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Review on Natural Fiber Composites: Banana/Hemp Fiber and Its Hybrid Composites

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Abstract

The centuries ago usage of composites materials plays important role in industrial revolution. In ancient days Egyptians used straw as reinforcement in clay bricks to build house. With the invented of glass fiber and resins, glass fiber reinforced composites found its application in many areas. Abundance nature and moderate specific strength than most of the organic fibers, low density and biodegradable nature make the natural fiber as attractive reinforcement in polymer matrix in recent few decades. However, few drawbacks such as incompatibility with hydrophobic polymer matrix less resistant to moisture and its tendency to form aggregate during processing generally reduce the use of natural fiber in composites. In this review, the recent literature on hemp, banana, and its hybrid are summarized and discussed, mechanical properties of composites and the effect of various physical and chemical surface treatments in composites.

Keywords: composites, fiber, hybrid

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INTRODUCTION

The natural fiber mainly used in interior applications where moisture pays no role such as doors, arm rest, package trays, automobile instrument panel, etc. they are classified based on source of fiber, such as bast fiber, fruit fiber, leaf fiber, seed fiber, grass fiber, animal fiber, and wood fiber (Table 1).

Table 1. *Classification of Natural Fiber.*

Bast fiber	Flax, kenef, urena, mesta, ramie, rosella, jute, banana, palmyra, hemp, henequen, bamboo, bagasse, and ramie
Fruit fiber	Oil palm, coconut, african palm, and palmyra fruit
Leaf fiber	Sisal, pineapple, abaca, curaua, cabuja, african palm, dates palm & palmyra palm petiole fiber
Seed fiber	Cotton, kapok
Grass fiber	Bamboo, bagasse, wheat, barley, rice, reed, corn, rape, rye, esparto, elephant grass, cannary grass, and oat
Animal fiber	Silk, wool, and feathers
Wood fiber	Soft wood and hard wood

These fibers are generally used as reinforcements in thermo-sets as well as thermoplastic system. Recently basalt fiber finds its berth in this natural fiber category because of its bio degradable nature. These are used as either short fiber or in woven mat as reinforcement. The performance of the natural fiber composites (NFC) depends on various factors such as length and amount of fiber, fiber surface, fiber and matrix strength, fiber matrix interaction, fiber orientation, age & cultivation environment of the plant and method of fiber extraction presence of voids and method of fabrication etc. The fiber length at which the composites exhibit maximum properties is called critical fiber length which varies from fiber to fiber as well as matrix in short fiber composites. The ratio of quantity of fiber to matrix is called volume fraction Vf/weight Wt fraction. The amount of fiber at which the composites exhibits maximum performance is termed as critical fiber content which also varies from fiber to fiber as well as matrix. Fiber matrix interaction can be improved by various chemical treatments. Performance of the composites could be improved by hybridizing with two or more fiber. Composites performance improved when the fibers are used either in continuous form as well as woven form. The composites fail at peak load due to various factors such as fiber breakage, fiber pull out, matrix crack, fiber strain, matrix strain, moisture etc.

In this review the recent literature on natural fibers like hemp, banana, and its hybrid are summarized and discussed, mechanical properties and the effect of various physical and chemical surface treatments in as well as thermo-plastic.

HEMP FIBER-BASED COMPOSITES

Characterization of thermoplastic composites made from PLA/hemp co-wrapped hybrid yarn prepregs was reported by Behnaz *et al*.[1] They assessed the properties of 0/90 bidirectional composite made from PLA/hemp co-mingled hybrid yarn preforms as reinforcement. The PLA /hemp hybrid yarns preforms were cowrapped in a laboratory yarn twist machine by winding PLA yarn filament around low twist very fine hemp yarn. They prepared multilayer 0/90 bidirectional hybrid yarn prepregs, by winding 12 layers of hybrid yarn around a rectangular steel frame. This mat was dried in a vacuum chamber and covered with a Teflon sheet and then placed in the mold of 20 × 20 cm with depth of 10 mm. The mold was heated to 175 °C at a pressure of 1.04 MPa for 15 min in a hydraulic compression molding machine. Teflon sheet is to prevent sticking of the matrix to the surface of the hot mold. Composites were prepared for wrap density (wraps per unit length 1 m) of 150 and 250 kg/m^3 and in each case with the fiber volume fraction in the range of 10–45 vol%. Compared to neat PLA, the tensile strength, tensile modulus flexural strength and flexural modulus of the PLA–hemp composites were significantly higher as due to the increased fiber content. The hybrid yarn with a wrapping density of 250 kg/m^3 showed a consistent improvement in tensile properties than the composites with 150 wrapping density. 4.6 and 14.7% improvement in tensile properties at low volume fraction and at high volume fraction was reported for 250 kg/m^3 wrapping density. Decrease in tortuosity associated with increase in wrap twist leads to improved fiber alignment which contribute the improvement in properties. Flexural strength of 250 kg/m^3 wrap density at 45 vol% was 3.3 times higher than the pure PLA. Impact strength of the composites decreased initially up to 10 mass% fibers loading and then improved in both case of wrapping. Impact value of 250 kg/m^3 wrap density was reported to be lower than 150 kg/m^3 wrap density. Fiber pull-out is a major energy-absorbing mechanism in impact strength. Because of higher fiber–matrix adhesion shorter average pull-out lengths was observed in the composites with 250 wrap density, it showed lower impact value than 150 wrap density. DMTA results showed that the incorporation of the fibers imparts a considerable increase in storage modulus and a decrease in temperature. The study performed with DSC revealed that the glass transition temperature and the melting point of PLA were not affected due to reinforcement with hemp. Decrease in crystallization temperature of the hemp-reinforced PLA composites was observed, which indicates that the hemp fibers hinder the migration and diffusion of PLA molecular chains to the surface of the nucleus in the composites.

