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Investigating Natural Fiber Reinforced Polymer Composites, Biocomposites, Bionanocomposites Thermo-Mechanical Attributes Emerging Implementations

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Abstract. *Natural fibers are progressively employed in manufacturing polymer composite structures beneficial to automotive, construction, and aerospace industries. The upsurge in the utilization of natural fibers in various industries is ascribed to enhanced awareness of the toxicity of man-made fibers. It is imperative to preserve the ecosystem. Thus, legislators and investigators are brainstorming on substituting conventional materials with earth-friendly resources. Natural fibers are green resources with multifarious advantages over synthetic materials, including ease of processing, reduction of* CO_2 *effusions, biodegradable, recyclable, acceptable thermomechanical attributes and improved compatibility with human health. Therefore, natural fibers are widely applied as modifiers for polymers. Recently, natural fibers reinforced polymeric composites, bio-composites and bionanocomposites are the hot potato of researchers ascribed to their attributes such as having low specific gravity, producing good results without costing a lot of money, earth-friendly, and sustainable among others. Jute, kenaf, coir, and hemp natural fibers derived from plants can be exploited to achieve novel lofty execution polymer composite systems. Thermo-mechanical behavior of natural fiber-reinforced composites, bio-composites and bionanocomposites including stress-strain, bending, failure resistance, impact toughness, temperature and deformation fashion them to be more sustainable and engaging than man-made fibers with exceptional biodegradable hallmark. Thermomechanical analysis (TMA) determines variations in specimen dimensions with varying temperature, time or load at ambient conditions. However, TMA of natural fiber-reinforced polymer composites is limited. Therefore, the review highlights on natural fiber-reinforced polymer composites, bio-composites, bionanocomposites, their crucial thermo-mechanical attributes, and emerging implementations.*
Keywords: *Composites; Biocomposites; Bionanocomposites; Natural fibers; Thermo-mechanical behavior.*

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1. Introduction

The terminology "natural fiber" denotes any native material that is similar to hair-like structure, which can be obtained straightly from vegetable, animal or fossil source. This resource

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can therefore be processed into nonwovens like paper or felt, or woven fabric after being spun into yarns. An additional way to define to define a natural fiber is as an assemblage of cells that have a small diameter in comparison to their length. Natural fibers are classified into three categories rooted on plants, animals, and minerals, whereas plant fibers are the ubiquitous type of natural fiber. Plant fibers contain cellulose, hemicelluloses and lignin in varying quantities and are produced by plants [1].

In a natural fiber composite material each component such as fiber, reinforcement or particle contributes distinct thermal, electrical, mechanical and thermal attributes to the end-use product. Blending them produces a material optimized for a given use, such as durability, lightweight, or electrical stability. Besides, they can support with toughness and strength, and their improved attributes and amenability present hem to be more preferable than traditional materials. Emerging ecological constraints and surging petroleum utilization, coupled with a common rise in public awareness of ecological challenges, have necessitated the quest for ecological benign alternatives. Various issues, such as pollution of the ecosystem, indiscriminate dumping of waste, outrageous use of fossil fuel etc, have triggered a global search for substitutes. As compared to man-made fiber, natural fibers possess unique attributes and are thus universally accepted as an environmentally-friendly material [2].

Therefore, it is expedient that natural fibers be implemented. Natural fibers proffer numerous advantages over traditional reinforcing materials, such as lesser density, reduced cost, lighter weight, eco-benign, higher specific strength, toughness, acceptable thermal attributes, and stability to corrosion. Fibers obtained from plants or animals are deemed natural, as juxtaposed to man-made [3]. There has been a lot of interest in using natural fibers from renewable and nonrenewable resources including oil palm, sisal, flax, and jute to create composite materials in recent decades [4]. Plants produce many kinds of cellulose fibers, including seed fibers (cotton, coir, etc.), bast fibers (jute, hemp, flax, ramie and kenaf), grass fibers (rice, corn, and wheat), leaf fibers (sisal, pineapple, and abaca), core fibers (hemp and kenaf,), and all other kinds (wood and roots) [5].

Artificial fiber-rooted composites have diverse contending limitations, such as exorbitant price, substantial energy usage in manufacturing and production process, inferior reprocessing, non-biodegradability, release of carbon dioxide, and health risks when inhaled [6]. Consequent upon these drawbacks, natural fibers composite materials have gained emerging implementation as a possible replacements for man-made fiber composites. When incinerated at the end of their service life, natural fibers, contrary to artificial fibers, gave increased energy recovery and zero net carbon dioxide emissions, which is apt for carbon footprints and mitigates the earth-warming impact [7]. Decreased water resistance, thermal degradation and weathering influence of fiber and the matrix, diminished durability, inferior interfacial contact that leads to fiber pullout, poor penetrability of polymer matrix impregnated into spots between fibrils, and fiber collapse during fabrication methods are just few of the challenges that obscure natural fibers and reusable polymers from being extensively applied in emerging new composites implementations [8]. Recently, the utilization of natural fiber polymer composites in consumer goods and emerging industrial sectors has improved. In diverse engineering implementations the applications of natural fiber polymer composites is expands quickly. As a result achievement of a reasonable balance between cost of composites production, and the final attributes maybe easily attained by diligently choosing the proper materials and designing the structure [9].

However, there is a surplus of fibrous materials in the natural world, particularly cellulosic types including cotton, wood stems, and straw, a very small fraction of these can be employed in textiles or other industrial benefits. Besides, the economic contemplations, the business profitability of a fiber is decided by attributes like its length, strength, uniformity, fineness, resilience, pliability, elasticity, resistance to abrasion, absorbency, and other surface characteristics. Some of the advantages and disadvantages of natural fibers are shown in Table 1.

Table 1. Advantages and disadvantages of natural fibers [10]

Fiber type	Advantages	Disadvantages
Natural Fiber	Lightweight	Flammable
	Recyclable	Dimensional Instability
	Improved specific mechanical attributes	Hydrophilic
	Environmentally-friendly, Carbon dioxide zero emission	Anisotropic behavior
	Do not release toxic gases during processing, reduced energy consumption during manufacturing	Limited processing temperature (approx. 200-230ºC)
	Good thermal features	Sensitive to ultraviolet radiation
	Good acoustic properties	Fungal attack and microbial
	Cheap, ubiquitous, sustainable, biodegradable	Low strength than synthetic fibers, mostly impact strength
	Non-abrasive & good moldable	Variable quality, prone to weather
	No skin challenges during handling	Low durability
	Safer crash behavior in tests	Poor fiber/matrix adhesion

The encompassing categorization of natural fibers is represented in Fig. 1.

