Study on the Development of Banana Fibre Reinforced Polymer Composites for Industrial and Tribological Applications: A Review

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Abstract. Fibres form one of the basic tenets of the human society. Fibres are used as the building block of human existence and thrive. The fibre technology is mostly comprised of artificial fibres in the present day due to their longevity, stability and inertness. However, these fibres destroy the integrity of nature as they are non-biodegradable and pollutant in nature. This has led to an increase in the usage of natural fibre based composites. These composites add to the effectiveness of the artificial composites. One such fibre is banana fibre. Banana fibre is obtained from the trunk of the banana tree (Musa acuminata) which is a plant native to Southeast Asia. Effectively considered as a waste material after the harvest of the fruit, banana fibre has shown remarkable properties as an additive in the preexisting fibres. The addition of banana fibres in the materials have shown to produce a remarkable improvement in the chemical, mechanical and physical attributes of the fibres. This paper gives the overall view in the field of banana fibre reinforced polymer composites and its physical, mechanical and tribological properties of the composites. Emphasis is laid in evaluating all the factors of the advantage of banana fibre. Banana fibre reinforced composites, in turn, enable the development of industrial and tribological components having excellent wear, friction and lubrication properties which finds numerous applications

1. Introduction
Composites are widely used in our day to day life. Due to their low weight and ability to be moulded for specific usage they have gained a considerable fame in performance applications, such as aerospace and automotive industry. Nowadays the industry is being by natural fibre reinforced composites. The reinforced composites are on a rise due to the properties of biodegradability and revamped properties of the base fibre. The reinforcing property of the natural fibers is due to their lignistic content and their crystallinity. In recent years, natural fibers are gaining considerable attention due to their properties of low cost and varied applications. The recent developments in the area of fiber technology has led to the realization of the potential of the composites in the near future[1]. One of the most important developments has been in the discovery of uses of banana fibers. Banana fibres
obtained from the trunk of the trees of the Musaceae species of plant have started to become as a renowned interest for scientist all over the world. Cellulose has been found out to be the main constituent of plant fibres followed by lignin, hemicellulose and pectin. Cellulose serves as the reinforcement for all other constituents. Higher the aspect ratio of the fibers, higher is the tensile strength aiding reinforcement. The variability of these properties enables plant fibers to exhibit characteristics of a composite material. As examine by Satyanarayana K.G. et.al. [2] Several plant fibers such as sisal, coir and banana find resourceful usage in industry. Palanikumar et.al. [4] Reviewed the inherent properties of fibers along with their extraction techniques employed as resins in the composite. Justiz Smith and Satyanarayana K.G. et.al. [2,3,5] have also shown the mechanical and physical properties of some naturally occurring fiber as shown in Table1 & Table 2

Table 1 Physical and Mechanical Properties of Natural Fibres Courtesy of Satyanarayana, K. G (1984) [2]

| Fibers  | Width or Diameter(μm) | Density (kg/m³) | Cell l/d ratio | Microfibrillar angle (degrees) | Initial Modulus(Gpa) | Ultimate tensile Strength (Mpa) | Elongation (%) |
|---------|-----------------------|-----------------|----------------|------------------------------|---------------------|-------------------------------|----------------|
| Coir    | 100-450               | 1150            | 35             | 30-40                        | 4.6                 | 106-175                       | 17-47          |
| Banana  | 80-250                | 1350            | 150            | 10±1                         | 7.7-20.0            | 54-754                        | 10.35          |
| Sisal   | 50-200                | 1450            | 100            | 10-22                        | 9.4-15.8            | 568-640                       | 3-7            |
| Pineapple Leaf | 20-80 | 1440            | 450            | 8-14                         | 34.5-82.5           | 413-1627                      | 0.8-1          |
| Palmyra | 70-1300               | 1090            | 43             | 29-32                        | 4.4-6.1             | 180-215                       | 7-15           |

Table 2 Physical Properties of Different Cellulosic Fibers, Courtesy of Justiz-Smith(2008) [5]

| Fibers   | Moisture Content (wt %) | Ash Content (wt %) | Carbon Content (wt %) | Water absorption (wt %) | Tensile Strength (Mpa) |
|----------|-------------------------|--------------------|-----------------------|-------------------------|------------------------|
| Banana   | 85.6                    | 8.3                | 50.9                  | 40                      | 142.9                  |
| Coconut  | 27.1                    | 5.1                | 51.5                  | 169                     | 138.7                  |
| Bagasse  | 52.2                    | 4.5                | 53                    | 235                     | 29.6                   |

Laly et.al. [6] has investigated on banana fibers to deduce the optimum quantity in composites to be about 40%. Justiz smith et.al. [5] have examined the longitudinal sections of banana fiber reinforced composites to calculate the presence of metal ions in the following percentages as shown in Table 3 .

Table 3 Metal elements present as ions in Cellulosic Fibers Courtesy of Justiz Smith (2008) [5]

| Fibers   | Al3+     | Ca+     | Mg+     | Na3+     | Si+4    |
|----------|----------|---------|---------|----------|---------|
| Banana   | 0.14     | 5.72    | 1.77    | 0.28     | 1.41    |
| Coconut  | 0.03     | 2.44    | 0.76    | 2.53     | 2.56    |
| Bagasse  | 3.89     | 3.87    | 1.32    | 0.97     | 27      |

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Reddy.N.et.al. [7] gave the various properties of cellulose based fibers as shown in. Table 4 and Table 5

Table 4 Chemical Properties of Natural cellulosic Fibers Courtesy of Reddy N.(2003) [7]

| Fibers  | Lignin (wt %) | Cellulose (wt %) | Hemicellulose (wt %) |
|--------|---------------|------------------|----------------------|
| Banana | 9             | 43.46            | 38.54                |
| Coconut| 59.4          | 32.65            | 7.95                 |
| Bagasse| 13            | 30.27            | 56.73                |

Table 5 Structure and Properties of Bio Fibers Courtesy of Geethama, V. G.(1995) [8]

| Fiber       | Fiber Structure | Fiber properties |
|-------------|-----------------|------------------|
|             | Cell Dimensions |                  |
|             | Length (mm)     | Width (μm)       | Crystanlity | Tenacity g/den° | Elongation % | Moisture % |
| Coir        | 0.3-1.0         | 100-450          | 27-33      | 2               | 17-47       | 10-12      |
| Bagasse     | 0.8-2.8         | 10-34            | -          | 0.9-1.25        | 5.5-11.8    | 8.8        |
| Banana      | 0.9-4.0         | 80-250           | 45         | 2.4-3.7         | 1.0-3.5     | 10-15      |
| Palf        | 3-9             | 20-80            | 44-60      | 0.7-3.8         | 0.8-1.6     | 10-13      |
| Wheat Straw | 0.4-3.2         | 8-34             | 45         | 2.3-4.8         | 1.0-3.5     | 10-15      |
| Rice Straw  | 0.4-3.4         | 4-16             | 40         | -               | -           | 6.5        |