Awwada *et al*.[2] reported the effect of hemp fiber on cement concrete and incorporation of hemp fiber resulted reduction of coarse aggregate quantity without affecting the flexural performance of concrete. They prepared three type of mix one without fiber for comparison another with 0.5% volume fraction of hemp and polypropylene fiber and third set of sample with hemp fiber in the volume fractions of 0.5, 0.75, and 1% with coarse aggregate reduction of 10, 20, and 30% in each case. The compressive strength was determined at 3, 7, and 28 days and the flexural strength was determined at 7 and 28 days. Addition of 0.5% polypropylene decreased the compressive strength by 3, 17, and 13%, at 3, 7, and 28 days, respectively. But the addition of 0.5% hemp reduced the compressive strength by about 20%, at 7 and 28 days of concrete ageing. 0.5% hemp mix and 0.5% polypropylene mix concrete had almost same compressive strength in all cases. For the mix with coarse aggregate reduction, 20–40%, 15–40%, and 20–35% reduction in compressive strength at different concrete ages was observed for all hemp fiber volume fractions. The compressive strength of concrete mixes decreased with the fiber addition as well as with coarse aggregate reduction as observed by them. Addition of fibers results in an increase in the concrete volume where the additional space is occupied by fibers which are weak under compression load. This reduction may further be magnified with decrease in coarse aggregate quantity. The control specimen without fiber showed brittle behavior on flexural testing, whereas in the case of the fiber with concrete, first crack initiated in the tension zone when the stress reached the concrete tensile capacity. The sudden failure did not occur because of the presence of fibers which bridge over the cracks. Finally, failure occurred only when the fibers tensile strength and bond splitting capacity was reached. This explains the ductile behavior of the new composites while the flexural strength was same as that of plain concrete. The use of the industrial hemp fibers in concrete mixes had beneficial effects with respect to maintaining the flexural strength and providing a ductile post-cracking behavior of the fiber-reinforced concrete mix. Moreover, the use of industrial hemp fibers allowed the reduction of coarse aggregate quantity without affecting the flexural load-deflection performance. Thus, reducing the natural resource consumption and resulting in a sustainable concrete material. Since the interfacial bond between the fibers and the concrete matrix becomes more mature after 28 days the increase in the flexural strength was more than that of 7 days tests. The results of the modulus of elasticity test conducted at 28 days showed the ductile behavior of the new hemp fiber-reinforced concrete. The new composite is more ductile and thus with less load-deflection stiffness. All hemp specimen results were less than the control specimens, even 0.5% hemp when added to concrete, which justifies their role in reducing the stiffness and increasing the ductile behavior. The shear resistance provided by concrete in reinforced concrete members is evaluated by splitting tensile strength test. Because of reduction in coarse aggregate the splitting tensile strength was reduced by 15–30% for the mixes with 0.5% hemp fiber. With the increase in hemp fiber content with 0.75 and 1% it increased to the level of control mix which shows that the reduction in coarse aggregate was compensated by the hemp fiber addition. The addition of hemp fibers therefore appears to have compensated the coarse aggregate reduction, by their role in bridging between shear cracks. The results indicated that the 0.75 and 1% hemp volume fractions are sufficient and adequate as an optimal substitute to the coarse aggregate reduction. The addition of these fibers to concrete resulted in reducing the slump of the composite mix because of its high water absorption. This was confirmed by the slump result of the polypropylene addition which did not affect the slump result. (polypropylene does not absorb water). Going beyond the 1% hemp fibers addition was not recommended by them since they observed a decrease in workability of the mix, when 1% hemp was added. Whenever coarse aggregate reduction was implemented, the density was 3–7% less compared with the control specimen. The thermal conductivity results showed reduction in the heat flow due to the hemp fiber presence. The 0.75% and the 1% hemp mixes showed the 35% decrease in thermal conductivity, compared with the control specimen.