The sphere of implementation for natural fibers diversifies every day, mostly in the automotive industry, which has remarkably increased their utilization. Hinged on these natural fibers, scientists have carried out tremendous study in this field. For implementations needing a towering strength-to-weight ratio and extra load moderation, natural fibers have the latent to be used instead of traditional reinforcement materials in composites. Therefore, the present review investigates natural fiber reinforced polymer composites, bio-composites, bionanocomposites, thermomechanical attributes and their emerging implementations.

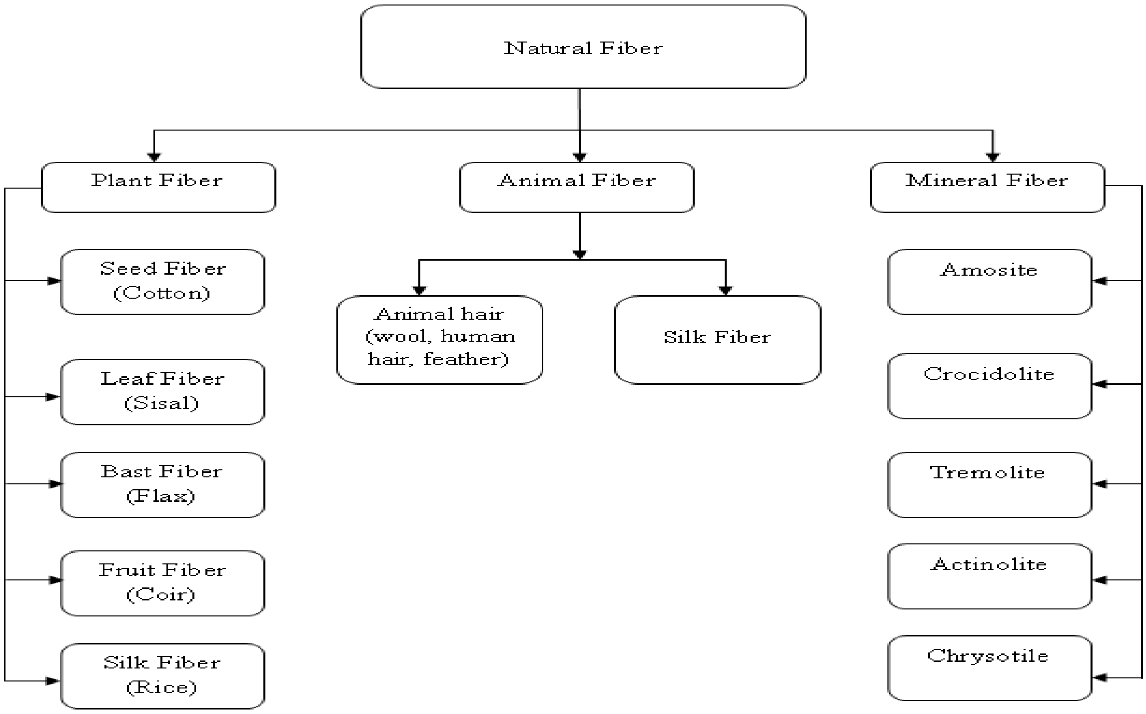

Fig. 1. Categorization of natural fibers [11]

2. Composites, Bio-composites and Bionanocomposites

A blended system comprises two or several disparate components or elements which when combined culminate into a structure with completely dissimilar attributes from their separate constituents [12]. Commonly, synthetic blends would include a reinforcing filler of rigid, hardy matter, normally a hair-like structure, enclosed in a continuous polymer matrix; which is frequently frail and more amenable than the reinforcing filler. The key roles of the matrix are to convey superficially applied forces through applied load at the boundary with the filler material and safeguard it against environmental and automatic destruction. The merit of such a connection is that the lofty clout and hardness of the fibers may be taken advantage of. Composites are capable of performing more than one function furnishing attributes unachievable from one distinct structure. **Composites** are defined as combined materials that vary from mixtures by the verity that the separate elements maintain individual attributes and intimately joined synergistically to attain optimized performance. Composites are tenacious materials created from mundanely associating more than one dissimilar element, with varying constitution, features and occasionally arrangement. This puniness in explanation lays the certitude permitting categorization of composites as combination of elements short of implying precision and jurisprudence differentiating them from platitudinous combinations [13]. Composites should not be construed ordinarily as a mixture of two materials. In the wider import, the mixture has its inherent peculiar attributes. With respect to strength, thermal resistance or certain other worthwhile standard, it is finer than either of the elements alone or fundamentally different from either of them. Composites are disparate elements made of several structures in close proximity possessing similar identical material features [14,15]. The appeal for bio-composites and natural fibers is burgeoning expeditiously on a universal scope. In 2020, the bio-composites emporium was valued close to $12.5 billion [16]. Spanning 2021 to 2027, it is predicted to rise at an aggregate yearly surge rate of 10.5% [17]. The overall bio-fiber business approximated in 2020 to $16.2b with anticipated multiplication by 6.5% aggregate yearly surge rate between 2021 and 2027 [18].

In the present climate, **bio-composite** structures are becoming more widespread in terms of low density, strength, inexpensive, environmentally friendly and renewability. Humans begin rely on bio-composites structures at this time ever than before and employ these products in various aspects of their existence. Lately, the ecosystem awareness and challenges of viability and price are on a global scale. As knowledge of environmental matters escalates, investigators and pathfinders are seeking for avenues to roll out more earth-friendly materials like natural fiber on the booth than traditional polymers [19]. Bio-composites are created from structures comprising of more than one discrete ingredient: the strengthening component planted in a binder or matrix [20]. A combination of man-made sources such as carbon, aramid, glass, nylon with bio-fibers including jute, hemp, kenaf, sisal and so on is utilized in bio-composite fabrication [21,22]. Bio-fiber has fine attributes than man-made fibers [23]. A typical instance is bio-fibers employed as augmentation for biopolymer composites gaining prominence among numerous academics and inventors owing to their benefits over traditional man-made materials [24]. Such bio-fibers proffer improved physical characteristics, rational, compostable, sustainable, low power requirement, reduced hazard, non-wearing of machinery, compatible with human body [25,26]. And used as a support structure owing to its softening and hardening responses. Natural fiber is a very cheap material the reason it is employed in diverse fields like aircraft manufacture, film packaging, vehicles, construction industry, etc [27–29]. Although natural fiber has multifarious benefits such as lightweight, cheap, earth-friendly, among others, a major limitation is the high moisture uptake. Thus, the use of chemicals to modify natural fibers is important to assuage high water affinity. Following chemical treatment physical characteristics of bio-fibers is considerably influenced by fiber dimension, aspect ratio, and fiber-matrix adhesion. Bio-composites are the viable answer in terms of stabilizing costs and gathering pertinent features for different justifications and accomplishments. Bio-composites are interpreted as a unique category of composite structures attained through combining natural fibers with natural or synthetic macromolecules. Bio-composites materials depict a biodegradable and inexpensive option than traditional crude oil-derived resources [30]. As a consequence, the culminating use of these substances is step by step expanding. The growing appeal and significance of the bio-composites escalated the volume of disseminations on that individual theme with a diversity of various viewpoints. These assorted reports give a number of evaluations in various bio-fiber strengthened composites [31–35]. Biomaterials made adopting brace sustainable materials buttress bio-plastics binder expanded the field of exploration advancement owing to hopeful automatic attributes, reusability, non-toxicity as well as environment-friendliness. Also, different possible implementations of such composites in diverse sectors: car manufacturing industry, wrapping, and domestic items. Bio-composites are employed in economical goods with disparate architectural attributes simultaneously[31,36–39].