Corbiere Nicollier et.al.[9] has investigated mechanical and physical properties of banana cement fiber composites. Natural fibers are called as reinforced materials and the cellulose content and microfibril angle determine the physical properties. High value of cellulose content and low microfibril angle for banana fibers indicate its apparent sustainability as a reinforcing material [10]. Hybridization of two different fibers’ has proved to be an effective method in the design of materials [10,11,12]. Corbiere Nicollier et.al.[9] has investigated mechanical and physical properties of banana cement fiber composites. Natural fibers are called as reinforced materials and the cellulose content and microfibril angle determine the physical properties. High value of cellulose content and low microfibril angle for banana fibers indicate its apparent sustainability as a reinforcing material [10]. Hybridization of two different fibers’ has proved to be an effective method in the design of materials [10,11,12]. The aging studies of reinforced composites show that reduction in mechanical properties of hybrid composite is nearly half of hybridized composite [10,11,12]. Thomas et.al. [13] has proved that ‘banana fibers’ and sisal fibers’ gives better performance and can be used as an effective reinforcement agent in polyester matrix. Laly et al [13,16] and Kalaprasad G et.al. banana fibres were hybridized with glass fibres to get better mechanical performance. Mohan Rao et.al. [17] showed that cross-sectional area of banana fibre taken for analysis is 0.3596 mm2. The cross-sectional dimensions are measured along different orientations. It is noticed that, magnitude of laser beam diffractions is dependent on the curvature of the cross-section. Hence we can conclude that the test gives us relative structures instead of actual structure. Laly A. Pothan et.al. [18] have compared the cellulose content and fibrillar angle to strengthen the notion of use of banana fibres as a reinforcing material. An increase in the quality of the
fibres has been observed wherever banana fibre has been used as a reinforcing material. All the classified properties show an improvement since the reinforcing causes change at molecular level. The various aspects can be evenly controlled by varying the percentage of different contents. Kulkarni et.al.[19] investigated the structure of fibre using optical microscopy. Banana fibres constitute of xylem, phloem, sclerenchyma and parenchyma. Also the number of various cells and helix angle for different diameter of the fibres are given in Table 6. Also the variation in mechanical properties with reference to diameter of fibre is also shown in Table 7.

Table 6 Number of Various cells and helix angle of banana Fibers for Various Diameter Courtesy of Kulkarni, A. G (1982) [19]

| Diameter of fiber(μm) | Average no. of xylem cells | Average no. of Phloem cells | Average no. of Sclerenchyma cells | Total No. of cells | Fraction of Sclerenchyma cells to the total no. of cells ( Strength donating ) | Helix or Microfibrillar angle (θ) |
|----------------------|----------------------------|----------------------------|-----------------------------------|-------------------|---------------------------------------------------------------------------------|-------------------------------|
| 100                  | 3                          | 6.25                       | 53                                | 62.25             | 0.85                                                                             | 12±1°                          |
| 150                  | 3                          | 8                          | 70                                | 81                | 0.875                                                                            | 11±2°                          |
| 200                  | 4                          | 7.75                       | 92                                | 103.25            | 0.886                                                                            | 11±1°                          |

Table 7 Mechanical Properties of Banana fibers of different diameters. Guage length =50 x 10-3

| Sample Number | Diameter of fiber (μm) | Initial Youngs Modulas (GN/m²) | SD Initial Youngs Modulas (GN/m²) | Breaking strength (MN/m²) | SD Breaking Strength (MN/m²) | % Strain | SD % Strain |
|---------------|------------------------|--------------------------------|-----------------------------------|--------------------------|-------------------------------|----------|-------------|
| 1             | 50                     | 32.703                         | 8.19                              | 779.078                  | 209.3                         | 2.75     | 0.957       |
| 2             | 100                    | 30.463                         | 4.689                             | 711.661                  | 239.614                       | 2.469    | 0.798       |
| 3             | 150                    | 29.748                         | 8.561                             | 773.002                  | 297.104                       | 3.583    | 1.114       |
| 4             | 200                    | 27.698                         | 7.083                             | 789.289                  | 128.558                       | 3.34     | 0.688       |
| 5             | 250                    | 29.904                         | 4.059                             | 766.605                  | 165.515                       | 3.244    | 1.284       |

Laly A. Pothan and Hoyur et.al. [20,21] have discussed the various technique for the production of the fibre and the strength of the bio-composites. Banana fibres obtained from the dried stalk of banana tree, offers possibilities for engineering applications. Even though considered as a waste by-product, it has good specific strength properties comparable to conventional materials [23,24,25]. The increasing population has led to the necessity of waste control and use of biodegradable composites lends a helping hand in this area. The further addition in all properties has just led to remarkable development being made in the field of bio composite production. Therefore, composites of high-strength pseudo-stem banana reinforced composite can be used in a broad range of applications.

2. Methodology
To begin with the Mechanical, Tribological, Morphological and Thermo gravimetric tests, The specimen should undergo steps for the preparation of woven banana fiber reinforced epoxy composites [22]. These steps are illustrated below

i. Abstracting the Natural Continuous Banana Fibre
ii. Thinning the Dried Banana Fibre (B.F.)
iii. Weaving the Continuous fibre
iv. Mould Preparation
v. Mixing the Epoxy and Hardener with a ratio
vi. Preparation of the Specimen
vii. Mechanical, Tribological, Morphological & Thermo Gravimetric Tests
viii. Results and Analysis

3. Results and Discussions

Bio-composites have served as an important factor in the production of economical, lightweight and superior composite structures. The mechanical properties of these bio-composites are superior to their base counterparts. The bio-composites developed vary in properties depending on the additive used.