Adel Ramezani et al [3] investigated that the mechanical properties and thermal stability of the hemp fiber reinforced maleated polyethylene (MAPE) matrix composites. When increasing the hemp fiber in MAPE composite significantly increasing the tensile and flexural properties. Impact strength was decreased when increasing the hemp fiber content. In water absorption, increasing of hempfiber increasing the water uptake.

mechanical properties as well as thermal stability remains unchanged for samples up to 30% hemp content and at higher fiber concentrations showed some degradation. Incorporation of modified hemp fiber significantly increased the tensile and flexural properties of the MAPE matrix but Impact strength decreased with increasing hemp content.
Bhoopathia *et al*.[4] carried the study on property evaluation of banana-hemp-glass fiber reinforced composites with the main objective to evaluate the mechanical properties such as tensile strength, flexural strength, and impact strength of the banana-hemp-glass fibers reinforced hybrid composites. They prepared three different types hybrid laminates fabricated by hand lay-up method. Three layers of glass fiber and two layers of banana fibers are used as reinforcing material with epoxy resin. Similarly the hemp-glass fiber and banana-hemp-glass fibers with epoxy resin laminates are prepared by same hand lay method. From the experimental results, it has been observed that the banana/glass fibers reinforced hybrid epoxy composites exhibited superior tensile properties whereas banana hemp glass exhibited superior flexural and impact properties. Hence, this can be used as an alternate material for synthetic fiber reinforced composite materials particularly for internal structures.

BANANA FIBER-BASED COMPOSITES

Paul *et al*.[5] have synthesized and tested a novel bio-based composite structure and investigated the mechanical, thermal, and morphological and biodegradation properties of the banana fiber based bio-composite. A non-woven mat prepared with untreated fibers by needle punching was used as reinforcement. They synthesized new resin with propylene glycol, maleic anhydride, and banana sap containing 35% styrene (BSM) and another resin without banana sap (control resin). Composites were prepared with the above two resin with two layer of non-woven banana fiber mats (30 wt%) by VARIM, The panels were subjected to temperature soaking from 25 to 80 °C at 10 °C/min and immediately tested for tensile and flexural strength at 55 ± 5 °C and also at ambient temperature. The addition of banana sap to the matrix resulted in an 18% increase in tensile and 6% increase in flexural strength, compared to the control resin when tested at ambient temperature. Tensile moduli of the BSM and control composites were 2968 ± 148.3 and 2609 ± 218.2 MPa, respectively, at ambient temperature. When tested at 55 ± 5 °C s the tensile strength, tensile modulus, flexural strength and flexural modulus were found to be reduced by 30, 19, 29, and 22%, respectively. Thermal decomposition of all samples occurs at 25–600 °C. The higher degradation temperature of 377 °C was reported for the BSM composite due to the presence of organics such as esters and phenolic compounds in the banana sap which resulted in increased thermal stability. Whereas for the control composites which was 366 °C. Higher melting point (369 and 385 °C) and crystallization temperature (317 and 343 °C) was observed for BSM composite than control composites. It was concluded BSM bio-composites are both amorphous and crystalline. The higher HDT values for the BSM (109 °C) than control composite (106 °C) were observed due the due to the stronger adhesion of banana fibers with BSM resin than the control. The storage modulus at150 °C of the BSM composite, control composite, and the pristine resin was 2638, 2300, and 1642 MPa, respectively. It was found that above 60 °C the storage modulus of the BSM resin, BSM, and control composite decreased with increasing temperature due to softening of the matrix at higher temperature. T_g values for BSM resin, BSM composite, and control composite were 186, 185, and 200 °C, respectively. The shifting of the T_g to higher temperature can be associated with the decreased mobility of the matrix chains, due to the addition of fibers. Two biodegradability tests, namely soil burial test and microbial growth test were conducted. After 120 days soil burial higher average mass loss for BSM was reported than the control composite. In the microbial growth test, the microbial growths of fungal species have been identified for the both control composite and BSM composite. Although both composites supported growth, the composite with the banana sap resin visually showed more growth than the control sample. The water uptake continuously increased for a period of 96 h for both samples. However, the control composite absorbed 12% more moisture than the BSM composite.