Bionanocomposites are composite materials containing components of biological genesis and specks with no less than one dimension in the gamut of 1–100 nm, made through combining nanomaterials or harden via biomimicking in a wet-chemical technique. It is noteworthy that the "components organic genesis" mooted definition, rather than biomaterials contemplated to be nanobiocomposites. Bionanocomposites could be thought as assortment of nanocomposites. Consequently, the normally recognized meaning of nanomaterials can be adapted. It chronicles for the existence of scattered particles with no less than a size in nano-size gamut. However, deep difference between bio-composites of man-made fossil-derived sources does not permit pinpointing nanobiocomposites from nanocomposites. There is variation of solubility, heat resistance, minimal toxicity, and environment-friendly, that govern procedure for synthesis, functionalities and field executions of substances. Considering the preceding, the subsequent meaning of nanobiocomposites is recommended. These composites are produced from different biomaterials like low-molecular mass substances like phospholipids being a key element of fat network of organic tissue layer [40], biological structure such as microbes, converted producing composites frequently termed "mixed". The terminology did not indicate the genesis and characteristics rather the contemplation of bionanocomposites. The reason that encompasses nanometer elements with organic root in line with the definition alluded above.

The position of nanobiocomposite amidst other composites structures is shown in Fig. 2. Bionanocomposites are produced through mixing artificial polymers with micro-sized mineral ingredients including nano-clay, carbon black, and calcium carbonate employed as reinforcements in elastomer companies as far back as 100 years ago [41]. Wherein natural elastomer was obtained which are included in the bionanocomposites. Interestingly, bio-composites are the major elements prior to 1950s when fossil-based chemical enterprises, such as production of polymers began rapidly growing [42]. Nanocomposites are different from composites in mineral ingredients obtained in the nanometer dimension. The natural part of fossil-derived polymers when replaced by bio-composites it becomes nanobiocomposite with a remarkable alteration of biocompatibility, eco-friendly, synthesis techniques, attributes, and functionalities [43–47].

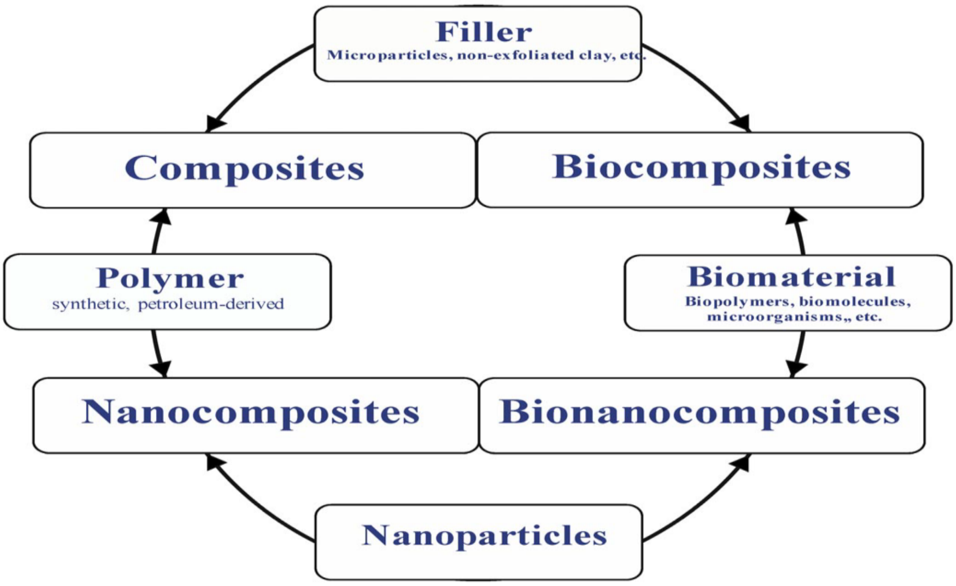

Fig. 2. Composite materials and their components.

2.1. Emerging implementations of natural fiber reinforced composites, bio-composites and bionanocomposites

Natural fiber reinforced polymer composites, bio-composites and bionanocomposites are excellent resources supplanting man-made substances through coupling articles for lightweight with power conservancy utilizations. Implementation of bio-fiber based plastic blends as innate-rooted substances substituting prevalent man-made plastic or fiber-glass strengthened earthly is enormous. Vehicle and airplane manufacturer is energetically advancing disparate varieties of bio-fibers namely hemp, flax, sisal and biomaterial structures in inner constituents. Definitive attributes having economical natural fiber composites fashion it appealing for several executions. The implementation of bio-fibers is expanding into numerous areas including vehicles, upholstery, packaging and building; mostly arising from benefits such as cheap, lightweight, ease of processing, enhanced surface gloss of molded composite, improved comparative mechanical attributes, copious and sustainable resources. Natural fibers are employed in diverse administrations including construction, wood-plastic-composites, medical and non-medical, essential and non-essential manufacturing. Bio-fibers possess average physical features juxtaposed with man-made sources such as fiberglass, hydrocarbon, aramid among others but having main drawback of excessive water absorption [48]. A comparison between composite, bio-composite and bionanocomposites is presented in Table 2.

Table 2. Comparison between composite, bio-composite and bionanocomposite

Composite	Bio-composite	Bionanocomposite
Composites present materials that are prepared by combining synthetic plastics and microsized inorganic additives such as layered silicates, talc, carbon black, calcium carbonate, etc.	Bio-composites are a kind of composites that are intended solely for bio-engineering implementations.	Bionanocomposites are significant as a result of their nanoscale dispersion with size less than 1,000 nm in a biomaterial.
Composites is a material made from two or more different materials that, when combined, are stronger than those individual materials by themselves.	Bio-composites are defined as biocompatible and/or eco-friendly composites. They consist of a large variety of organic and/or inorganic components, such as natural and synthetic polymers.	Bionanocomposites are used in fabrication of scaffolds, implants, diagnostics and biomedical devices and drug-delivery systems.
Composite materials are the assembly of two or more materials on a macroscopic scale (macroscale) to form a third with improved qualities.	Bio-composites are blends of different materials used for various tissue engineering and restorative implementations mainly due to their biocompatibility.	Bionanocomposites differ also from the bio-composites that are made partially from biopolymers, but they do not have the nano-sized additives.