Sapuan et.al.[22] studied the property of woven banana fibre experimenting with the tensile and flexural strengths combined with different materials. Joseph et.al.[25] compared the property of phenol formaldehyde resin when mixed with banana and glass fibre. In banana fibre composites, a small decrease in impact strength compared to neat resin occurs at lower fibre loading and a good increase in impact strength is observed with an increase in fibre loading. Thwe et.al [26] examined the effect of fibre content, fibre length, bamboo to glass fibre ratio, and coupling agent (maleic anhydride polypropylene) on Tensile and flexural properties of bio-composites. As observed by Murali M. Rao et.al.[27] natural fibres used as fillers in a polymeric matrix enable the production of economical and lightweight composites for load carrying structures. Geethama et.al. [28] estimated the tenacity and elastic modulus of banana fibre, and are in the range of 529.759 MPa, and 8.20 GPa, respectively. The percentage elongation at break of banana fibre varies between 1.0 and 3.5. The diameter of banana fibre will vary between 0.08 and 0.25 mm. The composites are well capable to be used in wider sectors. Zhu at.al. [29] Investigated the air-cured banana fibre reinforced cement composites and found that at a fibre loading of 14% by mass, flexural strength is about 25MPa and the fracture toughness value is 1.74 KJm2. They suggested that these mechanical properties with the water absorption of less than 25% are suitable for the use of building material. Mukherjee et.al.[30] showed in their investigation of banana fibre with polyester composites without weathering test that the specific modulus of the composites is 2.39 which are of the same order as that of glass fibre plastics. Maryes Idicula et.al. [31] showed in their investigation of Banana fibres have remarkable addition to the matrix structure of the pre-existing fibres leading to an increase in strength of the fibres. The effect of having varying percentage of banana fibres is to increase tensile, reinforcing and elongation properties. Tensile stress-strain behaviour of neat polyester and banana composite having different fibre loading by incorporating 0.20 and 0.40 Vf of fibre, the modulus is increased by 30% and 54%, respectively, as compared to neat polyester. As the fibre loading is increased, the elongation at break is increased. The addition of cellulose fibers makes the matrix ductile. K V P P Chandu et.al.[32] had shown in his research that direct relationship between the sliding distance and load. Coefficient of friction almost remains constant by evaluated the Banana-Pineapple fiber reinforced hybrid composite with defined constitues of fiber and found the wear rate proportionate due to increase in the normal applied. Hybrid composites 30B-70P shows lower weight loss, frictional force, wear and coefficient of friction with different loads at 1m/s sliding velocity when compared with pure composites and other hybrid composites due to proper bonding between matrix and reinforcements. A Shadrach Jeyasekarran et.al [33] has investigated to find the tensile characteristics of hybrid composite made by intruding unidirectional banana and glass fibers into epoxy resin mixture. The hand lay-up method
of fabrication was used for preparing the composites of unidirectional glass fiber (UGF) and unidirectional banana/glass fiber (UB/GF). Tensile properties of the composites are verified on ANSYS software. It was observed that the numerical analysis results were higher than experimental analysis. Hybridization of banana fiber has better tensile properties. The specimen composite material was produced with the banana (stem) particulate as reinforcement using compression moulding. Results showed that density and elastic Modulus of the composite decreases and increases respectively with increasing weight fraction of the particulate reinforcement by B. Dan asabe et.al [34], he shown that The tensile strength increased to a maximum of 42 MPa and then decreased steadily. The composition with optimum mechanical property (42 MPa) was determined at 8, 62 and 30 % formulation of banana stem particulates (reinforcement), PVC (matrix) and Kankara clay (filler) respectively with corresponding percentage water absorption of 0.79 %, Young’s Modulus of 1.3 GPa, flexural strength of 92 MPa and density of 1.24 g/cm3. Comparison with conventional piping materials showed the composite offered a price savings per meter length of 84 % and 25 % when compared with carbon steel and PVC material .M. A. Maleque et.al[35] conclude that the tensile strength on the pseudo-stem banana woven fabric reinforced epoxy composite is increased by 90% compared to virgin epoxy and with epoxy material banana woven fabric flexural strength increased also he showed that approximately 40% increment in the impact strength of the virgin epoxy material, and due to higher impact strength value it has higher toughness properties. Claudia Merlini et.al [36 ] In his context, the author used plant fibers and polyurethane derived from castor oil in polymeric composites can be a good alternative. The aim of study was to evaluate the influence of the fiber volume fraction, fiber length and alkaline treatment on the mechanical and thermal properties of short random banana fiber reinforced polyurethane derived from castor oil. The banana fibers were chemically modified through contact with 10 wt.% sodium hydroxide solutions for 1 h and characterized through Fourier transformed infrared spectrometry (FTIR), scanning electron microscopy (SEM), tensile strength and density were measured through the FTIR spectra and SEM micrographs, modifications in the chemical structure and morphology of the treated fibers were observed compared with untreated fibers. The composites were analyzed by SEM, dynamic mechanical analysis (DMA), FTIR spectrometry, tensile strength and pull-out tests. The tensile strength and Young’s modulus increased with increasing fiber volume fraction and length for the untreated and treated banana fiber polyurethane composites. On the other hand his result shown that, the treated banana fiber composites displayed higher tensile strength and Young’s modulus values than the untreated fiber composites, due to the stronger interfacial interactions between the treated fibers and the polyurethane matrix. These effects occurred due to the morphological and chemical changes in the treated fiber surfaces which promote better adhesion between the fibers and the polyurethane matrix. The effects of Banana fibre length on the physical and mechanical properties of banana fibre/epoxy composite were investigated by M.Sumaila1et.al.[37 ] Five different samples were produced by varying the length of the fibre between 5mm and 25mm at 30% wt. fibre loading using the hand lay-up moulding technique. The mean density, percent moisture absorption, void content, tensile strength, tensile modulus, % elongation, compressive strength, impact energy, flexural strength and modulus of the composite were analysed. The results showed that the percent moisture absorption, void content and the compressive strength increased with increase fibre length while a decrease in density was observed. Result showed that at 15mm fibre length suggesting critical fibre length for effective and maximum stress transfer. Carolyn Palma et.al.[38] also conclude that use of banana peel as promising material for the development of a global bioremediation strategy for wastewater containing hazardous compounds, such as dyes. Its high adsorption capacity of Acid Black 1 (250 mg g⁻¹) as well as the high decolourizing efficiency of the ligninolytic enzymes produced by Inonotus sp SP2 (97%) and Stereum hirsutum RU 104 (82%) allow to postulate the use of BP to implement a hybrid strategy of remediation based on the combination of physic chemical biological treatments. Laly A. Pothana et.al [39] The dynamic mechanical analysis of banana fiber reinforced polyester composites was carried out At lower temperatures (in the glassy region), the E’ values are maximum for the neat polyester whereas at temperatures above Tg, the E’ values was found to be
maximum for composites with 40% fiber loading, indicating that the incorporation of banana fiber in polyester matrix induces reinforcing effects appreciably at higher temperatures. The loss modulus and damping peaks were found to be lowered by the incorporation of fiber. The height of the damping peaks depended on the fiber content. When higher fiber content of 40% was used, an additional peak in the tan δ curve, pointing to micro mechanical transitions due to the immobilized polymer layer was evident. The glass transition temperature associated with the damping peak was lowered up to a fiber content of 30%. The Tg values were increased with higher fiber content. To understand the phase behaviour of the composite samples, Cole-Cole analysis was made and he constructed a master curve based on time temperature super position principle, which allows the prediction of long-term effects. Satish Pujari et.al.[40]. In this research, biodegradable and eco-friendly composites with various volume fractions of fenugreek banana composite materials were successfully developed and their thermal properties were investigated as a function of volume fraction. From obtained results, the following conclusions were drawn. The thermal conductivity of composites decreased with increase in volume fraction of fenugreek due to non-conducting nature of the natural fibers. At the maximum volume fraction of fenugreek, the thermal conductivity of the composite material is 0.259 W/m K. The results of this study indicate that the fenugreek banana composites are economical and possess good thermal insulating properties. Hence, the newly developed composite material can be used for different applications like steam pipes, automobile interior parts, electronic packages and building construction materials.T.P. Mohan et.al.[41]. Aim of this research work was to study the tribological properties of natural fiber based composites using nanotechnology. The naturally available banana plant fibers were treated with nano clay particles and these treated fibers were then reinforced in an epoxy polymer to form composites. The friction and wear properties of nanoclay treated banana fiber (NC BF) reinforced composites were compared with untreated banana fiber (UT BF) reinforced composites. Short NC BF and UT BF reinforced composites with fiber concentration ranging from 20 wt.% to 60 wt.% was prepared by vacuum resin infusion processing method. The result indicates that the NC BF reinforced composites has shown improved friction and wear properties. Microscopy examination revealed that NC BF reinforced composites were able to form transfer layer between wear test specimens, resulting in improved wear properties. The nanoclay particles were also added to increased hardness and friction to the composites and improving the braking properties. Jinguo Wang et.al [42] showed in their investigation that, coir fiber board was reinforced with banana stem fiber to improve the mechanical properties of the board. Different ratios of banana stem fiber and coir fiber were mixed to make composite boards. These ratios had different effects on the physical (TS) and mechanical (MOR, MOE, and IB) properties of the particleboard composites. Banana fiber improved the MOE and MOR of the hybrid coir fiber boards, SEM and FTIR, and SSA were used to analyze the fiber micro-structures, and bonding mechanisms of the particleboard were examined. These results confirmed that a novel hybrid particleboard composite could be produced. They suggested that coir fiber/banana stem fiber Particleboard composites were suitable for non-load bearing partitions and outdoor building materials. S Visheshkumar et. al [43] has carried out an Experiment with fiber reinforced polymer composite on Pin on disc equipment. And investigated the changes of wear and friction performance of the sisal and rice husk composite weight. The carbon, sisal fiber and rice husk composite wear and frictional performance was improved with the increased load array an orthogonal array method. with the increase in the load and sliding velocity the sisal, banana and kenaf fiber composite weight loss was more and Sisal and rice husk composite wear and frictional force was more with respect to increasing the speed and time. A. Alavudeenet.al [45] showed in their investigation that a high wear resistant material using banana fibre has been used to develop a hybrid clutch plate composite matrix with strength and rigidity. The composite material also improves the life-cycle of the composite Haneefa et al. [47] concluded that the hybridization of banana fiber and glass fiber increases the tensile strength and Young’s modulus of the composite with increase in volume fraction of glass fiber because of greater compatibility of glass fiber with polystyrene matrix. Zainuddin et al. [48] on the work found that the decomposition temperature of banana pseudo stem fiber/unplasticized polyvinyl chloride decreases from 279°C to 256°C on the addition of banana filler from 10-40%. They
also predicted that the thermal stability of acrylic modified composites was found to be more stable than unmodified banana pseudo stem fiber/unplasticized polyvinyl chloride composite. Kumar et.al. [49] have carried out research on preparing green composites using banana fibre and soy protein as matrix. The results show that at 0.3 volume fraction tensile strength and modulus of alkali treated fibre reinforced with soy protein composites increased to 82% and 96.3% respectively compared with soy protein film without fibres. Biodegradability test shows the composites are 100% bio degradable. Due to low density, higher tensile strength, higher tensile modulus, and lower elongation at break of banana fibers, composites based on banana fibres have potential use in the various sectors like construction, automobiles, machinery, etc., Thus the use of bio-additives to existing fibre technology can lead to an improvement in the overall mechanical properties of the fibre.