Fiber surface treatment and its effect on mechanical and visco-elastic behavior of banana/epoxy composites was reported by Venkateshwaran *et al*.[6] They treated the fiber with various NaOH concentrations and reported that properties 1% of NaOH treated composite were more than those of 5, 10, and 20% NaOH. Randomly orientated and plain weave pattern composites prepared by reinforcing the treated and untreated fibers using hand layup technique were considered for their study. 52% improvements in tensile and 16.65% improvement in flexural strength were reported for 1% NaOH randomly oriented composites. Tensile modulus of 1.68 GPa and flexural modulus of 13.22 GPa, respectively, which were found to be higher than untreated composites. The impact strength of 1% NaOH treated composite is 12.25 J/m, which is 81.8% more than that of the untreated fiber composite. Increase in the alkali concentration results in decrease the properties of the composite. This decreasing trend is due to the damage caused by the alkali over the fiber surface. 1% NaOH provides better tensile flexural and impact strength than the other percentages. Similar trend was also observed in the case of plain wove fiber composites also. The moisture absorption percentage of the treated fiber composite was lesser than that of untreated composite for both short fiber as well as woven fiber composites and also reported that composite with 1% of NaOH treated fiber had least decrement in mechanical properties due to moisture absorption. It was found that the alkali treatment increases the storage modulus of the composite due to improved interfacial adhesion between fiber and matrix and the storage modulus decreases with an increase in the temperature due to softening of the matrix at higher temperature, irrespective of whether the composites were made of treated fiber or not. Further, on changing the frequency, the storage modulus of the composite also changes its behavioral pattern. The fiber content at which they carried the studies was not specified in this paper.

In the study on treatment of banana fiber for use in the reinforcement of polymeric matrices Benítez *et al*.[7] investigated the effect of physical and chemical treatments on the suitability of fiber from the Canary banana tree for use as reinforcement for polymers in injection molding processes. Sodium hydroxide (PA-ACS-ISO; Panreac) and maleic anhydride (98+ %; Alfa Aesar) were used to treat the fiber under different conditions of pressure and temperature. The fiber was examined by TGA and Fourier transform infrared spectroscopy of NaOH (0.1, 1, and 4 N) at room temperature and atmospheric pressure for 1 h and another sample at a temperature of 107 °C for 1 h. They conducted the tests to study the influence of temperature on the treatment of fiber. The effect of pressure on the treatment of the fiber was also analyzed with a third set of samples, in a discontinuous reactor with a working pressure of 129 kPa for 1 h at the temperature of 10 °C (which corresponds to a saturation temperature). The FTIR results concluded that banana fiber and the pure cellulose has a similar spectrum. The degradation temperature of sample treated with 0.1 N NaOH was virtually identical to that of virgin fiber whereas all other samples treated with higher NaOH concentration showed higher degradation temperature. Highest degradation temperature was observed when the treatment was carried out at under pressure. The substances such as lignin, pectins, and hemicellulose were removed when the fiber was treated with alkali solutions, and performing the same treatment under pressure improved the efficiency of removal of these substances. Again, maleic anhydride treatment of fiber that had been treated with different concentrations of NaOH resulted in the chemical modification of the fiber, although it seemed that the fibers were unaffected if they were treated with NaOH. It was observed that treatment with 4 N NaOH did not result in improved thermal or mechanical behavior, as compared with lower NaOH concentrations in all cases. Further maleic anhydride treatment modified the fiber, and hence there was increase in degradation temperature but no significant change in mechanical properties. Treatment with 1 N NaOH, under high pressure resulted in improved degradation temperature, but no considerable improvement on mechanical properties. Further followed by maleic anhydride treatment resulted in decrease in tensile strength, but no significant difference in degradation temperature.

The combined treatments resulted in not only the removal of nonfibrous elements from the fiber but also surface modification. They concluded that in spite of the lack of an improvement in thermal stability, the maleic anhydride treatment is essential to be considered, because the use of it improves adhesion between the fiber and matrix. This was due to the introduction of carbonyl groups on the fiber surface as observed in FTIR. The effects of pressure and NaOH concentration have been analyzed and concluded that the influence of pressure seems to be more important than NaOH concentration.

Banana fiber composites based on HDPE/polyamide (PA-66) blends were prepared by twin screw extruder in two stages by Kumar *et al*.[8] HDPE (77 wt%), maleic anhydride grafted polyethylene (MA-g-PE) (3 wt%), and nylon 66 (20 wt%) were mixed and melt blended in a corotating twin screw extrusion plant in the first stage and the untreated 3 mm banana fibers were dispersed into the blends of HDPE/PA 66 in the second stage and again melt blended in the same extrusion plant. Another set of samples were prepared by treating with 5% sodium hydroxide (NaOH) aqueous solution by the same approach. Composites with various fiber content such as10, 20, 30, and 40 wt% were prepared for this study. An increase of banana fibers loading up to 40% lead to a continuous improvement in tensile strength, tensile modulus, and flexural strength of composites, while impact toughness found lowered gradually. In dynamic mechanical analysis, the storage modulus vs. temperature plots showed an increase in the magnitude of the peaks with fibers reinforcement. The heat of fusion of treated banana fibers composites decreased with respect to untreated Banana fiber composites. The morphological studies of tensile fractured specimen showed better fiber matrix adhesion over untreated and hence the performance of the composites made of treated banana fibers was found to be greater than to those of untreated one.