3. Natural fibers

The exploitation of natural fibers by man started as far back as seven thousand eras in the ancient Egyptian civilization. The utilization of natural bras has garnered considerable notice, in which these fibers may be put together with thermosetting and thermoplastic polymeric substrates to produce bio-composites possessing singularly lucid renewability characteristics. Viability attributes of bio-fibers comprises bountiful materials drawing up carbon dioxide and releasing oxygen into habitat, teeny maturation life cycle, ease of fabrication, reusable, earth-friendly and reduced risk manufacturing [49]. The utilization of reinforcements like pulverized coal and bauxite residue in combination to bio fibers presents great intrigue to their investigations. This is owing to its higher advancement in mechanical attributes, reduced cost and easy availability in the business emporium. It was reported that the commercial mixing of pulverized coal alongside bauxite residues improved the automatic properties of composites materials [50]. A composite is an admixture or blend of two different components in which one constituent is a binder like polymer, cement and metal. Polymer matrix composites are mainly customarily applied whereby various binding constituents are obtained in a viscous or rubbery state. Polymers are categorized two varieties namely thermoplastic and thermosetting wherein filaments natural and synthetic bristles employed for discrete execution. Composites are recently frequently been utilized for recovery and hardening the previous materials that have been reconstructed to generate earthquake resistant or to regain the destruction created by geologic bustle. Different from traditional structures such as metals attributes of polymeric structure are planned scrutiny architectural facets. There are three classes of composites premised on the type of matrix substance such as: Polymer Matrix

Composites (PMC), Metal Matrix Composites (MMC), and Ceramic Matrix Composites (CMC) [51]. Implementations of bio-composites include manufacturing of vehicles, upholstery, packaging and building chiefly owing to inherent benefits in contrast with man-made ones, that is economical, lightweight, reduced wear to processing machinery, enhanced surface gloss of molded parts composite, these composites have improved comparative mechanical attributes, available and sustainable resources (Table 3) [52].

Table 3. Analogy of natural and man-made fibers

Aspects	Property	Natural fibers	Manmade fibers
	Mechanical attributes	Moderate	High
Industrial	Moisture subtlety	High	Low
	Thermal subtlety	High	Low
	Resource	Infinite	Limited
Ecological	Manufacture	Low	High
	Reusability	Good	Moderate

3.1. Native and man-made fibers

Natural and man-made fibers are used as reinforcing materials in composite structures and are the main portion of the arrangement responsible for transfer of constructional stress. The major grouping of fibers is into natural and man-made. Petrochemical byproducts are the main sources of man-made fibers, while natural fibers are derived from plants and animals [25]. Fibers of plant origin are cellulosics such as leaf, seed, bast, fruit, wood, grass, and stalk among others whereas animal fibers are proteins including hair, silk, wool, etc [53–55]. Natural and man-made fibers give brawn and inflexibility and minister as buttress in polymeric structures. Natural and man-made fibers have been employed by man for the manufacture of composites over millennial of ages; however, utmost advancements have materialized in recent times. Wood or non-woody vegetable fibers comprise of cellulose, hemicelluloses and lignin in the extracellular matrix. Manifold extractives like waxes, nitrogenous residues and salts of inorganic compounds are also available. Fibers are composed of millions of hairy segments designated filaments [56–61].

3.2. Classification of Natural Fibers

Natural fibers have reevaluated their function in smart and intelligent food packaging, affording a viable clue that extends service life and checks food standard [62]. Their application is assuming progressively momentum due to their earth-friendly feature, inexhaustibility, extra advantage in abating waste and power usage compared with conventional man-made fibers [63]. Fig. 3 show some of the frequently applied bio-fibers in the bagging industry.

Fig. 3. Frequently applied natural fibers in food packaging.

Bio-fibers are copiously accessible cheap resources conversely animal fibers have lately attained awareness as strengthening substance for bio-composites. Animal fibers have gained considerable scrutiny in elasticity, elevated exterior hardness, towering length to diameter ratio, reduced water absorption character [64]. Most plant and animal fibers including hemp, kenaf, flax, cotton, ramie, wool and silk are normally employed in fabric production [65].

3.3. Animal Fibers

Sources of animal fibers are mostly hair, feather and taffeta. The outstanding physico-mechanical attributes fashion animal fibers as probable buttress resource for polymer composites. Wool a source of animal fiber from hairy mammals is obtained from sheep, alpaca, bison, angora rabbit, cashmere/pashmina goats, among others. China, New Zealand and Australia are the main producers of wool a textile fiber frequently employed in fabric production [66]. The origin of wool determines the physical and chemical attributes. For instance, angora, alpaca, qiviut and cashmere wool fibers have a diameter ranging from 12 to 16 μm, 12 to 29 μm, 15 to 20 μm and less than18.5 μm [67]. The high affinity of wool fibers for moisture makes it to soak up water to one-third of its mass. Wool fiber has limited speed of fire proliferation, heat discharge, and heat of combustion [65]. Animal fibers such as anatomical fur from goat, horse and camel are also generally employed. Plumage tuft filaments from fowl and birds are called avian fibers. Cock tuft mostly made from fibrous protein are offshoots of abattoir [64]. Cock tuft filament is 91% fibrous protein, 8% H_2O, and 1% fats [65]. Cock tuft filaments is applied for microorganism rust-free execution for manufacturing penetrable porous absorbents and composite porous absorbents in scrubbing glassy very pristine faces due to immersion character of protein [66]. Research has shown that using chicken tuft for composites formulations exhibited increased automatic, thermal and acoustic attributes owing to their chemical make-up, reduced density and structure [65].

Taffeta is commonly obtained from numerous species of butterfly larvae as well as from numerous species of spiders [64]. Taffeta is discharged through organs close by gob of insects in the course of cocoon growth. Chitosan an amino group found in taffeta confers chemical resistance and automatic durability. The domestic silk moth highest extensively employed taffeta larvae are made of proteins. The protein comprises thousands of massive amino acids possessing toughness close to or almost above most of the plant fibers. Taffeta is utilized in bioengineering executions such as towel manufacturing, fabricating cathartic scaffolds for tissue engineering applications [65]. Spider web is a taffeta made using wood or banana tarantula. Spider webs fiber is made of two extremely monotonous amino acids, dragline silk, partly-crystalline presenting nether level structural order compared to taffeta [65]. Amidst different species of taffeta fiber, spider web has toughness comparable to lofty tough steel [66].