Table 8: Summary of Banana Reinforced polymer Composites and its outcomes

| Authors/Title | Materials Used | Methodology | Outcomes |
|---------------|----------------|-------------|----------|
| K V P P Chandu et.al. "Experimental Analysis on Wear Behaviour of Banana - Pineapple, Hybrid Natural Fiber Composites"(2018) [32] | -Banana Pineapple fiber reinforced hybrid composite by using hand layup technique -Epoxy resin -Hardener | -Wear test by Pin on disc type Friction and Wear monitor (DUCOM TL20) with data acquisition system | -Evaluation using composites with defined constitutes of fibre and matrix the wear rate proportionate due to increase in the normal applied load. -Coefficient of friction almost remains constant. -Direct relationship between the sliding distance and wear rate as the sliding distance increases proportionately with respect to wear Rate. -Hybrid composites 30B-70P shows lower weight loss, frictional force, wear and coefficient of friction with different loads at 1m/s sliding velocity when compared to pure composites and other hybrid composites due to proper bonding between matrix and reinforcements. |
| A Shadrach Jeyasekarann et.al. "Numerical and experimental analysis on tensile properties of banana"(206) [33] | -Unidirectional glass fiber epoxy laminate (UGF), and unidirectional banana/glass fiber - Epoxy laminate (U/B/G F) by using hand lay up technique - Epoxy resin LY556 -Hardener HY951 as binder | -Tensile test by according to the ASTM 3039 standard -Tensile properties of composites by using ANSYS software - Surface Morphology through scanning electron microscope (SEM). | -UGF composite possesses higher ultimate tensile strength among the samples and can withstand the strength of up to 567 Mpa at a load of 60 kN - Experimental stress value was 567.7 Mpa and ANSYS Von misses stress value was predicted to be 616.69 Mpa for UGF composite. -The average load displacement was found to be 10.8 mm for the UGF composite and 11 mm for UB/G F composite. -It can be used in applications which require moderate strength, especially in house hold articles such as partition boards. -Based on experimental and numerical analysis using ANSYS software, the deviation was mainly due to the assumptions in numerical analysis such as increase of interfacial bonding, between fibre and matrix, alignment of |
fibre, non porous, uniform diameter of fibres and these assumptions made the predicted tensile value to be higher for UGF and U B/U F composites.

