulding pressure of 5 MPa, the mechanical properties are improved due to the surface modification of the fibre and increased the fibre surface area.

2.4. Jute fibre polymer composites

Jute is a bast fibre whose scientific name is Corchorus capsularis of Tiliaceae family. Plant of jute is cut and kept immersed in the water for retting process during season. The inner stem and outer gets separated and the outer plant gets individualized to form fibres. Rafiquzzaman et al. [78] prepared glass-jute fibre reinforced polymer composite by hand lay-out technique and the mechanical properties were investigated. Fractured surface were examined in scanning electron microscope (SEM) to determine the microscopic fracture mode and from their results it can be inferred that jute fibre can be a very potential usage in making of composites, especially for partial replacement of high-cost glass fibres for low load bearing applications.

Siddiquee and Helali [93] studied the effects of Fibre Length (1 mm and 3 mm) and Fibre Ratio (5%, 10% and 15%) on the Biodegradability of Jute Polymer Composites. They revealed that the prepared composites has higher degradation rate at compost condition when compared to soil and natural weather.

Rajesh and Prasad [79] studied the Tensile Properties of Successive Alkali Treated Short Jute Fibre Reinforced polylactic acid (PLA) Composites. They demonstrated that the alkali treated (5%, 10% 15%) fibre and with H_2O_2 had considerably increased the tensile strength of the composites compared to strength of composites with untreated jute fibre. The tensile modulus of composite with 10% NaOH/ H_2O_2 treated fibres at higher fibre loading was 125% and 40% higher than that of neat PLA and untreated fibre/PLA composite respectively.

Mohanty et al. [54] studied the effect of maleic anhydride grafted polypropylene (MAPP) as coupling agent for the modification of fibres in the preparation of jute fibre reinforced polypropylene composites. The effect of fibre length composites at 6 mm showed superior tensile strength (31.27 MPa), flexural strength (59.18 MPa) and impact strength (65.96 J/m) respectively in comparison to 3 and 10 mm fibre length composites. The time period of impregnation of fibres in MAPP coupling agent was varied from 3, 5 to 10 min. The result showed that with increase in treatment time from 3 to 5 has better mechanical properties than the increase in treatment time from 5 to 10 min. At 30% of fibre loading showed rise in tensile strength, flexural strength and impact strength to about 17%, 24% and 31% respectively.

Dash et al. [21] prepared jute polyesteramide (BAK) composite by varying the mass of the fibre as 45%, 50%, 55%, 60% and 65%. The result mentioned that at 60% weight fraction of jute fibre has highest tensile strength, tensile modulus, flexural strength and flexural modulus of 41.23 MPa, 3346 MPa, 41.75 MPa and 8613 MPa respectively. Soil burial test was conducted to test the composites biodegradability. Reduction in 30% weight and mechanical strength could be observed for the materials after 21 days. These results also reflected in IR spectra and SEM micrographs.

Ray et al. [83] conducted the study on mechanical properties of jute fibre reinforced vinylester composites of untreated and alkali treated (5%NaOH with the time period of 0,2,4,6 and 8 h at 30ºC. The mechanical properties increased in the type of fibre treated with alkali for 4 h in the following fibre weight fraction of 0%, 8%, 15%, 23%, 30% and 35%. Composites prepared from alkali treated fibres for 8hrs showed maximum impact fatigue resistance.

Kumar and Verma [46] reported the fabrication, properties and degradation studies of jute fibre renforced LDPE polycaprolactone composites. Various treatments were given to the fibres for better mechanical properties of composites. Silane and ethyltitanate treatment of jute fibres resulted in an increase of roughness in surface of fibre, diameter as well as denier and an increase in mechanical properties such as tensile strength and modulus and decrease in elongation at break is noticed with increase in weight fraction of fibres.