3.4. Plant Fibers

Through ancient civilizations plant fibers have been employed in making textiles, interior and exterior parts of vehicles, buildings, grocery items, certain doodads, hence functioned as a notable fount of crude material for diverse applications [67]. The main constituents of plant fibers are celluloses, hemicelluloses and lignin with traces of extractives like pectin and wax in which their amounts differ according to the plant species and geographical location [68]. Factors that determine the chemical physical attributes of plant fibers are location, soil condition, species, age, maturity, portion, and extraction method [69]. The outstanding requirement of plant fibers in substituting man-made fibers to employ to produce polymer biocomposites is earth-friendly sustainable buttressing structures. Generally, the highest applied plant-based sources in place of glass fibers for polymer composites manufacturing are kenaf and sisal fibers [70].

Plant fibers are categorized as primary and secondary based on their conditional benefits. Kenaf, hemp, jute, sisal, and cotton mostly cultivated for fibers production are called primary fibers. Secondary fibers such as coir, oil palm, and pineapple and banana leaf are produced from individual plants as offshoots [64]. Plant fibers are broadly grouped on the foundation of their botanic sources like bast, leaf, seed, fruit, stalk, grass and wood fibers for merchandizing reasons. Bast fiber, also called phloem fiber may be defined as those obtained from the outer cell layers of the stems of various plants. Among the main plants used for the supply of bast fibers are flax, jute, hemp, ramie and kenaf. Leaf fibers or hard fibers are a type of plant fiber mainly used for producing rope such as sisal, agave, abaca, and pineapple. Seed fibers develop in the seedpod of the plant from which it must be separated to be used. Seed fibers include cotton, kapok, and milkweed. Example of fruit fibers are coir, oil palm and luffa. Stalk fibers are actually the stalks of the plants, such as straws of wheat, rice, barley, and other crops including bamboo. Example of grass fibers are baggase, esparto, elephant grass, canary grass, and switch grass. Wood fibers are usually cellulosic elements that are extracted from trees and used to make materials including paper mainly softwood and hardwood, e.g., rosewood, and teak [71]. Moreover, there are plants that have different kinds of fibers such as kenaf, hemp, flax, and jute possess bast fiber in addition to main fibers. Whereas coconut, oil palm and agave have both stem and fruit fibers. Cereal grains have husk and bast fibers respectively [68]. Amidst plant fibers bast fiber exhibits outstanding stiffness and flexural strength while the leaf fibers present high impact strength [70].

Kenaf is indigenous to Central Africa cosy weather yearly odoriferous fiber [72], broadly acknowledged bast fiber having close to cellulose content of 65.7% and pectin and lignin content of 21.6% [68], with outstanding toughness and bending strength that can replace man-made fibers [70]. Areas of application of Kenaf fiber includes fabric and carpet manufacturing, vehicle components and certain profiled plastic implementations as shown in Fig. 4 [68].

Fig. 4. Implementations in automobile industry

Flax known as Linum usitatissimum as well from the roots of Malvaceae is one of the aged cultivated fiber plants in mild climate locations [73]. Flax fiber consists of cellulose, hemicelluloses, lignin and pectin in various percentage compositions. It exhibits toughness betwixt Kevlar and glass [68]. It can substitute glass fibers in assorted executions such as strengthening plastics and composite materials in the production of certain simpler components in automotive factories [68,72]. Hemp fiber is a single growing season non-woody flower and seed producing plant indigenous to Asia and mainly grown in Eurasia [70,74]. A crude hemp fiber is generally slender, bawdy, lustrous, and glow shaded [60] and show superb toughness and water repellence [74]. The fiber extracted from hemp is utilized for executions such as cloth, pulp, therapeutic supplies, structuring materials, automobiles, and so forth [60]. Jute fiber (Corchorus capsularis) from yearly plant Tiliaceae group is a multipurpose burly cellulosic fiber cultivated in cyclone altitudes at china, India and Bangladesh [73]. Towards macerating method fiber is lacerated immersed in seasonal flowing water. The fiber possesses small quantitative density, reduced scraped spot, small heat potential, and balanced moisture holding and acceptable mechanical attributes. It also has superb insulation and flame-retardant nature employed as grocery bags, cords, and plastic buttressing products [68]. Ramie also known as Boehmeria nivea of Urticaceae genre is a blossoming bast fiber, collected beneath slim bark film comprises of cellulose above 70%, hemicelluloses above 13%, pectin about 5.5%, and lignin 1.5% [74], with a superlative brawny dehydrated condition and get fitter. It has higher cellulose content and greater grit [74]. In addition, ramie fiber has attributes comparable with jute and flax. Amongst bast fibers ramie, flax and hemp show greater resistance against parasites, blight without need for unique environments to development [68]. Sisal also referred to as Agave sisalana of Asparagaceae genre indigenous of Mexico, produces rigid fibers by removing the outer covering which is conventionally utilized for twines and rope production [70,74]. It is economically cultivated in Asia and East Africa. Sisal fiber is brawny, rough and stiff cultivated annually mostly applied in textile fiber manufacture. Due to its analogously facile growth it can resist scorching altitudes with ability of development in desert location. Sisal is defiant to tick and plaque afflictions thrive in land other than clay [75]. The chemical composition of sisal fiber is cellulose (65%), hemicelluloses (12%), lignin (10%), pectin (0.8%) and wax (0.3%), having strength-to-weight ratio, absolute value equal to glass fibers [74]. It is employed as fiber reinforced plastic composites in vehicular executions like interior engine cloak, seat backs, visor cap and aerospace components [75]. Abaca fiber known as Musa textilis of Musaceae genre derived from banana plant long-lasting and defiant to briny, is among dominant economically accessible lignocellulosic fibers in Philippines and Ecuador applied to make twines a suitable substitute to glass fibers in vehicles [60,73]. Pineapple leaf fiber (Bromeliaceae) a tropical plant indigenous of Brazil well-off in cellulose is extracted from Ananas comosus. Pineapple leaf fiber is a plenteous accessible agro-waste resource gotten after the pineapple farming which is presently employed for diverse polymer strengthening operations [73]. Curaua fiber (Ananas erectifolius) found in the Amazon forests, a leaf fiber identical to pineapple fiber. In contrast with certain natural fibers, curaua fiber shows less density, acceptable toughness with ductility appropriate for constructive operations [76]. Coconut fiber (Cocus nucifera) also known as ‘coir’ is an equatorial palm from the genre of Arecaceae, containing cellulose and lignin fibers situated in the outermost covering or the husk of coconut [70]. Coconut husk is a copiously accessible agro-waste obtained after coconut processing mainly applied to the manufacture of fabrics, cords, bags, baskets, mats, among others. Coir possesses permanence and resilient properties rendering good reinforcement for plastics composites such as cushions for cars and motorcycle seats [68,74].