- In experimental analysis fabrication defects in composites such as voids, cracks, matrix and fibre fracture, poor bonding, improper matrix distribution and nonalignment of fibres were the probable causes for obtaining lower tensile value for UGF and U B/G F composites when compared with the numerical analysis.

- By chemically treating the natural fibres can enhance the tensile strength.

B. Dan-asabe et. al. “Mechanical, Spectroscopic and Micro structural Characterization of Banana Particulate Reinforced PVC Composite as Piping Material” (2016) [34]

- Kankara kaolin clay (200 g)
- Polyvinyl chloride (PVC, 500 g)
- Banana stem (200 g)
- Sodium hydroxide (NaOH)
- distilled water (5 litres)

- Carver-3851 compression machine.

- Fourier Transform Infrared (FTIR) analysis

- Tensile test according to the ASTM D638 standard
- Flexural test according to BS EN ISO 14125
- Weight impact test as per

- The tensile strength on the pseudo stem banana woven fabric reinforced epoxy composite was increased by 90% compared to virgin epoxy.
- The flexural strength increased when

M. A. Maleque et. al. “Mechanical properties study of pseudo stem banana fiber reinforced epoxy composite” (2005) [35]

- Pseudo-stem banana woven fabric reinforced epoxy composite by the hand layup method
- Epoxy resin grade 3554A

- Density and Elastic Modulus of the composite decreases and increases respectively with increasing weight fraction of the particulate reinforcement.
- Tensile strength increased to a maximum of 42 MPa and then decreased steadily.
- The composition with optimum mechanical property (42 MPa) was determined at 8, 62 and 30 % formulation of banana stem particulates (reinforcement), PVC (matrix) and Kankara clay (filler) respectively with corresponding percentage water absorption of 0.79 %, Young’s Modulus of 1.3 GPa, flexural strength of 92 MPa and density of 1.24 g/cm³.
- Fourier Transform Infrared (FTIR) analysis of the constituents showed identical bands within the range 4000–1000 cm.
- Scanning Electron Microscopy (SEM) result showed fairly uniform distribution of constituents’ phases.
- X Ray Fluorescence (XRF) confirms the Xray diffraction (XRD) result of the presence of minerals of kaolinite, quartz, rutile and illite in the kaolin clay.
- Comparison with conventional piping materials showed the composite offered a price savings per meter length of 84 % and 25 % when compared with carbon steel and PVC mater.
| Author(s)                                             | Details                                                                                       |
|-------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Sevgi Hoyur et al.                                    | Production of banana / glass fiber biocomposite profile and its bending strength"(2012) [21]      |
|                                                       | - Banana fibers                                                                          |
|                                                       | - Polyester resin (CE 92 N8)                                                               |
|                                                       | - Multi faceted glass fibers (MAT8)                                                         |
|                                                       | - Hardener (MEK)                                                                          |
|                                                       | - Cobalt naftanat as a catalyst                                                            |
|                                                       | - Bending tests were carried out on a SHIMADZU AG-IS unit with a capacity of 50 kN.      |
|                                                       | - The highest and lowest bending strengths for a single layer specimen were found to be 13.085 N/mm² and 8.957 N/mm². |
|                                                       | - The highest and lowest bending Strength for the double layer specimens was found to be 18.196 N/mm² and 16.834 N/mm². |
|                                                       | - Produced banana / glass fibre bio composites can be used for indoors and outdoors applications. |
| Claudia Merlini et al.                                | Influence of fiber surface treatment and length on physicochemical polyurethane composites"(2011)[36] |
|                                                       | - Banana fibers                                                                          |
|                                                       | - Sodium hydroxide                                                                       |
|                                                       | - Polyol                                                                                 |
|                                                       | - Prepolymer                                                                            |
|                                                       | - Diphenylmethane diisocyanate (MDI)                                                       |
|                                                       | - Resin (IMPERVEGUG 132 A)                                                                |
|                                                       | - Attenuated Total Reflectance-Fourier Transform Infrared spectroscopy (ATR-FTIR)        |
|                                                       | - Scanning electron microscopy (SEM), Jeol model JSM- 6390LV                              |
|                                                       | - EMIC testing machine (model DL2000) following ASTM C1557, D638 and D3039 standard methods. |
|                                                       | - Pull out test by Universal Testing Machine                                            |
|                                                       | - Dynamic mechanical analyzer (DMA-983 interfaced to a TA 2000).                          |
|                                                       | - To evaluate the influence of the fibre volume fraction, fibre length and alkaline treatment on the mechanical and thermal properties of short random banana fibre reinforced polyurethane derived from castor oil. |
|                                                       | - The banana fibres were chemically modified through contact with 10 wt.% sodium hydroxide solutions for 1 h and characterized through Fourier transformed infrared spectrometry (FTIR), scanning electron microscopy (SEM), tensile strength and density measurements. |
|                                                       | - The tensile strength and Young’s modulus increased with increasing fibre volume fraction and length for the untreated and treated banana fibre polyurethane composites. |
|                                                       | - The treated banana fibre composites displayed higher tensile strength and Young’s modulus values than the untreated fibre composites, due to the stronger interfacial interactions between the treated fibres and the polyurethane matrix. |
|                                                       | - The morphological and chemical changes in the treated fibre surfaces which promote better adhesion between the fibres and the polyurethane matrix. |
| M.Sumaila et al.                                      | Effect of fiber length on the physical and Mechanical properties of                         |
|                                                       | - Mature banana pseudo-stem                                                              |
|                                                       | - 5% sodium hydroxide                                                                     |
|                                                       | - Moisture Absorption Test(Mettler Toledo balance, Model XP603S).                        |
|                                                       | - The percentage moisture absorption and void content increases with increase fibre length at constant fibre |
random oriented non woven short(musa balbisiana)Fibre/epoxy composite Banana”(2013) [37]

| Material | Description |
|----------|-------------|
| (NaOH) solution | -Epoxy resin (LY556) -Hardener (HY591) -Petroleum jelly (debonding agent) |
| Density Measurement | -Tensile Test according to ASTM D638 standard -Compressive Test According to ASTM D 695-02a standard -Izod impact test machine according to ASTM D 256 standard -Flexural Test according to ASTM D790M standard |

- Density Measurement
- Loading of 30%wt while there was a decline in composite density.
- The tensile strength, tensile modulus and percentage elongation of the composite attained a maximum in composite fabricated from 15mm fibre length.
- The compressive strength increases whereas the impact energy decreased with increasing fibre length.
- The mean flexural strength and modulus of the composite increased with increasing fibre length up to 25mm.

