A brief review on mechanical and thermal properties of banana fiber based hybrid composites

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Received: 19 September 2020 / Accepted: 14 January 2021 / Published online: 22 January 2021
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Abstract

The usage of banana natural fibers along with polymer matrix composites had created much interest among the researchers due to their low cost, easy availability, strength and enhancement in properties such as mechanical, wear, electrical and thermal. Banana plant is cultivated all over the world which is familiarly used as food products especially banana fruit as well as many household items made from banana fibers. The natural fiber extracted from the banana stem proves to be a potential reinforcement in the composite manufacturing. This review is very much needed because of the enormous research reported on the banana fiber reinforced polymer composites, with such an excellent property offered by this banana fiber reinforcement the impact of hybridization and its need also to be addressed. This brief review article gives a detail information about the combinations of various hybrid composites produced using the banana fiber along with various other natural/synthetic fibers in the polymer matrixes and its performance improvement especially in the mechanical and thermal properties. From the review it was inferred that 30–50% increase in all the mechanical properties such as Tensile, Flexural and Impact strength. Also in addition an enhancement in thermal and moisture resistance also noted. In addition during this review the research gap observed is that the development of bio composites based on banana fiber is very limited and also the influence of banana fiber along with bio resin needs to be studied. The properties such as fatigue, fire resistance also to be analyzed using the banana fiber reinforcement.

Keywords Banana fiber · Hybrid composites · Thermal properties

1 Introduction

The Composites produced from natural fibers has created more interest among the researchers due to their good strength, less cost and more importantly their easy availability. In the world, various types of natural fibers available such as sisal, bamboo, okra, pineapple, jute, banana, coconut, palmyra, flax, hemp and remie which are cultivated as plant and fibers extracted from those are used as reinforcement especially in the polymer matrixes to produce the composites [1–3] and have found their applications in various household items to automobile parts. Among

all the plants available which is grown by nature itself not suits for either using reinforcement or as a natural fiber for composite making. Based on the following conditions only it should be decided:

- The fibres will be easily extracted from the concern natural plant or any sources.
- The fibres easily bond with the matrix.
- The strength of all the natural fibers and the fiber content depends on cellulose and lignin presence. This is an essential factor that decides a fiber to be used as reinforcement along with the matrixes. A most suitable

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natural fiber has the cellulose content between 6 and 80 wt% and the lignin content between 5 and 20 wt%. The moisture content is upto 20% wt.

Few interesting merits offered by the natural fiber composites [4] are:

- When compare to E-glass fiber the specific weight is very low which in term offers higher stiffness and specific strength.
- A natural fiber composite uses the nature available sources itself hence it is a renewable ones as well as it protects the environment in such a way inhaling CO₂ and releasing oxygen.
- Developing countries utilize this material effectively for an efficient product manufacturing because of its low cost investment.
- Excellent healthier work environment, no hazards to human and also enhanced tool life is some other special features of the natural fiber composites.

With these many advantages the natural fiber composites find its applications in:

- Transportation sector—Interiors of automobiles, railway coaches and boats
- Building and construction sectors involves the replacement of panels for partition and fall ceiling, partition boards, wall, floor, window and door frames, roof tiles.

The usage of various natural fiber based composites in the automotive sector [5] is high due to the advantages such as low density, good mechanical and acoustic properties, accident performance favours, high stability, less splintering and environment friendly. When compared to glass fibers during the production natural fibers possess price advantage both for material as well as the applied technologies.

2 Banana fiber hybrid composites and its fabrication

The world is moving towards adopting enhanced technology day by day which indirectly influences the usage of materials that needs updation. Based on this aspect the researchers are focusing on the development of new innovative materials from various renewable sources. In this regard, the development of composite materials from various natural fibers is growing rapidly. One such available natural source is the banana fiber which is extracted from the banana stem and banana fruit which is used worldwide by all the humans. The banana fiber possess

high strength and stiffness that makes it as a suitable reinforcement in both thermoplastic and thermoset matrices. Another interesting factor that makes the banana fiber as a suitable reinforcement replacing the existing ones is its composition which has a high cellulose content of 63–64% and lignin content of 5% [3]. The banana fibers are extracted by using a fiber extracting machine. The fiber rich area is one which is the pseudo stems of the banana plant. This raw material is cheap and abundantly available. The banana fiber utilized for composites making is completely a waste product obtained during the banana cultivation. Moreover, without any additional cost input, banana fiber can be obtained in bulk quantity. A typical prepared banana fiber polyester composite cut specimens are shown in Fig. 1.