Oil palm fiber (Elaeis guineensis) from Arecaceae genre is also a major lignocellulosic fiber derived from trunks, fronds, fruit mesocarps and empty fruit bunches of oil palm. The peculiar attributes of oil palm has attracted surging embrace as reinforcing filler for plastic models [74].

Bamboo (Bambusoideae) enduring long standing blossoming plant from the genre of Poaceae develops reaching about forty meters tall in deluge environment [73]. The strong trunks, branches and leaves provide bamboo fibers mainly via vaporized water explosion and automatic regimen [74]. In addition to the attributes of natural fiber, bamboo show acceptable UV radiation permeability hence utilized in making manual crafted paper, carpentry and assembly operations [68,73]. Through investigations it was observed that bundles of bamboo fibers exhibited enough specific weight ratios analogous to traditional glass fibers [73].

Bagasse (Saccharum officinarum) is a fibrous waste of sugarcane juice milling procedure. Following garnering sugarcane is pulverized by the jagged rolls of the milling machine. Sugarcane bagasse contains up to 70% of cellulose and hemicelluloses, attracting admiration by numerous explorers as a buttress in natural fiber-reinforced composite manufacture [70,77].

Wood fiber is a major utilized filler for various implementations normally derived as wood residue of diverse rarefaction such as carpentry, building and construction, among others utilized as reinforcement objectives later facile shaving method [73,75]. Lately, numerous new plant fibers such as Parthenium hysterophorus [78], Impomea pescaprae [79], Catharanthus roseus [80], Coccinia grandis stem [81], Carica papaya bark [82], Cardiospermum halicababum [83], Saccharum bengalense grass [84], Tridax procumbens [85], Cereus hildmannianus [86], Ficus racemosa [87], and Dracaena reflexa [88] are seen as possible fillers for plastic models compared to the prevailing natural fibers.

4. Natural Fibers Physical Attributes and Analytical Methods

Various species of natural fibers presents differences in their physical attributes [89]. Mammalian in addition to plant fibers normally plastic, contract and enlarge upon heating or assume fragile and pliable on cooling become vulnerable to fungal degeneration [90]. The physical attributes of natural fibers are based on several elements such as type, years and maturity of plant, earthly spot, ecospecies such as heat, water and soil situations as well as fiber removal processes [64,89]. The natural fiber features, mostly mechanical attributes are determined by quantity of cellulose, thread angle, extent of cellulose fibers polymerization [91].

Understanding fiber qualities is vital to increase employment and implementation in composites manufacture and enhanced prosecution. Configuration and analysis of natural fibers is highly regulated by lignin volume available [63]. Main constitutional disparities in cell wall reach, concentration, width and solidity generate great differences in physical features [73]. Table 4 depicts the physical and mechanical attributes of natural fibers. The exterior coarseness, cell wall arrangement, thickness certain constitutional property of fibers is resolved by electron and atomic force microscope scanning.

Table 4. Natural Fibers Physical and Mechanical Attributes

Physical attributes	Mechanical attributes
Type, Year, Plant maturity, Earthly spot, Heat, Water, Soil condition and Fiber extraction process.	Quantity of cellulose, Thread angle, Extent of cellulose fibers polymerization, Lignin volume available.

Scanning electron microscopy (SEM) study provides a thorough excellent-resolution form sweeping across the electron beam targeted on the sought after fiber via exposing secondary and backscattered electronic indicator [62].

Atomic force microscope (ATM) is an extremely excellent-resolution nature microscope, depicting resolution magnitude of fractions nanometer a thousand times finer compared to optical microscope extent. Exterior scratchiness guidelines such as mean facial roughness, highest apex to gorge elevation, and origin average square roughness, among others are resolved by atomic force microscope [62]. The facial roughness of filaments is also resolved by perpendicular examining procedures such as confocal microscopy, confocal multicolored anomaly and consistency probing interferometry, and by plane scanning processes such as arranged light probing and probing laser microscope. The non-probing approaches such as computer-generated holography microscopy employed to resolve facial roughness [62]. Width facial roughness of fibers exerts remarkable involvement to determine permeability character in fiber-matrix with bulk toughness of the composites. The moisture permeability of natural fibers is controlled through measurement of contact angle is based on character and quantity in slick material of the fibers [63]. Fiber thickness is evaluated using pycnometer scientific procedures applying xylene true specific gravity analyzer such as helium pycnometer evaluated using American Standard for Testing and Materials D3800M found using Archimedes principle utilizing hexane [92].

Fourier-transform infrared spectroscopy (FTIR) is a scientific instrumentation that subjectively and numerically evaluates the presence of functional organic compounds in doing so furnish needed data on molecular arrangement and actinic attachment in natural fibers [72]. Among the two Fourier-transforms infrared spectroscopy approaches namely absorbance and transmittance techniques, the Fourier-transform infrared spectroscopy transmittance approach is extensively applied in natural fibers [74], with spectrograms resolved as individual peaks that are visible by wave number against transmittance plots relying on extension, flexing and agitation of fiber reactive moieties [88].

Table 5. Comparison of Natural Fibers Analysis Methods

SEM	ATM	FTIR	XRD	DSC	TGA
Is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. SEMS are used in materials science for research, quality control and failure analysis. In modern materials science, investigations into polymer composites, bio-composites, nanotubes and nanofibers, mesoporous architectures and alloy strength.	ATM is a powerful technique that can image almost any type of surface, including polymers, ceramics, composites, glass, and biological samples. ATM can measure surface physical properties, such as magnetic fields, surface potential, surface temperature, friction and many other surface physical properties.	FTIR is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. An FTIR spectrometer simultaneously collects high-resolution spectral data over a wide range spectral range. FTIR is an analytical technique used to identify organic, polymeric, and, in some cases, inorganic materials. The FTIR analysis method uses infrared light to scan test samples and observe chemical properties.	XRD is the experimental science determining the atomic and molecular structure of a crystal, in which the crystalline structure causes a beam of incident x-rays to diffract into many specific directions. XRD is a versatile non-destructive analytical technique used to analyze physical properties such as phase composition, crystal structure and orientation of powder, solid and liquid samples.	DSC is a thermal analysis apparatus measuring how physical properties of a sample change, along with temperature against time. In other words, the device is a thermal analysis instrument that determines the temperature and heat flow associated with material transitions as a function of time and temperature. DSC measures how much energy a sample absorbs or releases during heating or cooling.	TGA is a powerful technique for the measurement of thermal stability of materials including polymers, composites, and bio-composites. In this method, changes in the weight of a specimen are measured while its temperature is increased. Moisture and volatile contents of a sample can be measured by TGA. In brief, a TGA instrument measures a sample's mass as it's heated or cooled.