Mechanical and water absorption behavior of banana/sisal reinforced hybrid composites was carried out by Venkateshwaran *et al*.[9] They studied the composites with fibers of different lengths (5, 10, 15, and 20 mm) and weight percentages (8, 12, 16, and 20) in epoxy matrix composites. Composites with 15 mm fiber length at 16% weight reported high mechanical properties. The mechanical properties for this length and weight percentage were 16.12 MPa in Tensile, 57.53 MPa in Flexural and 13.25 kJ/m^2 of impact strength. The addition of sisal fiber up to 50% in the composite resulted in 16, 4, and 35% increase in tensile, flexural, and impact strength, respectively, but less than sisal composites. Minimum moisture absorption was observed for 50:50 hybrid composites. They also concluded that hybridization of natural fiber composite by another natural fiber does not yield superior mechanical properties. However, the length of the sisal fiber considered for this study was mentioned in the report.

Arthanarieswaran *et al*.[10] reported the hybridization effect of woven E-glass (400 gsm with the randomly oriented natural fiber such as banana and sisal. Nine different type of laminates were prepared by them, as per the following stacking sequence of B, S, BS, G/B/G, G/S/G, G/BS/G, G/B/G/B/G, G/S/G/S/G, and G/BS/G/BS/G. Tensile strength of pure banana and sisal laminates were 21 MPa and 23 MPa whereas for banana–sisal(equal weight) hybrid was reported as 25 MPa The addition of one glass layer on top and bottom with banana, sisal and banana–sisal improved the tensile strength by 119, 126, and 156%, respectively, than equal weight randomly mixed sisal/banana hybrid. G/BS/G/BS/G stacking showed highest tensile strength than G/S/G/S/G and G/B/G/B/G stacking. It was observed that the addition of two of glass fiber improved the tensile strength sisal banana hybrid by 2.34, were as for three layer addition the improvement was 4.13 times. The flexural strength of the natural fiber combination ranges between 56 and 62 MPa. The addition of one glass layers each on top and bottom with banana, sisal and banana–sisal improved the flexural strength by 135, 160, and 209%, respectively, than banana/sisal hybrid. Addition of one more layer of glass fiber with stacking sequence of G/B/G/B/G, G/S/G/S/G, and G/BS/G/BS/G increased the flexural strength value by 214, 201, and 163%, respectively. Maximum strength of 192 MPa was observed in the banana–sisal fiber with two glass ply (G/BS/G) as extreme layers. The improvement in the flexural properties of the two layers of glass (G/BS/G) was greater than that of the banana-sisal groupings with three layers of glass fibers (G/BS/G/BS/G) as witnessed in their study. This was mainly due to the nonuniform load transfer between the layers due to the more number of diversity layers. Generally the laminates are subjected to compressive load at the top and tensile load at the bottom and shearing force in the intermediate layers. Maximum impact energy of 13.3 J was obtained for the glass/sisal fiber laminate when stacked alternatively (G/S/G/S/G).

There was a sharp increase in the impact properties of the natural hybrid composites with the incorporation of glass fibers. The impact energy of the sisal, banana and banana/sisal fibers laminates were nearly same. 34, 39, and 53% enhancement of impact value due to addition of two layer glass on extreme ply to the banana (G/B/G), sisal (G/S/G), and banana–sisal (G/BS/G) laminates. The tensile test specimen image illustrated the fiber pullout characteristics of the glass fiber and breakage of the banana and sisal fibers.

SEM analyses revealed that tensile, flexural, and impact performances were affected by the factors such as poor adhesion between fiber and matrix, formation of microcracks, presence of voids, and fiber pullout. In the hybrids major part of the load was absorbed by glass fibers, after its failure the remaining load was transferred to the banana and sisal fibers.