The one which is said to be a hybrid composite has two or more different types of fibers combine together in a common matrix. It is not only the fibres in few cases with fillers in a common matrix are also said to be a hybrid composite. The phenomenon of hybridization drastically improves a wide range of properties as reported earlier through many research works. The material costs can be reduced to a greater extent and also high performance can be obtained by the effect of hybridization. Few combinations of hybrid composite developed using natural fibers are banana/sisal, glass/banana, glass/sisal, oil palm/sisal, glass/oil palm, pineapple/glass, coir/glass, which produce better performance. A lot of research works has been carried out by earlier researchers [2, 3] using glass fiber as a hybrid. Natural fibers of various types are reinforced with synthetic fibers produce a composite with high strength and low cost.

Some common fabrication methods that are available for the manufacturing of natural fiber reinforced composites that well suit for the banana fiber also are as follows:

- Hand lay-up method
- Open moulding methods
- Resin infusion processes and
- High volume moulding methods

A typical hand layup method involves a mould for the purpose of bonding the resin and reinforcement. In this

Fig.1 Banana fiber reinforced polyester composite specimens

the fibres are arranged in random form or in layers that were placed in the mould then the resin was poured over the fibre. The mould is closed and then left to cure to obtain the final composite. The open moulding method is a partial automated one where the same pattern like hand layup is adopted in which the major difference is the resin pouring way which involves sprayup method. The resin infusion process replace the hand layup in the case of faster production rates need where the same process is repeated in which the mixing of resin and fiber varies in the sense of applying pressure. Some of the familiar methods used were resin transfer moulding (RTM), reaction injection moulding (RIM) and vacuum assisted resin transfer moulding (VARTM). The last method involved is a very popular one where by means of applying high uniform pressure the composites were manufactured. Typical techniques involved are compression moulding, injection moulding, filament winding, tube rolling, pultrusion and centrifugal casting. Among this existing various methods for the composite production opt ones selected depending on the applications. The nature of the banana fiber suits well for most of the methods. The most familiar method used for fabrication of banana fiber composites is the compression moulding method. In this the banana fiber reinforcement and polymer matrix of different weight percentages and different lengths were taken and placed in the mould. Then the mould is placed on the compression moulding machine where it is subjected to a high pressure press by means of which the matrix and reinforcement bonded together strongly. A sample banana fiber composite specimens prepared using compression moulding method is shown in Fig. 1.

3 Banana fiber hybrid composites and its thermal properties

An indepth thermal properties analysis on the banana fiber reinforced polypropylene (PP) composites has been carried out on varying fiber weight percentages and fiber treatments where the thermal conductivity and thermal diffusivity are measured. It was noticed that the untreated banana fiber into the PP matrix reduces the thermal conductivity but in other way the treated banana fiber enhance the thermo physical properties drastically [6]. Manorajan Biswal et al. [7, 8] carried out same banana fiber with PP matrix in addition includes nano clay to develop a nanocomposite with more enriched thermal performance. It was inferred that the mechanical properties improved drastically by means of nano clay addition also the thermal stability of the composites improved a lot which is evident from the thermogravimetric analysis. Again studies have been done using banana fiber reinforced PP matrix

in which the composites were prepared by melt bending technique. When compared to pure PP the presence of nano clay in the composites improves the T_c value to a greater extent.

Thermal properties analysis on the hybrid composites prepared using banana and jute fiber [9, 10] reinforced in the epoxy matrix have been fabricated and it was inferred that the addition of equal weight percentage of jute that is 50%wt possess excellent thermal and mechanical properties. The tensile, flexural and impact strength of the composites were increased by means of the hybrid fiber and the thermal property starts to decline in few weight percentage combination which is improved by means of fiber treatment also reported. For the same hybrid combinations the thermal stability, specific heat and the thermal conductivity studies have been performed using a new micromechanical model. In this it was inferred that the composite with 10%wt banana and 30%wt jute fiber possess higher thermal stability and thermal conductivity when compared to the normal ones.

The hybrid composites were prepared using the combination of short banana and sisal fiber [11] in polyester matrix with variation in layering pattern. The composites were prepared as bilayer and trilayer in which the banana fiber used as skin and the sisal fiber used as a core material. From the testing it was noticed that the trilayer composite shows the high stiffness property whereas the bilayer shows the high damping property. Jandas et al. [12] performed the studies on bio composites developed using the banana fiber and polylactic acids prepared by means of melt bending technique followed by compression. The banana fiber used for preparing bio composites are treated with NaOH as well as various types of silanes subjected to thermal property studies and this indicates that the silane treated possess better thermal stability. Also found that the surface treated fiber possess higher storage modulus. In addition the surface treated fibers only had shown high microbial performance.