Maries Idiculae et.al.”A Study of the Mechanical Properties of Randomly Oriented Short Banana and Sisal Hybrid Fiber Reinforced Polyester Composites”(2004) [31]

| Material | Description |
|----------|-------------|
| -Banana fiber and sisal fiber | -Unsaturated polyester resin HSR 8131 -Curing agent, methyl ethyl ketone peroxide -Catalyst cobalt napthenate |
| Mechanical testing | -universal testing machine of 500 KN capacities. -fiber diameter was measured using a Leica (DMLP) Polarizing light microscope. -load displacement curves -tensile as well as flexural strength and modulus were calculated. -Izod impact test ( 25 Joules pendulum impact testingmachine) - Fracture Surface Study by SEM |
| Mechanical properties | - such as tensile, flexural, and impact properties, of short banana/sisal hybrid fibre reinforced polyester composites were evaluated by varying the relative volume fraction of banana and sisal at a total constant fibre loading of 0.40 volume fractions. - The tensile strength was found to be increased in banana/sisal hybrid fibre reinforced polyester composites when the volume fraction of banana was increased. - Higher compatibility was obtained in hybrid composites, which leads to better stress transfer ability in composites. When the Vf of sisal is 0.26, the maximum modulus is obtained - A positive hybrid effect can also be observed for flexural strength and flexural modulus. When the Vf of banana is 0.19, the flexural modulus is maximum - It can be concluded that the reinforcement of banana and sisal fibre in polyester results in a positive hybrid effect for tensile and flexural properties - Value added and cost-effective composites having high tensile and flexural properties could be well developed by the judicious selection of banana and sisal fibre.

Carolyn Palma et.al.”Eco friendly Technologies Based on Banana Peel Use for the Decolourization of the Dyeing Process Wastewater(2010)”[38]

| Material | Description |
|----------|-------------|
| - Banana peel (Mussa ssp) | - Microorganisms Inonotus sp SP2 and Stereum hirsutum RU 104 - Dyes of analytical grade from Sigma–Aldrich Co |
| - Particle size Distribution by laser diffraction using the Mastersizer X equipment (MALVERN INSTRUMENTS, MSX1) | -Specific Surface by by nitrogen gas adsorption according to Brunauer, Emmett and Teller (BET) |
| - Banana peels as promising material for the development of a global bioremediation strategy for wastewater containing hazardous compounds. - High decolourizing efficiency of the ligninolytic enzymes produced by Inonotus sp SP2 (97%) and Stereum hirsutum RU 104 (82%) allow to postulate the use of BP to implement a
isotherm method.  
- Point Zero Charge (pHPZC)  
- Biadsorption of Dyes In Banana Peel(UV–V spectrophotometer Spectronic Helios Gamma model)  
hybrid strategy of remediation based on the combination of physicochemical biological treatments.

| Laly A. Pothana et.al. "Dynamic mechanical analysis of banana fiber reinforced polyester composites" (2001) [6] | - Banana fiber  
- Unsaturated polyester HSR 8131  
- Methyl ethyl ketone peroxide  
- Cobalt naphthenate | - A dynamic mechanical thermal analyzer M K I I  
- scanning electron microscope (SEM) model Jeol JSM-35 C and Cambridge 250 MK3 stereo scan | - The dynamic modulus shown a decrease with incorporation of fibre below the glass transition temperature and had a positive effect on the modulus at temperatures above Tg.  
- The maximum improvement in properties was observed for composites with 40% fibre loading, which is chosen as the critical fibre loading.  
- Increase of frequency shifts the Tg to higher temperatures supporting the good fibre/matrix interaction.  
- An additional peak occurred at high fibre loading in the tan δ curves, due to the interlayer effect.  
- Addition of fibre lowers the tan δ peak height, which again points to the improved fibre/matrix adhesion.  
- Cole Cole plots shown an imperfect semicircle showing the heterogeneity of the system as well as the good interfacial. Adhesion at high fibre loading.  
- Use of master curve and the relationship of the shift factors were useful in predicting the long-term behaviour of the composite. |

| Laly A. Pothana et.al. "The Static and Dynamic Mechanical Properties of Banana and Glass Fiber Woven Fabric Reinforced Polyester Composite" (2005) [39] | - Banana fiber  
- Unsaturated polyester HSR 8131  
- Methyl ethyl ketone peroxide  
- Cobalt naphthenate | - The tensile test (ASTM D 638-76)  
- Charpy impact tester Instron Wolpert PW5, ASTM D256  
- Fractography optical microscopy using ‘Citoval’ stereo microscope Carl Zeiss, Jena  
- Dynamic mechanical analysis DuPont Instrument DMA 983 | - Woven fabric composites of banana and glass fibre had proved to be an effective reinforcement in imparting high strength to polyester.  
- The tensile properties for composites with two layers of the fabric with closed weave architecture were found to be max.  
- The flexural strength, showed the highest value for composites with three layers of the fabric.  
- The highest impact strength was obtained for composites with four layers of the fabric with closed weave Architecture.  
- The damping peaks were found to be lowered by the incorporation of higher number of layers of the fabric indicating an improved fibre/matrix interaction.  
- The mechanical properties of |
| Reference | Description | Details |
|-----------|-------------|---------|
| S.M. Sapuan et al. "Mechanical properties of woven banana fibre reinforced epoxy composites" (2004) [22] | - Banana fibre | - Tensile and flexure tests Galdabini 1890
- Statistical analysis of variance-one way (ANOVA) |
| Satish Pujari et al. "Experimental Investigations on Thermal Conductivity of Fenugreek and Banana Composites" (2016) [40] | - The banana stem layers - Fenugreek | - Thermal Conductivity Measurements per ASTM E 1225-87 |
| T.P. Mohan et al."Tribological properties of nanoclay infused banana fiber (NC-BF) reinforced epoxy composites" (2018) [41] | - Banana fibers - Untreated raw Na+ montmorillonite (MMT) clay - Diglycidyl ether of bisphenol A (DGEBA) based epoxy resin and cyclic aliphatic amine based epoxy hardener - Nanoparticle infusion were NaOH, acetic acid. - Steel material of surface roughness | - Scanning electron microscopy (SEM) technique (Zeiss Environmental Scanning Electron Microscopy ESEM ESEM: model EVO HD 15)
- Wear test (pin-on-disc tribometer, ASTM G99-05 2010) |
| Jinguo Wang et al."Novel Particleboard Composites Made from Coir Fiberand" | - Raw coir fibers - Waste banana stem fibers - Type 14L962 phenol | - Mechanical Testing (modulus of rupture (MOR), modulus) |

Composites made out of woven fabrics of natural and synthetic fibres were comparable with those of synthetic fibre composites whereas from an economic point of view, these composites have an edge over the other conventional materials.