Gopinath et al. [30] studied the experimental investigations on mechanical properties of jute fibre length of 5–6 mm reinforced composites with polyester and epoxy resin matrices. The fibre matrix weight ratio used for the preparation of composites are 18:82. The prepared jute reinforced epoxy composite material has good properties than jute fibre polyester composites. The reason behind the good mechanical properties is, at the molecular level, the polar hydroxyl and ether groups, which is present in the epoxy resins improved better adhesive properties. Consequently epoxy has an effective bonding with the fibre material, results the prepared jute reinforced epoxy composite to have good mechanical properties which makes it better suited for the automotive applications rather than jute-polyester composites.

2.5. Kenaf fibre polymer composites

Kenaf fibre is obtained from stems of plants genus Hibiscus, family of Malvaceae and the species of H.Cannibinus. Yusri H Muhammad et al. [111] fabricated the hybrid glass/kenaf fibre-reinforced epoxy composite – whilst the glass fibre was treated using a silane coupling agent. The physical properties were performed to determine the effect of fibre treatment and liquid epoxidised natural rubber addition on the mechanical properties of the hybrid fibre-reinforced composite. It was found that the treatment and the addition of liquid epoxidised natural rubber contribute to the increment of the impact strength by 40% whilst the flexural properties recorded a 13% and 15% increment for both flexural strength and flexural modulus, respectively.

Yousuf Ali et al. [110] optimized the processing parameters and fibre size of Thermoplastic Polyurethane/Kenaf fibre composite. Three different fibre sizes were examined < 125, 125–300, and 300–425 µm. It was observed that the fibre size between 125 and 300 µm has higher strength which implies that it has better interfacial bonding and wettability in the fibre. The fibre size < 125 µm has lower strength is because of smaller size fibre possess larger surface area, leaving more surfaces nonreactive to the matrix. A larger fibre size 300–425 µm showed only a slight increment of impact strength of about 7%. Therefore, a fibre size between 125 and 300 μm was considered to be the optimum size amongst the three size ranges examined.

Hafizah et al. [31] conducted tensile tests on longitudinally arranged kenaf fibres with different types of thermoset resin (epoxy, polyester and vinyl ester). Their experimental results indicated that the composites performance increased gradually with every increment of fibre volume fraction. Kenaf fibre treated with 6% NaOH recorded the best improvement in terms of mechanical properties while comparing fibre treated with 3% and 9%. The effect of treated pultruded kenaf reinforced composites shows better physical properties compared to those of untreated pultruded kenaf reinforced composites [69].

Abu Baker et al. [1] investigated the effect of liquid epoxidised natural rubber (LENR) to the flexural and impact strength of the kenaf fibre reinforced epoxy composites. The authors varied the fibre weight of 5%, 10% 20% and 25% with and without the addition of LENR. The results indicated that the addition of LENR increased the flexural strength 17.6%, flexural modulus 11% and impact strength 47% respectively.

Salleh et al. [87] improved the mechanical properties and interfacial adhesion behaviour of kenaf fibre reinforced high density polyethylene composites by the addition of maleic anhydride grafted high density polyethylene (HDPE). 8% MAHDPE provided maximum increment in tensile and flexural properties, indicated that addition of maleic anhydride leads good adhesion between matrix and the fibres.

Shekeil et al. [92] prepared the kenaf fibre reinforced thermoplastic polyurethane composites by melt blending method. In this work, the authors varied the processing temperature (190ºC), time (11 min), speed (40 rpm) and with different fibre sizes on the mechanical properties of composites. Tensile and flexural strength was good at 125–300 μm fibres and impact strength has increased with increasing size of the fibres.

Shekeil and Sapuan [91] studied the effect of alkali treatment (at 2%, 4% and 6% NaOH conc) on physical properties of kenaf fibre reinforced thermoplastic polyurethane composites. The result indicated that tensile stress and strain were deteriorated with increase in NaOH concentration where modulus increased slightly in the kenaf fibre reinforced polyurethane composites.

Mutasher et al. [57] prepared the kenaf fibre epoxy composites and investigated the effect of alkali treatment of fibre on the composite specimens. The authors observed that alkali treated fibre composites showed better performance than the untreated fibres. The increment in tensile strength as 27.72 MPa and flexural strength as 56.91 MPa is noted in 24% weight fraction of kenaf fibre composites. At 40% weight fraction of kenaf fibre showed the highest impact strength of 14.3%.