Jawaid et al. [13, 14] performed review on the importance of hybrid composites especially the combination of natural fiber along with the synthetic ones. Also discusses about the mechanical, physical, DMA and thermal properties of the same combination prepared composites. It was concluded that the research in hybrid composites with synthetic/natural fiber composites yields high strength. Also it was economically feasible and biodegradable ones. In addition noticed that the thermal properties studies on these hybrid composites is still in the lacking part and their applications limited only in automotive sectors be extended to other sectors such as construction, biomedical and aircraft industries in the near coming future. Another interesting study on the banana fiber has been carried out to known its aging behaviour in phenol

formaldehyde matrix with the glass fiber reinforced composites. To know the aging it is subjected to tests such as water, thermal, soil burial and outdoor weathering. It is inferred that both the composites shows low effect only in water and the thermal tests. In the case of soil burial and outdoor weathering test the treated composites produces better results [15]. Kulkarni et al. [16] in their research performed the studies on banana fiber hybrid composites with flyash and polypropylene composites. This combination composite offers better strength due to the filler flyash addition which is easily available. This offers strength in such a way that it replaces the synthetic glass fibers. Banana fiber composites were produced using high density poly ethylene and nylon 6 blends [17]. The composites were fabricated using two-step extrusion process and both matrixes are compatible in such a way offers better mechanical properties as well as thermal stability.

Mohan et al. [18] performed studies on the banana fiber with a special reference to infusion of nano clay as a filler in the composite. The nano clay infused by means of NaOH treatment of fibers and the results were compared with that of untreated fiber. It is noted that the addition of 6%wt nano clay infusion improves the thermal properties and mechanical properties of the composites to a greater extent i.e., 53% increase in tensile strength and 18% increase in high temperature degradation was observed. The studies on hybrid composites continued by varying different combinations of fibers such as sisal/jute, glass/jute [19] and fillers, one such combination is the banana and carbon fiber reinforced epoxy composites. It has been noted that the combination of 20% carbon fiber and 80% banana fiber posses better mechanical enhancement as well as moisture absorption [20]. A new type of chemical treatment of banana fibers using sodium hypochlorite has been carried out to know its performance on the thermal properties, mechanical properties and moisture resistance since the treatment improves the compatibility rate between the reinforcement and matrix. It was concluded that the physical, thermal and mechanical property of the composites increased drastically which make it as a better suitable ones for the production of bio composites [21].

A thorough analysis on the effect of hybridization in natural fiber and synthetic fiber in the polypropylene matrix has been done to know its mechanical performance and thermal behaviour. The combination of bamboo/glass fiber [22], banana/glass fiber [23] performance when reinforcing in the polypropylene matrix reported that there is an drastic increase in the mechanical property as well as thermal stability in both the cases of fiber combination mainly due to the polypropylene matrix which creates an enriched bonding between the matrix and fiber as well as the temperature, visco

elastic properties also get increased. Further development focuses on the production of bio composites using banana fiber as many researchers' starts moving towards the concept of "bio" that is environment friendly ones. The bio composites were prepared using banana fiber, flyash cenospheres and recycled high density polyethylene [24]. It was noted that the combination of 30%wt banana fiber, 7.5%wt flyash cenospheres and 3wt% of matrix shows a tremendous increase in the tensile strength by 17%, flexural strength by 38% and hardness by 37%. The dynamic mechanical behaviour studies also indicate a high increase in the storage and loss modulus of the composite.

Sathish et al. [25] performed the studies on hybrid combination of banana and kenaf fiber reinforced epoxy composites with special reference to the fiber orientation and fiber stacking sequence. It is inferred that the kenaf fiber with 60% wt and banana fiber 40% wt improves the tensile, flexural, impact, shear and compressive strength properties in a quite good manner, on the other hand the thermal expansion property of the composite also notably good for the same composite combination as well as the flammability property. Another combination is the banana and flax fibers [26] both are natural fibers and placed in glass fiber reinforced polymer i.e., silica glass used for covering and epoxy used as the matrix. From the results it is clear that the hybrid behaviour increases the mechanical and thermal stability of the composites when compared to individual fiber reinforcement. The mechanical property and thermal stability is high in the case of this composite also. Another interesting study done on the banana fiber in the form of nano composites which is fully biodegradable that is bio nano composites production. For the same the banana fiber reinforced into polylactic acid and the nano clay filler. This combination subjected to the thermal degradation and flammability studies using TGA analysis from which it is strongly proved that the addition of nano clay increase the thermal degradation temperature when comparing with the PLA and banana fiber [27]. Further thermal studies on the banana fiber pseudo stem carried out using UPVC composite [28]. To improve the properties the UPVC is blend with acrylic resin and noted an enhanced thermal stability. The hybridization studies on the banana fiber expanded using another combination in such a way Palm and glass fiber added to form the composites. From the study it has been concluded that the optimum weight percentage for banana and palm fiber composites is 40% wt which yields better results. Both the hybrid composites at 40%wt offer better degradation temperature. The summary of various combinations of banana fiber composites is shown in Table 1