Influence of red mud on the mechanical, damping, and chemical resistance properties of banana/polyester hybrid composites was reported by Arumuga Prabu *et al*.[11] The effect of varying parameters such as particle size (4, 6, and 13 µm) and weight percentage (2, 4, 6, 8, and 10 wt%) of red mud were analyzed on static mechanical, free vibration, and chemical resistance properties of hybrid composites. The addition of red mud showed enhanced performance compared to the virgin BFRPCs in all the above said properties. The maximum increase of 50% in mechanical strength was observed for the BFRPCs with the addition of red mud having 4 µm particle size and 8 wt% of filler content compared to pure BFRPCs. The tensile strength of the BFRPCs increased with the increase in wt% of filler content for all particle size except 13 µm. The flexural and impact strength of BFRPCs were also extensively influenced by the varying particle size of red mud rather than the wt% of filler content. Silane treated composite showed higher tensile strength than alkali treated and untreated one. The change in nature of interfacial bonding between banana fiber and polyester matrix was visually seen for all specimens with different condition, however, the closely packed fiber matrix arrangement seen in the treated BFRPCs which assist the increased tensile strength value due to improved inter facial adhesion. However, the increased stiffness of chemically treated banana fibers resulted in decrease in flexural and impact strength due to the restrained shearing action between the fibers. Addition of red mud with the BFRPCs increased the natural frequency and damping characteristics. All the composites were found to be resistance against various chemicals and due to the uniformly distributed red mud particles.

Hybrid composite made of banana and flax fibers was reported by Srinivasan *et al*.[12].

They prepared composites by sandwiching one layer of banana (B) fiber between two layers of flax fibers (F) and again with Glass fiber reinforcement (G – Woven Roving) top and bottom by hand layup technique. The direction of the banana and flax fibers were varied as vertical (v) and horizontal (h) and used long fibers of equal length. The banana and flax volume fraction was 40% in Epoxy resin system. It was found that hybrid composites of flax and banana with GFRP have better thermal stability and flame resistance over mono fiber composites. The result of test showed that hybrid composite had far better properties than glass fiber reinforced composite under impact and flexural loads. The ultimate tensile strength of the composite G/B (v)/B (h)/B (v)/G was 39 N/mm^2 which is the highest when compared to the composite G/F (v)/F (h)/F (v)/G (32 N/mm^2) and composite G/F (v)/B(h)/F (v)/G (30 N/mm^2, 18.58, 14.04, and 10.24% elongation of was reported for composites stacking, G/F (v)/F (h)/F (v)/G, G/F (v)/B(h)/F (v)/G and G/B (v)/B (h)/B (v)/G, respectively. G/F (v)/B (h)/F (v) G stacked composite has good flexural properties and has excellent ability to absorb impact force and which was established by the results obtained from impact test. Hence, it can be inferred that cracks cannot propagate, when all the layers are of different types of fiber. From values obtained in double shear test, the ultimate shear strength of composite G/F (v)/B(h)/F (v)/G was found to be highest than all other composites considered in their study. They concluded that composite G/F (v)/B (h)/F (v)/G have highest flame resistance and LOI value than the other composites considered in this study.

Banana/pineapple hybrid composites were studied by Madhukiran *et al.*[13] banana/pineapple fibers hybrid composites were prepared for 0/40, 15/25, 20/20, 25/15, and 40/0 weight fraction ratios, while overall fiber content was fixed as 40 wt%. Hybrid composites showed higher flexural strength than the monofiber reinforced composites. The banana/pineapple hybrid composite with weight fraction of 25/15 showed maximum flexural strength, flexural modulus, and maximum inter laminar shear strength.

Bisen *et al.*[14] studied the mechanical behavior of banana (B) and pineapple (P) hybrid composites reinforced with epoxy resin. They prepared 300 mm long aligned fiber composites in the combination of 100 P, 70P30B, 30P70B, 50P50B, and 100B. The tensile strength of banana fiber and pineapple fiber composites was reported as 29.62 and 39.75 N/mm^2, respectively. 30% banana/70% pineapple showed tensile strength of 23.47 N/mm^2 and 70% banana/30% of pineapple by weight was reported as 25.05 N/mm^2. 50:50 combinations composites were found to have maximum bending strength. Higher impact strength for pine apple was reported and it improved with increase in pineapple content in the hybrid. Also they concluded that the combination was not as strong as compared individually. The author had not mentioned the total fiber wt% at which the composites were fabricated and tested.

Ramesh *et al.*[15] prepared a three layer banana fiber composites for their study. The banana fibers were mounted on the base plate and then the resin mixed with the catalyst and accelerator was applied. Before the resin gets dried up the second layer and third layer were placed in similar manner and resin was applied. Then it was pressed under pressure of 6 MPa, at room temperature. 1084.2,112.58, and 98.34 MPa tensile strength, 72.34, 64.68, and 77.21 MPa flexural strength and 8.62, 9.48, and 11.22 Joules impact strength was reported for 40, 50, and 60 wt% of fiber composites, respectively. Micrograph studies showed the good reinforcement of the banana fibers and fiber fracture due to tensile loading. Matrix crack and fiber breakage were also observed on the SEM image of flexural and impact tested samples.