X-ray diffraction (XRD) is non-damaging investigative technique employed to evaluate the crystallographic arrangement, crystal dimension and structural order exponent in natural fibers. Diffused concentration of X-ray radiation slamming specimen is dependent on wavelength, diffusion, deed and dispersed angle [53]. Plant fiber has two clear acme of diffractogram. Initial climax seen close when 2θ is equal to 18°, showing availability of non-crystalline components. Second acme was visible close to 2θ equal to 22° [74]. Crystal dimension and structural order exponent performs crucial function to improving automatic attributes in natural fiber-reinforced composites, by facial treatment or chemical modification same are altered. Growth of crystal dimension increases water resistance of fiber and composite properties are also upgraded [74]. The hollow and lignocellulosic character of natural fibers confers acceptable sound resistance and thermal attributes [73].

Differential scanning calorimetry (DSC) is used to evaluate the chemical composition and thermal transitions of natural fibers reinforced polymer composites. Thermogravimetric analysis (TGA) is used to evaluate the thermal responses of natural fiber reinforced polymer composites and also to assess the heat threshold and percent mass loss rate of natural fiber during thermal decomposition. Plant fibers present excellent heat resistance making them usable to produce products for thermal implementations [74]. The toughness of fiber is an important deciding factor for choosing natural fibers for express executions [73]. However, the automatic attributes of natural fibers are analogously reduced compared to man-made fibers. Natural fibers automatic attributes are improved by suitable facial adjustment approaches. As opposed to man-made fibers, the flat density, lofty specific stiffness and fracture strain entice numerous manufacturers to engage natural fibers in multifarious composite implementations [64,93]. Commonly, fiber volume fraction influences the physic-mechanical attributes of composites [63]. Hydrogen bonding and certain interactions in cellulosic fibers control firmness and hardness [93]. Increase in cellulose percentage of fibers increases the toughness and elastic modulus [63]. Therefore, performance of fibers in determined applications is based on crucial elements such as structure, cell size, thickness, microfibrillar angle, chemical makeup, automatic characteristics and interface boundary in fixed milieu conditions surroundings [94]. Table 5 shows the comparison of natural fibers description methods.

4.1. Bio-composites

A composite material is a material which is produced from two or more constituent materials. These constituent materials have notably dissimilar chemical or physical properties and are merged to create a material with properties unlike the individual elements. Within the finished structure, the individual elements remain separate and distinct, distinguishing composites from mixtures and solid solutions [89]. A bio-composite is a composite material formed by a matrix (resin) and a reinforcement of natural fibers. Bio-composites are defined as biocompatible and/or eco-friendly composites. They consist of a large variety of organic and/or inorganic components, such as natural and synthetic polymers, polysaccharides, proteins, sugars, ceramics, metals, and nano-carbons [60]. Natural fibers act as the reinforcing material which is the discontinuous phase that is embedded in a matrix or resins which is the continuous phase. The function of the reinforcing material is to enhance the physical and mechanical properties of the fabricated composite. Typically, optimal strength of 1-4 Gega Pascal as well as toughness of 20-200 Mega Pascal is obtained in natural fiber reinforced polymer bio-composites [89]. The addition of natural fibers influences heat stability, electric charge transmission, structural attributes, structural order, deterioration, fabrication and price of bio-composites. Fundamental employments of bio-composites are in vehicles, airplanes, and architectural assemblies [63]. Certain observable merits of bio-composite utilizations are renewability, cheap, low-density characteristics, acceptable specific strength, decomposability, earth friendliness, sustainability and medical and well-being of producer and end users [68]. The matrices and fibers can be produced using two processes: mass and layered composites. The fibers are irregularly aligned in 3- dimensions structure, nearly showing identical actions in mass composites. However, layered composites are symmetric, in which fibers are aligned in many layers and held in unison with resin. Individual fiber laminates give 2-dimensional alignment [89]. The natural fiber-plastic resin attachment is achieved through absorption exchange, chemisorption, attractive force, reaction cling, coulomb interaction, and mechanical entanglement. The instruments of bond hinges on various elements including chemical constitution and molecular arrangement, structural feature, distribution of constituents and the microscopic ordering [60]. Attributes of bio-composites are influenced by fiber type, fiber loading, water absorption, fiber modification, composition, composite modeling, boundary attachment, voids, additives and binder [61,93]. Different strengthening elements and plasticizers impact the thickness, water absorption, vapor permeability, decomposition, and expiry date of bio-composites. Therefore, the water propensity of natural fiber and water repellency of bio-composites motivates the scientist to chemically modify fibers to enhance bonding strength. Bio-composites performance is accelerated by chemical treatment as a function of the processing class, processing requisites, and surrounding conditions [62]. Non toxicity and long-lasting of bio-composite are of critical worry as there is no true remedy accepted of recent to comprehensively assuage these two factors.

4.2. Natural Fiber strengthened Bio-composites

Bio-composites are blends of different materials used for various tissue engineering and restorative applications mainly due to their biocompatibility, superior mechanical properties, and biodegradability. Scientists are producing these materials as a substitute to traditional materials that are finite, intractable, or developed via toxic discharging methods [95]. Natural fibers which are lignocellulosics are extensively employed for the fabrication of bio-composites. Jute, kenaf, hemp, oil palm, pineapple, flax, and sugarcane are cheap, earth-friendly resources used to create novel lofty execution plastic products. Natural fiber bio-composites structures have outstanding attributes of environmentally-friendliness, low-density, tough, inexhaustible, low-cost, ecological, and renewable. Juxtaposed to man-made fiber it possesses almost tougher characteristics. Lately, various investigators and experts have utilized bio-fibers as an optional reinforcement for plastic conglomerate owing to benefits compared to traditional man-made material [96–99]. Bio-fibers are employed in bio-composites due to facile processing as well as cross-linking attributes is greatly enhanced compared to man-made fibers. Epoxy, polyester, unsaturated polyester resin, polyurethane, and phenolic curing polymeric resins are extensively employed in producing conglomerates giving higher performance diversified implementations; having enough mechanical attributes and the cost is equitable for such commodity. As a result of their acceptable mechanical features like toughness, lightweight and biodegradable merits, scholars, investigators, graduates, and also experimentation areas of businesses give diligence to natural fiber bio-composites instead of traditional man-made fiber bio-composites [100]. Ecological nature, sustainability and non-abrasiveness to processing machinery has brought effective improvements in the utilization of bio-fibers compared to man-made fibers such as acrylic, aramid fibers, mica and stone possess lessened weight forms bio-composites low density, cheap and biodegradable [101].