Table 1 Various combinations of banana fiber hybrid composites

S.No	Type of hybrid composites- reinforcement/matrix	Fabrication methods	Thermal testing done
1	Banana fiber /polypropylene	Compression Moulding	Thermal conductivity and thermal diffusivity
2	Banana fiber /polypropylene/nanclay	Melt blending and compression Moulding	DSC and TGA
3	Banana fiber /Jute fiber/epoxy	Hand Layup and compression Moulding	TGA and HDT
4	Banana fiber /sisal fiber/polyester	Hand Layup and compression Moulding	DMA
5	Banana fiber /glass fiber	Compression moulding	DMA and TGA
6	Banana fiber/Flyash/polypropylene	Injection moulding	DSC
7	Banana fiber/nylon 6 blends/polypropylene	Injection moulding	DSC and TGA
8	Banana fiber/kenaf fiber/epoxy	Hand lay-up process	TMA and TGA

4 Banana fiber hybrid composites and its mechanical properties

This section discusses briefly about the mechanical performance studies on the banana fiber reinforced various polymer matrixes composites and its applications. In addition the effect of hybridization in banana fiber reinforcing with other natural fibres and synthetic fibers also discussed which is as follows:

The banana polyester reinforced composites mechanical properties studies were performed by Laly Pothan et al. [30] with varying fiber length and fiber weight percentage and it was evident that the combination of 40% wt and 30 mm fiber length showed drastic increase in the mechanical strength as well as moisture absorption that produces an increase in water uptake with the fiber content.

Sabu Thomas et al. [31, 32] performed various studies on the stress relaxation behavior of banana fiber-reinforced polyester composites with varying parameters such as fiber loading, fiber treatment, hybridization with glass fiber, sisal fiber and also as woven fabric composites. From the results it has been observed that the banana fiber with 40% wt, banana fiber treated with NaOH shows lowest decrease in stress and hybridization with glass decreases the stress more as compared with other cases, also an increase in tensile and flexural strength happens by the hybrid effect of sisal fiber.

Another interesting study has been done by Maleque et al. [33] on pseudo-stem banana woven fabric reinforced epoxy composites mechanical properties and it was identified that the tensile strength increased 90% by reinforcing with epoxy and the impact strength increased by 40%. This indicates the high toughness properties of the banana/epoxy materials. Further studies done based on the characterization of banana fibers [34] to know about their diameter variability and the mechanical properties with reference to fracture morphology. From this study the

potential usage of banana fiber as reinforcement strongly justified as an effective one for natural fiber reinforced composite production.

The mechanical properties, moisture absorption comparison studies on woven banana fiber and pandanus fiber reinforced polyester composites have been done by Mariatti et al. [35]. In this vacuum bagging technique was used to fabricate the composites and it was inferred that the woven banana fiber possess better flexural and impact property than the woven pandanus fiber. Further experimental studies has been done by Linaherrera-Estrada et al. [36] to optimize a process for the production of banana fiber reinforced polyester and epoxy composites suitable for automotive and transportation industry applications. Also they continue the studies on the performance of treated banana fibers.

Anshida Haneefa et al. [37] carried out studies on the development of hybrid composites to improve the mechanical performance of banana fiber reinforced composites. Along with banana fiber, glass fiber was hybridized and the influence of hybrid effect, fiber content and fiber effect on the mechanical properties was reported. It was inferred that the tensile and flexural strength increased by increasing the fiber weight percentage. Further studies have been done on banana empty fruit bunch fiber (banana-EFB) reinforced with polyester [38] and inferred that the tensile strength increased by 36% and the flexural strength by 1.42 times of polyester resin respectively. Light weight composites were fabricated by means of this combination.