Mohammad Taib et al. [51] tested the physical properties (thickness swelling and water absorption) and mechanical properties (static bending and internal bonding tests) for the high density kenaf fibre composite board. In this study, thermochemical treatment given to the fibre leads to reduce the physical properties and static bending test. Modulus of elasticity is increased upto 130ºC of treatment than started to drop when treated with 150ºC of temperature.

Nishino et al. [66] investigated the properties of kenaf fibre composites and polyL –Lactic acid (PLLA) resin. In these studies, the authors determined the maximum values (Young's Modulus 6.4 GPa and Tensile strength 60 MPa) with the increase of fibre content 70 vol %. These properties were higher than those of PLLA film (Young's Modulus 1.3 GPa and Tensile strength 21 MPa). They suggested at the end that kenaf fibre can be good reinforcement material for better performance in biodegradable composite material world.

2.6. Ramie fibre polymer composites

Ramie, the strongest of all bast fibres belongs to urticacease family yielding fibre from the bark of the canes which provides excellent raw material for blending with the natural and synthetic fibres. Binita et al. [10] revealed that the physical properties of Ramie fibre exhibited high tenacity, high luster and brightness and have resistance to heat, light, acid, alkali etc.

Irawan et al. [38] expressed through his experiments that mechanical properties of ramie fibre reinforced epoxy composites (RE) composite materials has the highest value compared to ramie fibre reinforced polyester composite (RP) and Fibre glass reinforced Polyester(FGP) composite materials. Further, the RE composite material have the potential to be developed as an alternative material of socket prosthesis substitute with fibreglass polyester composites (FGP), which are locally available, bio mechanically appropriate, as lightweight as possible, comfort and psychosocially acceptable.

Xu et al. [16] studied the properties of surface-treated ramie fibre fabric/epoxy resin composite fabricated by vacuum-assisted resin infusion moulding with hot compaction. They found that surface-treated ramie fibre fabric has lower compressibility than the untreated one. Moreover, hot compaction with suitable conditions is effective in increasing fibre content and mechanical properties of all studied ramie fabric composites.

Zhang et al. [115] prepared unmodified ramie fibre(RF) reinforced polypropylene(PP) composites by means of melting hybrid technology and studied its properties. Varying the weight fraction of fibre content, the physical properties were investigated. The thermal degradation temperature of the PP/RF composites becomes lower due to the presence of higher fibre content in the composite material. The crystallization rate of the PP matrix is accelerated by the unmodified RF. The tensile strength of composites is low, because of the inferior interfacial bonding between the ramie fibre and the polypropylene matrix. That is, when longer fibre is used for the preparation of composites then it is not mix well with the matrix material resulting the decrement of tensile strength. During the fabrication process, the ramie fibre is used as a raw one, no hazardous waste is delivered. The raw fibre which gives enhancement to polymer and composites with better mechanical performance should lead a economic route to a rural society.

Paiva Junior et al. [70] prepared polyester/hybrid ramie–cotton fabric composites by using compression techniques. The composite showed an increase in tensile strength over the resin of upto 338% and the results suggested that the ramie fibre have a good potential candidate as fibre reinforcement in resin matrix composite materials.

Krasowska et al. [45] prepared the ramie fibre/ ecoflex and ramie fibre/cellulose nanofibre reinforced corn starch resin composites. The characteristic parameters such as incubation time and rate of degradation were monitored for the composite materials, which was subjected to natural environments(i.e., sea water and compost). Due to different microbial activities, the ramie fibre biocomposites were degraded in compost. The ramie / ecoflex biocomposites was degraded more distinctly than ramie/cellulose nanofibre reinforced composites in both natural environments.

He et al. [33] prepared ramie fibre reinforced polypropylene composites and studied its mechanical properties. The results showed that the pre-treatment of ramie fibre is 10–15% NaOH is good to mechanical properties of RF/PP. Increment of fibre length (range of 3–8 mm) and fibre content (20 wt%) could enhance the tensile strength, flexural strength and compressive strength, at the same time, the result showed the decrement of impact strength and elongation behaviour of RF/PP composites. Due to their reduction in weight, better mechanical properties and environmental friendly ecomaterials, this RF/PP composites can be used to automobile industry.