Banana fibre - Epoxy 3554A - Hardener 3554B
- The maximum value of stress in x direction was 14.14 MN/m² and the maximum value of stress in y direction was 3.398 MN/m².
- The Young’s modulus, the value of 0.976 GN/m² in x direction and 0.863 GN/m² in y direction were obtained.
- Three point bending (flexural), the maximum load applied was 36.25 N to get the deflection of woven banana fibre specimen beam of 0.5 mm.
- Gave a good opportunity to use woven banana fibre especially in producing household utilities.

The banana stem layers - Fenugreek
- The thermal conductivity of composites decreased with increase in volume fraction of fenugreek due to non-conducting nature of the natural fibres.
- The maximum volume fraction of fenugreek, the thermal conductivity of the composite material was 0.259 W/m K.
- The fenugreek banana composites were economical and possess good thermal insulating properties.
- The newly developed composite material can be used for different applications like steam pipes, automobile interior parts, electronic packages and building construction materials.

- The NCBF reinforced composites had shown improved friction and wear properties.
- Microscopy examination revealed that NCBF reinforced composites were able to form transfer layer between wear test specimen wear surface and counter face, resulting in improved wear properties.
- The nanoclay particles also induced increased hardness and friction to the composites and improving the braking properties.

- Banana stem fibre had a significant impact on the mechanical performance (MOR, MOE, IB, and 24-hTS) of CB
**Waste Banana Stem Fiber**

(2016) [42]  
- formaldehyde (PF) adhesive  
- Paraffin wax as a waterproofing agent  
- of elasticity (MOE), internal bond strength (IB), and thickness expansion  
- Best fit curves  
- Regression equations  
- Specific Surface Area (SSA) of Fibers Analysis  
- SEM Analysis  
- FTIR Analysis  

- The mechanical properties of the CB particle board had linear correlations with banana fibre content.  
- The properties of microstructure and high surface area for banana fibre brought about the increase in the PF resin content and 24-hTS for the CB particleboard.  
- The chemical composition of banana fibre influenced the performance of the CB particleboard, which was ascribed to two characteristics of banana fibre: higher cellulose and hemicelluloses contents and lower lignin content.

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**S Vigneshkumar et al.**

"Experimental analysis on tribological behavior of fiber reinforced experimental analysis on tribological behavior of fiber reinforced composites"  
(2018) [43]  
- Sisal, banana, kenaf and carbon fiber filler material is rice husk  
- unsaturated polyester resin  
- 1.5% accelerator (Cobalt Octate)  
- 1.5% catalyst (Methyl ethyl ketone peroxide).  
- wear with ASTM G99.  
- Wear and Friction monitor- TR 201,(Pin on disc)  
- Scanning Electron Microscopy of FEI Quanta 200 FEG (FEI Company)  

- Experiment was carried out with fibre reinforced polymer composite on Pin on disc equipment. The carbon, sisal fibre and rice husk composite wear and frictional performance were improved with the increased load an orthogonal array method.  
- The sisal, banana and kenaf fibre composite weight loss was more with the increase in the load and sliding velocity.  
- Sisal and rice husk composite wear and frictional force was more with respect to increasing the speed and time.

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**T. Hariprasad et al.**

"Study of mechanical properties of banana coir hybrid composite using experimental and FEM techniques"  
(2013) [44]  
- Pseudo stem banana woven fiber  
- Coir  
- Epoxy or polyepoxide  
- Polyamine “hardener”.  
- Hardener (EH758)  
- Tensile Test(ASTM Standard D638)  
- UTM Lloyd LR100K Testing Machine  
- flexural test (ASTM D 790)  
- Izod and Charpy test.  
- Finite-Element Analysis (FEA)  

- An alkali treated banana coir epoxy hybrid composite had greater tensile strength and impact strength than an untreated banana coir epoxy hybrid composite.  
- The alkali treated banana coir epoxy hybrid composite had less flexural strength than the untreated banana coir epoxy hybrid composite.  
- This analysis was useful for realizing the advantages of hybrid fiber reinforced composites in structural applications and for identifying where the stresses were critical and damage the interface under varying loading conditions.  
- The simulated stress distribution for the mechanical properties of the treated and untreated banana-coir hybrid samples, under different loading conditions, was obtained. The maximum stresses are averages of the values of the center elements used in the FEA.

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**A. Alavudeen et al.**

"Clutch plate using woven"  
-Banana (Musa sepentium)/kenaf (Hibiscus)  
- The tensile test (Shimadzu AG- 50 kN as)  