Gopinath and Suresh[16] reported that the fly ash filled, woven banana fiber reinforced hybrid composites can be used as wood substitute. Selected ratio of resin and fly ash mixtures was applied over the woven banana fabric. By keeping four layer of banana fabric as constant, the fly ash (40–55) and polyester weight (60–45) percentages were varied. A load of 250 N applied for 2 hours and cured at room temperature for 24 hour. The developed composites have a tensile strength in the range of 18.4–20 MPa and flexural strength in the range of 40.0–59.6 MPa. The results are compared to the commercially available medium density fiber board and teak wood. The medium density fiber board has tensile strength in the range of 0.6–0.7 MPa and flexural strength 20.0–35.0 MPa and teak wood in range of 4.0–5.0 and 18.0–20.0 MPa.

Da Silva et al [17] investigated the tensile properties of banana and sisal fiber reinforced epoxy composites. The unidirectional long fiber was used to analyze the elastic properties of the fiber.
The experimental stress–strain curve was compared with the Finite Element Analyses (FEA) result and reported that both 2D and 3D models were not able to predict mechanical behavior on sisal fiber composites. Also stated in their study, that the FEA based on the elastic properties from the “Rule of Mixture” exhibited better results compared to Halpin–Tsai model for both sisal and banana fiber composites. Using the scanning electron microscopic images of the composite cross-section, they designed a three-dimensional model (3D). The 3D model was able to simulate the experimental results of the banana fiber composites because of the uniformity and homogeneity of banana fiber composites. But the 3D simulation was not able to predict the mechanical behavior of sisal fiber composites which was attributed to the non-uniformity and heterogeneity of the fibers.

Mizera *et al*.[18] studied the composites fabricated with 2 wt.% of the ensete fibers (false banana originated from Ethiopia region Hawasa) in epoxy resin. They considered short-fiber of 1–2, 2–3, 3–5, 5–6, 7–8 and 9–10, 10, 15, 20, 25, 30, and 35 mm fiber for their study. The modulus of elasticity of the epoxy resin (2.173 GPa) increased due to the addition of fibers and observed improvement with increase in fiber length. The modulus of elasticity of 3.217 GPa was reached at the short-fiber composites for the specimen with the length of the fibers 10 mm. The highest modulus of elasticity 3.341 GPa was reached at the composite with the length of the fiber 35 mm.

Venkatasubramanian *et al*.[19] in their study on evaluation of mechanical properties of abaca-glass-banana fiber reinforced hybrid composites concluded that the abaca/glass composite may be the best option for all general application whereas banana/glass composite can be used in applications where high impact strength is necessary. They studied three different composites samples like banana–GFRP, abaca-GFRP, and abaca–banana–GFRP. They prepared sample in the following combination. Abaca/glass (40–60%) and (50–50%), banana/glass (40%/60%) and (50%/50%), and abaca-banana/glass (40–60%), (50%/50%), respectively. Woven roving glass fiber (E glass type) with a density 610 g/cm^2 was kept in the top and bottom most layer of the laminate. The chopped natural fiber was taken approximately 15 - 20g and volume fraction of 0.5 was used with GFRP for fabricating the all types of composites. The natural fiber 3 plies and 4 plies of glass fiber which is layered intermediate of natural fiber.

Likewise in abaca-banana-glass composite the plies were aligned in the order of intermediate glass fiber and natural fiber which constitutes totally 9 plies (5 plies of glass fibers and 2 plies of sisal fiber and 2 plies of banana fiber). The tensile and flexural properties of abaca/glass was reported to be the highest when compared to abaca/banana and abaca banana/glass considered their study. But banana glass composites reported highest impact strength. The adhesion between the abaca and glass with biphenyl polyester is far better than the other two combinations.