Wang et al. [104] investigated the variation of water uptake and mechanical properties with immersion time for the ramie fibre reinforced phenolic composites. In these studies, due to strong hydrophilic nature of ramie fibres, the water content and coefficient of diffusion for this composites were high and showed a remarkable deterioration in flexural and short beam shear properties.

3. Critical analysis on the advantage of different polymers like epoxy, polyester and vinyl ester

Braga and Magalhaes [14] described the mechanical and thermal properties of raw jute and glass fibre reinforced epoxy hybrid composites. To improve the mechanical properties, jute fibre was hybridized with glass fibre. Epoxy resin, jute and glass fibres were laminated in three weight ratios (69/31/0, 68/25/7 and 64/18/19) respectively for the preparation of composite materials. The tensile, flexural, impact, density, thermal and water absorption tests were carried out using hybrid composite samples. The result showed that the addition of jute fibre and glass fibre in epoxy, increases the density, the impact energy, the tensile strength and the flexural strength, but decreases the loss mass in function of temperature and the water absorption.

Jawaid et al. [39] studied the effect of jute fibre loading on the mechanical properties of oil palm–epoxy composites. Increase in flexural strength and modulus, and decrease in impact strength of this hybrid composites is observed with increase in jute fibre contentS. Analysis of variance statistical of flexural and impact properties were also carried out; there is a statistically significant difference between the mean flexural strength, flexural modulus and impact strength from one level of composite to another at the 95% confidence level.

Alavudeen et al. [3] prepared and studied the mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites with the effect of weaving patterns (such as plain, twill type) and random orientation by using the hand layup process. In the plain woven hybrid composites there is maximum increase in mechanical strength was noted rather than in randomly oriented composites. This indicates minimum stress development at the interface of composites due to the distribution of load transfer along the fibre direction. Moreover, alkali (NaOH) and sodium lauryl sulfate (SLS) treatments appear to provide an additional improvement in mechanical strength through enhanced interfacial bonding.

Boopalan et al. [13] studied the mechanical and thermal properties of jute and banana fibre reinforced epoxy hybrid composites. Jute fibre was hybridized with banana fibre, in order to enhance the better mechanical properties of composites. Using moulding techniques, the composite material were prepared by varying the jute and banana fibre weight ratio at 100/0, 75/25, 50/50, 25/75 and 0/100, and it was incorporated into the epoxy matrix. The study showed that addition of banana fibre in jute/epoxy composites of up to 50% by weight results in increasing the mechanical and thermal properties and decreasing the moisture absorption property.

Ramesh et al. [81] evaluated the mechanical properties of sisal–jute–glass fibre reinforced polyester composites. The interfacial properties, internal cracks and internal structure of the fractured surfaces are evaluated by using Scanning Electron Microscope (SEM). The results indicated that sisal–jute fibre incorporate with GFRP would enhance the mechanical properties and can be used as an alternate material for glass fibre reinforced polymer composites.

Fairuz et al. [25] analyzed the effect of gelation and curing temperature on tensile, flexural, compression and morphological properties of pultruded kenaf reinforced vinyl ester composites. Enhancement of mechanical properties of composites when the increase of gelation and curing temperature. Further addition of these two temperatures, the tensile strength, tensile modulus, flexural strength, flexural modulus and compression strength were affected and they were either increased or decreased. The optimum value of the tensile strength obtained for gelation and curing temperature of kenaf pultruded composites were found by the author.

Hafsat R. Saliu et al. [32] studied the effect of Epoxy Concentration and Fibre Loading on the Mechanical Properties of ABS/Epoxy-Coated Kenaf Fibre Composites. Tensile strength has increased with increase in both epoxy and fibre loadings to a maximum point. Impact increased with epoxy loading as hardness increased with both parameter loadings. The optimum tensile strength was observed at 40 wt% epoxy and 30 wt% fibre loading. The higher tensile strength of 90% is obtained in the banana fibre reinforced polyester(BFRP) composites when compared to virgin polyester composites and this BFRP composites a ductile appearance with minimum plastic deformation (Bandi [7]).