- The tensile strength test of the woven hybrid reinforced polyester composites
| Authors                                      | Materials                                                                 | Methods                                                                                                                                                                                                 | Results                                                                                                                                                                                                 |
|---------------------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lina Herrera-Estrada et al. “Banana fiber composites for automotive and transportation applications” (2015) [46] | - Banana fibers - 6% NaOH solution - SC-15 epoxy resin - ENVIREZ 1807 polyester - catalyst (alkyl polyamine and benzoyl peroxide/tert-butyl perbenzoate mixture, respectively). - Polytetrafluoroethylene (PTFE) release agent - Teflon Cloth | - Three point bending test method as per ASTM D 790-03 - compressive strength as per ASTM D 695-96. - universal testing machine SATEC T-5000. | - The flexural strength of banana fibre/eco polyester composites was 40.16 MPa, which is 14.78% higher than the strength of banana fibre/epoxy due to fibre/matrix interaction. -The highest compressive strength of 122.11 MPa of the banana fibre/epoxy composite was attained after fibre pre-treatment and was 38.35% higher than the observed strength without the treatment. - The highest compressive strength in banana fibre/eco-polyester composites was 122.88 MPa and was achieved without fibre pre-treatment. - It was observed that environmental resistance is higher in banana fibre/epoxy composites with alkaline pre-treatment, followed for banana fibre/polyester composites without any treatment. Because of improvement in fibre/matrix interaction with the fibre chemical pre treatment in epoxy composites and to deterioration of the inter phase in polyester composites. |
| W. H. Zhu et al. “Air-Cured Banana Fibre Reinforced Cement Composites” (1994)[29] | - Banana stalk - 9% active alkali (as Na2O) - 25% sulphidity - 7:1 liquor to sample ratio - Ordinary Portland cement | - Modulus of rupture (MOR) as perASTMD790 - Modulus of elasticity in flexure (MOE) as per ASTM-D790 - Program for routine flexural testing of cellulosic fibre-cement -Fracture Energy - Water absorption /density tests As perASTM-C220-75. | - Pulped banana fibre (Cavendish) was a satisfactory fibre for incorporation into a cement matrix - At a loading in the range of 8-16% by mass, flexural strengths in excess of 20 MPa (as high as those found in some synthetic fibres reinforced cements, and up to 90% that of pulped softwood fibre cement materials). - At a fibre loading of 14% by mass, the flexural strength is about 25 MPa and the fracture toughness value is 1-74 kJm². |
| Author(s) | Material | Reinforcement | Results/Findings |
|-----------|----------|---------------|-----------------|
| H. Savastano Jr et al. | Sisal (Agave sisalana), Banana (Musa cavendishii) pseudo-stem fibres, Waste Eucalyptus grandis pulp, Active alkali (as Na2O), Sulphidity (as Na2O), Plain cement paste and Pinus radiata kraft reinforced cement composites | - Modulus of rupture (MOR) - Modulus of elasticity - Flexural testing of cellulosic fibre-cement - Fracture Energy - Water absorption /density tests As per ASTM C948-81 | Mechanical testing showed that optimum performance of the various waste fibre reinforced composites was obtained at fibre content of around 12% by mass, with flexural strength values of about 20 MPa and fracture toughness values in the range of 1.0±1.5 kJ m². E. grandees was the preferred reinforcement for low cost fibre cement. |
| M. Jannah et al. | Banana fibers, Unsaturated polyester P9509, Methyl ethyl ketone peroxide (55%) as hardener. | - Tensile test as per ASTM D3822-01 - Fourier-transform infrared spectroscopy (FTIR) model Perkin Elmer System 2000 - Flexural test as per (ASTM D790-98) - Izod impact tests as per (ASTM D4812) - Scanning electron microscopy (FESEM) model ZEISS SUPRA 35VP. | - The flexural strength and modulus of woven banana fibre composites increased with the increase in fibre content to optimum fibre content of 10 volume %. - Treated composite systems showed improvements in flexural properties. - The impact strength increased with the fibre content up to 15 volume %, with an obvious trend shown by acrylic acid-treated banana reinforced polyester composites. - Treated fibre composites reduced the water absorption compared to the untreated composite system. |
| Anshida Haneefa et al. | Banana fiber, Glass fiber (E-Glass), Polystyrene (PS) crystal grade, Polystyrene maleic anhydride as a surface modifier | - Tensile test (Universal testing machine) - Flexural tests as per ASTM D 790 - Scanning Electron Microscopy (SEM) JEOL JSM 35C model SEM. | - The tensile strength and Young’s modulus of the composite increased with respect to increase in volume fraction of glass fibre due to the greater compatibility of glass fibre than banana fibre with polystyrene. - The influence of fibre content, fibre loading, and hybrid effect on the mechanical properties such as tensile strength, Young’s modulus, elongation at break, and flexural properties of the composites, was evaluated. - The volume fraction of glass fibre based on total fibre content increased all the mechanical properties, except elongation at break. - The tensile and flexural properties of composites were observed to had improved as the fibre loading (volume %) increases. - Modification of the banana fibre improved the optimum fibre-matrix properties. - Hybrid effect was calculated using additive rule of hybrid mixtures. |
E.S. Zainudin et.al. "Thermal degradation of banana pseudo stem filled unplasticized polyvinyl chloride (UPVC) composites" (2008) [48]

- Banana pseudo-stem (BPS)
- Unplasticized polyvinyl chloride (UPVC)
- BPS filler
- Acrylic FM50

- Thermogravimetric analysis (TGA)

- The thermal stability of the composites was found to be higher than that of BPS fibre and the UPVC matrix.
- The incorporation of BPS filler decreased the thermal stability of BPS/UPVC composites for the case of non-acrylic.
- The thermal stability of BPS/UPVC composite with acrylic was found to be higher compared to BPS/UPVC composite without acrylic.

Vijay Sitaram Shivankar et al. "Some studies on 100% banana parallellaid and 60:40% banana: polypropylene cross laid non-woven fabrics" (2019) [52]

- Three varieties of banana fibres

- The tensile Test Instron (model 4301) machine
- Non woven fabric ASTM D 5729-97 standard
- GSM of non-woven fabric ASTM D 3776-96 standard.
- Stiffness of non-woven fabric ASTM D 5732-95 standard.
- Air permeability FX 3300 Air permeability tester ASTM D 737-96 standard.
- Bursting strength Eureka bursting strength tester ASTM D 3786-87 standard

- Graint Naine banana nonwoven fabric had shown higher elongation% for machine cross direction.
- Increased air permeability of C.L. (60:40) banana/polypropylene blend non-woven fabric observed than P.L. 100% banana non woven fabric.
- Bursting strength of P.L. nonwoven fabric was higher, both in the machine as well as in cross direction than C.L. nonwoven fabric for three varieties of banana fibres
- Bending length of the C.L. banana nonwoven fabric was higher than the P.L. nonwoven fabric.

4. Conclusions
Therefore we can conclude that banana fibre due to its varying properties and differing usages is going to serve an important part in the development of the future of fibre industry. The results of different tests conducted on the fibre indicate that it can be used in varying applications across different fields. The fibre can be used in combination with other fibres as an additive and enhance the properties of the base fibres.

I. Value intensive and cost effective composites having high tensile and flexural properties can be well-developed by judicial usage of banana fibres.

II. A high wear resistant material using banana fibre has been used to develop a hybrid clutch plate composite matrix with strength and rigidity. The composite material also improves the life cycle of the composite.

III. High variability along the length and between fibers is displayed by the banana fibers, This is a characteristic of natural fibers to completely illustrate the banana fibers and provide suitable applications in natural fiber reinforced composites

IV. Banana peel shows potential of being the feasible material for the development of a global bioremediation plan for wastewater containing hazardous compounds.

V. Biodegradable and eco-friendly composites with volume fractions of fenugreek banana composite materials were successfully achieved. Moreover, thermal properties were examined as a function of volume fraction. Therefore, it can be seen recently made composite material can be used for various applications like steam pipes, automobile interior parts, electronic packages and building construction materials.
VI. Banana natural reinforced polymer composites have balance of structure and property, due to which these composites can be manufactured at a lower cost.

VII. Banana natural reinforced polymer composites can be infused with the nanoclay for the application in wear and braking works.

VIII. To improve tensile properties of banana natural reinforced polymer chemical modification (alkali treatment, benzoyl chloride treatment and PSMA) can be added. The addition of chemical displayed decreased hydrophilicity of banana fibre, and improvement in the fibre/matrix compatibility through mechanical anchoring, physical and chemical bonding.

IX. User friendly and cost effective banana natural reinforced polymer with sufficient stiffness and damping behaviour can be developed by hybridization of banana and sisal fibre. As the current situation of environment is depleting while the demand for the alternative energy is increasing. To provide a solution banana natural reinforced polymer can be best suited for energy applications and diminish its consumption

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