The banana fiber as a suitable reinforcement in cement and polymer based composites and its performance review studies has been done by Venkateshwaran et al. [39]. In this special inference given to the structure, physical, mechanical properties and different surface treatments of the banana fiber based composites. Banana fiber due to its low density, high tensile strength and low elongation at break is suitable for usage in various sectors like

construction, automotive and machinery. Further review study on the use of woven natural fiber especially the banana and kenaf fiber as hybrid composites reinforced polyester were performed by Alavudeen et al. [40] with a special reference to weave pattern, chemical modification and other factors which affects the mechanical properties. In the review it was concluded that this hybrid composite potentially used in non load bearing automotive components.

Maries Idicula et al. [41] carried out the preparation of hybrid composites using the combination of banana/polyester, sisal/polyester composites with varying weight percentages of 20–50%wt were taken. Both sisal and banana fiber volume fraction varied with respect to each other and it was noticed that the composite with 40% wt shows better performance on the mechanical properties when compared with other weight percentages. Studies on the banana fiber reinforced low density polyethylene composites were carried out by Nur et al. [42] in which the composites are prepared by using compression molding technique in this both treated and bleached (untreated) fiber of different weight percentages range 7.5, 15, 22.5 and 30% wt were taken and noticed that the tensile and flexural strength take an increase of upto 22.5%wt.

Tensile strength studies on banana fiber with vinyl ester resin have been done by Rajesh Ghosh et al. [43]. The increase in fiber volume fraction increases the tensile strength gradually on other hand lowering the volume fraction the composite strength gets reduced. Also they suggested that the usage of banana fiber reinforced vinyl ester resin for various engineering utilities because of its high specific tensile strength. Fibers were extracted from the banana stem and the banana bunch fibers reinforced composites were subjected to the tensile property studies [44]. After extraction the fibers were surface treated and laminated with rubber. From the results obtained it was identified that the banana stem fiber treated with a mixture of NaOH and Na₂SO₃ shows enhanced strength when compared with that of untreated ones. The various hybrid composites combinations used and its applications are presented in Table 2

5 Conclusions

From this brief review the following conclusions were drawn:

- In this review banana fiber reinforced polymer composites research were discussed and observed that this predominantly play a vital role for the past 25 years in replacing the conventional materials.
- This review also discusses about the various researches carried out in the banana fiber reinforced composites hybrid combinations produced and utilized especially during the period 1990–2013 and between 2014 and 2018.
- It is clearly evident that the banana fiber reinforced composites in the polymer medium shows an excellent improvement in the mechanical properties such as Tensile, Flexural and Impact strength. An approximate 50% increase in the strength has been observed in all the mechanical properties during the review.
- Among the various weight percentages of banana fiber it was noted that the banana fiber between 30 and 40%wt shows better performance. The same be mentioned and reported in earlier reviews and researches.
- The banana fiber reinforced polymer composites also possess better thermal stability when compared with other natural fiber which widens its application in thermal fields as a temperature resistance one.
- In general natural fiber has a high moisture absorption capability and banana fiber not a exception from that the addition of banana fiber with polymers produces an excellent moisture resistance property.
- Few works have been reported on the flammability and electrical resistance properties of the banana fiber composites also give better satisfying results which makes it more suitable for producing chips, resistors, batteries etc.,
- Another major criterion in the era of composites is the hybrid concept. Tremendous works has been done on the same by using banana fiber with sisal, kenaf, jute, coir and glass fibers with varying weight percentages,

Table 2 Hybrid composite combinations of banana fiber composites and its applications

Type of hybrid composites-reinforcement/Matrix	Fabrication methods	Mechanical Testing Done	Applications
Banana fiber /polyester	Hand layup method	Tensile strength	Automotive industries
Pseudo stem banana Woven fiber /epoxy	Resin transfer moulding	Flexural strength	Transportation industries
Banana fiber /pandanus fiber/polyester	Twin screw extrusion	Impact strength	Construction industries
Banana fiber /glass fiber/polyester	Compression moulding	Compressive strength	Packaging
Banana fiber/kenaf fiber/polyester	Injection moulding	Shear strength	
Banana fiber /low density polyethylene	Filament winding		
Banana fiber/vinylester	Pultrusion		

layers and fiber length, orientation. From this many of them reported that the mechanical properties and thermal properties get further enhanced by means of combining two natural fibers.

- Based on this review it was noted that further intense studies on the thermal properties of the banana fiber composites were needed. Another essential thing is as the generation is moving towards the bio concept the development of biocomposites is initiated using banana fiber but further research still needed to widen its scope. Also more interesting properties such as erosion, flammability, electrical resistivity and adaptability performance also needs attention.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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