Venkatesha Prasanna *et al*.[20] studied the matrix blend composites reinforced with Pseudo-stem banana and Palmyra fibers treated in 5% NaOH solution and also the untreated fiber. They used epoxy and unsaturated polyester resins blend as matrix material. Composites were prepared with 0, 10, 20, and 30% by volume of untreated and treated samples by the hand lay-up technique. It was observed that 20% volume of treated fibers composite showed higher compressive flexural and impact property properties. 16% increase in compressive strength, 22% increase in flexural strength, and 12% increase in impact strength were recorded for treated fiber composites when compared to untreated one. SEM analysis indicated that there was good fiber/matrix interaction and wetting at 10 and 20% fibers content. But in 30% fibers reinforced blend composites due to more fibers content less number of voids with decreased void size and incomplete wetting between fibers and matrix was observed and hence there was reduction in properties. The effect of some acids, alkalis and solvents that is acetic acid, nitric acid, hydrochloric acid, sodium hydroxide, sodium carbonate, ammonium hydroxide, benzene, toluene, carbon tetrachloride, and distilled water on untreated and treated fibers reinforced composites was studied. Percentage of weight loss or % weight gain values of untreated and treated fibers reinforced blend bio composites immersed in acids, alkalis and solvents were calculated. Weight gain of composites was observed for almost all the chemical reagents except toluene and carbon tetrachloride for treated as well as untreated fiber composites. The reason was the wt loss in toluene and carbon tetrachloride was due to the attack of the chlorinated hydrocarbons on the cross linked epoxy-polyester system as stated by the author. This study clearly showed that the banana-palmyra fibers reinforced matrix bled composites are substantially resistant to almost all the chemicals except toluene and carbon tetrachloride and therefore suggested that these banana-palmyra fibers reinforced blends can be used in automobile and transportation applications. However the author had not clearly spelled the resin blend ratio and the fiber lengths and wt% of individual fiber considered in their study.

Singh et al [21] investigated the effect of silica in banana fiber reinforced epoxy composites. It was found that when increasing the silica wt% there was an increase of modulus of elasticity and reduction ultimate tensile strength. When increasing of banana fiber highly reduce the yield strength than silica composites. In case of impact strength both banana and silica showed improved strength.

Addition of fibers increases water absorption and the silica addition enhanced the same. Addition of banana fiber and silica reduces bending strength. But improvement in Rockwell Hardness values on M-scale was observed for addition of banana fiber and further addition of silica enhanced it. The author had mentioned neither fiber length nor the silica particle size.

Chitosan is a kind species found Indian Sea Foods, Cochin, and Kerala. Mubashirunnisa *et al*.[22] developed a banana/glass short hybrid fiber reinforced nanochitosan (NC) polymer composites. About 15 g of chitosan was dissolved in 3 L of conductivity water containing 60 mL of 2% v/v acetic acid and stirred well for 45 minutes. 12 g of sodium hexametaphosphate dissolved in 1600 mL of conductivity water was added dropwise to the chitosan solution prepared earlier. A milky colored emulsion like appearance was obtained. Milky colored solution allowed to settle by adding conductivity water for 24 hours and it was kept overnight. Fiber was added with glutaraldehyde agent and stirred for 30 minutes. This mixture was poured in to the nanochitosan solution and allowed to dry to get the composites. They studied the sample made of NC with glass, NC with banana fiber. The lengths of the fiber considered were of 0.25 cm dust of and 3 cm short fiber of banana as well as glass. They reported that there were no significant differences in the molecules and the bonding in the composites when compared to the materials such as banana fiber, glass fiber, and nanochitosan. The XRD results concluded that the glass fiber reinforced composites were more crystalline nature and higher dispersion than banana fiber composites in the matrix. TGA and DSC studies revealed higher thermal stability and degradation temperature for the nanochitosan with banana fiber composites than the nanochitosan with glass fiber composites.

Banana fibers of 30 wt% aligned reinforcement in epoxy resin and vinyl ester resin matrix was studied by Santhosh *et al*.[23] They studied the composites prepared with untreated, 5% NaOH treated and also by adding coconut shell power (the size and the quantity of the powder not reported) by hand layup method. The tensile, flexural, and impact properties of the untreated banana epoxy composites were found to be 6.185 MPa, 24.621 MPa and 4.91 kJ/m^2 whereas for vinyl ester resin it was 11.416 MPa, 33.84 MPa and 2.56 kJ/m^2, respectively. The tensile, flexural, and impact properties of the treated banana epoxy composites were reported as 22.63 MPa, 51.28 MPa and 8.11 kJ/m^2 whereas vinyl ester resin showed 17.65 MPa, 48.205 MPa and 4.41 kJ/m^2, respectively. The coconut shell powder banana epoxy composites reported 19.63 MPa in tensile, 45.78 MPa in flexural and 4.27 kJ/m^2 in impact but coconut shell powder vinyl ester resin it was 19.63 MPa, 43.076 MPa and 3.63 kJ/m^2, respectively. The result recorded that the banana epoxy had higher mechanical properties than banana vinyl resin and the alkali treatment had more effect on the epoxy matrix than vinyl matrix. The coconut shell powder addition did not showed any improvement in properties in both matrixes.

CONCLUSIONS

The natural fiber banana and hemp fiber are more eco-friendly. Although it is old materials the potential of its usage in various industrial applications increases day by day due to its high mechanical performances. Nowadays the hybrid composites usage increases due to the high strength compare to glass fiber. These fibers used along with polymer matrices which give some potential enhancement in properties also along with fillers these fibers proved to offer better results.

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