4. Effect of various techniques on the bast fibre reinforced composites

Himanshu Bisaria et al. [34] manufactured and described the mechanical properties of randomly oriented short jute fibre reinforced epoxy composite. Using hand lay-up method, the composites were prepared with 30 wt% of jute fibre in the various lengths of 5, 10, 15 and 20 mm into epoxy matrix. They found the maximum tensile and flexural properties for the composite with 15 mm length of fibre whereas the maximum impact properties were found with 20 mm length of fibre.

Donnell et al. [24] prepared the composite panel with plant oil based resin and natural fibres. The composites prepared by vacuum infusion process were found to possess mechanical properties and it was suitable for the application in building construction materials, furniture and automotive parts. Mechanical properties and failure topography of banana fibre phenol formaldehyde macrocomposites fabricated by resin transfer moulding (RTM) and compression moulding (CM) techniques were studied by Indira et al., [37]. The increase in tensile and flexural strength, and decrease in impact strength is noted from the RTM composites compared to CM composites. From the experimental observations, it was found that mechanical properties increased with the increase in fibre loading, reached a plateau at 30–40 wt%, and then subsequently decreased with an increase in fibre loading in both techniques. A decrease in strength is obtained at high fibre weight fractions due to poor wetting and very poor stress transfer. The stress value increased up to 30 mm fibre lengths and then decreased.

Mohd Yuhazri et al. [55] manufactured the kenaf/polyester composites by using vacuum infusion and hand lay-up method. The fibres were treated with alkali at 6% and 9%, and continue long kenaf fibres materials were used to prepare the composites. From their findings, vacuum infusion process showed better tensile properties compared to the composites manufactured by hand lay-up method. Also, vacuum infusion method used in this study offers the advantages over hand lay-up method for better comparison ratio between fibres to resin which resulting in stronger and lighter laminates.

Yang et al. [109] studied the effect of different jute fibre contents and hot water immersion on the tensile properties jute/polypropylene composites (Jute/PP) by using injection molded techniques. The results indicated that tensile modulus increased linearly with the increasing content of jute fibres, while the tensile strength increased initially and decreased at jute fibre content above 30 wt%. Both properties decreased significantly by aging in jute/PP with higher fibre content, as a result of the degradation of the interfacial adhesion between jute fibre and PP.. Suhad D. Salman et al. [96] described the influence of fibre content on mechanical properties of woven kenaf reinforced PVB Film produced using a hot press technique. The composites were prepared with various fibre contents: 0%, 10%, 20%, 30%, 40%, 50%, and 60% (by weight), with the processing parameters 165 °C, 20 min, and at a pressure of 8 MPa applied on the material. The minimum tensile and flexural properties is observed with the kenaf fibre content of 40%, and also impact properties were affected in markedly different ways by using various kenaf contents and decrease with the increase in kenaf fibre content up to 40%; however, high impact strength was observed even with 40% kenaf fibre content.

Arumuga prabu et al. [4] presented the effectiveness of redmud as polymer matrix on the mechanical properties of banana fibre reinforced polyester composites. Using compression moulding technique, the composite was prepared with redmud as secondary reinforcement in banana fibre reinforced polyester (BFRP). The mechanical properties of the composite materials have been evaluated for different fibre weight percentage, weight percentage of red mud and chemical treatment of fibre. The result showed that there is increment in the impact and flexural properties for both silane treated and untreated banana fibre with the addition of 10% wt of redmud but there is a decreased trend for tensile strength.

Hu and Lim [35] prepared and studied the mechanical properties of biodegradable hemp fibre reinforced polylactic acid composites by using the hot press method. The mechanical properties of composites with different fibre volume fractions were tested, and the effects of alkali treatment on the fibre surface morphology of the composites were investigated. Finally the test results showed that the composite with 40 wt% volume fraction of alkali-treated fibre has the best mechanical properties. At 40% treated fibre, the tensile strength, elastic modulus, and flexural strength of the composite are 54.6 MPa, 8.5 Gpa, and 112.7 MPa respectively, which are much higher than those of polylactic acid composites alone.

5. Applications of bast fibre reinforced polymer composites

Bast fibres derived from natural fibres such as banana, ramie, hemp, flax, kenaf and jute have high specific strength, low density and are extremely concerned in several industrial applications [40]. Lina Herrera-Estrada et al. [49] established the production of banana fibre reinforced composite materials with a thermoset, suitable for engineering, automotive and transportation industry applications. Banana fibre reinforced with tamarind seed gum polymer composites showed the highest tensile strength of 3.97 MPa which has an important feature to promote the application of these composites as a false roofing material instead of thermocole material [44]. Jute-coir hybrid composites find into railway coaches for sleeper berth backing, for building interiors, doors and windows besides in transportation sector as backings for seat and backrest in buses [2]. According to researchers, the bast fibres possess striking mechanical properties that make them as a replacement to glass fibres in polymer composites as reinforcing elements as they are taken from bast, core, and pith and make it suitable for various applications [26,42,71]. The bast fibre containing composites are more environmental friendly, used in transportation (automobiles, railway coaches, aerospace) military applications, aircraft indoor structures, building, construction (ceiling, paneling, and partition boards) and packaging industries [95].

Libo Yan [48] evaluated the performance of natural flax fabric reinforced epoxy polymer (FFRP) composites as external strengthening materials for concrete components. Plain concrete cylinder and beams with and without FFRP were tested and results indicated that FFRP has better peak strength, strain, fracture energy and ductility of the concrete cylinder by 6 layer FFRP is 134% and 2570% respectively. Similarly, for concrete beam, the 6 layer FFRP has 374% and 4660% increase in peak load and fracture energy. Finally they concluded that this FFRP composite is suitable potential candidate for strengthening of concrete structures in construction and building materials.

Bledzki et al. [11] developed the manufacturing technology of microfoam of flax fibre and wood fibre reinforced polypropylene composites. By optimizing the various parameters, they characterized the forming of microvoids and degree of foaming. Mechanical properties were carried out and density of microfoamed wood fibre PP composites was reduced by 24% and decreased by 0.77 g/cm^3. From the experimental observations, it can be noted that this composites have good engineering properties and lower density for technical applications.

6. Conclusion

The present review explored the works related to bast fibre reinforced polymer composites. The physico-mechanical properties of bast fibre reinforced polymer composites such as hardness, tensile, flexural and impact properties and the effects of chemical treatments to improve the interfacial matrix–fibre bonding resulting in the enhancement of physical properties of the fibre polymer composites were also reviewed. In order to replace conventional materials, material scientists have concentrated their attention on using bast fibres that weigh less, durable, efficient and have high mechanical properties.

Some of the restrictions of bast fibre reinforced composites are inferior fire resistance, lower durability, problem of storing raw material for extended time due to possibility of degradation, lack of uniformity of properties due to climatic conditions when cultivated, biological attack of fungi and mildew, limited its applications. Also bast fibre contains high hydroxyl content of cellulose that makes it liable to higher water absorption that affects the materials' mechanical properties. To overcome these problems, suitable chemical treatment can be given into the bast fibre.

Hence, it can be concluded that the bast fibres have better physical properties that make it as a suitable material to replace conventional materials as reinforcement in the existing composite world. As a major source of indigenous raw material in polymer industry not only provides a biodegradable resource, but also provides a chance for economic development in rural areas. In general, bast fibre reinforced polymer composites have bright future because of their light in weight, affordable cost and decomposable in nature, and demand in alternatives to glass fibre composites. As there is a continuous rise in the environmental temperature, weather casting becomes a necessary one for the buildings, for which the present usage of materials are not eco-friendly. In this juncture, the preparation and usage of environmental friendly composite materials can make a revolution in the field of Civil Engineering. Thus, the composites stand the most wanted technology in the fast growing current trend.

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