4.3. Characterization of Bio-fiber Strengthened Bio-composites

The key opposition to operating bio-fiber buttressed bio-composites lies in the huge differences regarding their characteristics. Factors such as fiber type, surrounding locations, manufacturing processes, and fiber treatment Attributes of bio-composites is impact the attributes of bio-composites [96]. Cautious choice of brace bio-fibers and resin plastic are foremost stride to achieve conglomerate having required attributes considering the desired use. Bio-composites performance hinges upon numerous elements including fibers chemical constituents, cell magnitude, microfibril angle (MFA), flaws, arrangement, palpable attributes, and automatic features, and fiber-matrix interplay. Understanding of fiber features increases employment of natural fibers for bio-composites execution [102,103].

4.4. Physical Characterization of Bio-fibers

Natural fiber supremacy over man-made fiber is surging on daily basis owing to its inexpensive, lightweight, reduced production cost, plenty, sustainable materials, almost great material and mechanical features like toughness, modulus of elasticity, flexural strength and ecological and earth friendly features. Natural fibers have been grown and employed mostly in farming growing nations for making non-load bearing applications like bag, broom, fishnet, and filters [104]. The dimension of the fibers, flaws, toughness, inconsistency, orderliness, and arrangement is crucial parameter determining physical attributes. Knowing fiber dimensions as well as thickness are important in juxtaposing natural their various categories. Paramount configuration variations like closeness, broadness, stretch, and width give rise to distinction in physical properties. Furthermore, engrossing evidence gives strong differences between structures ground and water plant fibers. Fiber concentration, spiral angle and fiber grades vary from fiber to fiber as well as single fiber model. The crystallinity of the natural fiber value differs over different portions and as the plant grows older crystallinity diminish [103,105]. Table 6 presents the physical characterization of bio-fibers.

Table 6. Physical Characterization of Bio-fibers

Fiber	Specific gravity (g/cm^3)	Tensile strength (MPa)	Modulus of elasticity (GPa)	Fracture strain (%)
Jute	1.3-1.46	393-800	10-30	1.5-10
Hemp	1.47-1.48	550-900	70	1.6-4
Kenaf	1.2-1.45	295-930	53	1.6-6.9
Bagasse	1.2-1.25	20-290	17-27.1	1.1
Coir	1.15-1.45	106-593	1.27-6	15-59.9
Bamboo	0.6-11	140-230	11-17	-
Abaca	1.5	400-980	3-12	3-10
Cotton	1.5-1.6	287-597	5.5-12.6	3.0-10.0

4.5. Mechanical Characterization of Bio-composites

Properties such as stretching, bending, and toughness are extensively investigated properties of composite materials that involve a reaction to an applied load. Toughness with respect to automatic execution constitutes unwanted fragile spots in materials. In addition to stretching, bending and toughness characters, time-dependent behavior (creep), energetic automatic deportment, squeezing attributes of bio-composites are studied [106,107]. Numerous facets including the type of bio-fibers, superficial science, fiber type, water absorption, fiber shape, type of matrix and boundary status are accounted in attaining sought after automatic attributes of bio-composites. Attributes of bio-fibers is dependent on fiber classification, agronomy, developing age, removing method, separation or preparation process [108–110]. Mechanical features of flax, abaca, kenaf, ramie, hemp, jute, sisal, bamboo, and bagasse fibers is extremely fine, toughness and rigidity is greater compared to man-made fiber [111]. Table 7 illustrates the mechanical characterization of bio-composites.

Table 7. Mechanical Characterization of Bio-composites

Bio-composite	Tensile strength (MPa)	Modulus of elasticity (GPa)	Bending strength (MPa)	Bending modulus (GPa)	Toughness (J/m)
PP-Jute	23-29	1.6-2.4	45-54	1.7-2.8	30-51
PP-Coir	25-28	1.7-2.7	47-49	1.6-2.8	41-54
PP-Abaca	23-27	1.6-2.6	46-48	1.4-2.6	39-46
PP-Bagasse	17-22	1.2-1.4	21-34	0.8-1.6	3.3-6.2
PP-Hemp	27-29	1.6-1.8	-	-	-
PP-Banana	36-41	0.82-0.98	-	-	10.2-12.8
PP-Palm	21-30	1.1-1.6	44-45	1.6-2.6	39-53

5. Thermogravimetric Analysis of Mixed Bio-composites

Thermoplastic and thermosetting bio-composites show identical responses when heated. The type of fiber, fiber structure and fiber volume fraction controls responses to thermal degradation. Aji *et al.* [112] opined that mixing pineapple leaf fiber/kenaf with high-density polyethylene changed heat responses by (i) altering degradation of high-density polyethylene from two-step to three-step following mixing and (ii) reduced thermal degradation. Using a fiber volume of 10wt% of Pineapple leaf fiber/betel nut husk mixed with polypropylene gave mass loss at peak thermal degradation temperature. Increase in the fiber volume resulted to mass loss at a lesser temperature [113]. Several researchers [114–116] have reported marginally greater degradation temperatures were achieve applying same fiber volume in banana/betel nut/polypropylene, banana/coir/low-density polyethylene and alfa-fiber/clay/polypropylene bio-composites. Besides, mixed bio-fibers having dissimilar fiber volume showed different lower heat responses. The drawback happened mostly with bio-composites composition having higher non-cellulosic core compared to their analogue in the mixed arrangement; the hemicelluloses content of betelnut fiber was higher compared to that of banana fiber [115]. In addition, mixed bio-composites are generated mixing disparate thermoplastic resins with a single fiber. Incorporation of soil clay particles caused a decrease in percentage mass loss, increase in degradation temperature of pine cone/polypropylene and oil palm fiber/high density polyethylene bio-composites [117,118]. It was found that the soil clay particles formed vapor barricade which enhanced thermal decomposition temperature of the hybrid bio-composites. Increase in carbon percent and aluminosilicate content for polypropylene/pine wood flour mixed bio-composite was observed. The thermal resistance and carbon residue of the composites were boosted by the silicates [119].

5.1. Thermo-mechanical Analysis

Manufactured resin, polymer, yarn and polyethylene applied in utensils, health tools, food storage, pharmaceuticals, blood banks, and surgical threads in addition to plastic devices, including space engineering and auto devices. Polymers to some extent behave like a liquid and a solid material that has time-dependent strain unlike metals and ceramics. Macromolecules comprise of liquid and solid components that modulate automatic behavior with respect to space and temperature. Characterizations of polymer systems are fundamental to the determination of performance and service life. Thermo-mechanical analysis (TMA) determines variations in specimen dimensions and mass related to temperature/time, stress under standard atmosphere. Usually, stress could be steady or dynamic. Thermo-dilatometric method is determined under infinitesimal stress. Thermo-mechanical analysis examinations in contraction, stretching or bending are mostly carried out under the static stress. Thermal expansion coefficient from TMA as well as glass transition temperature of a polymer composite is evaluated. As well, approximation of further analysis is achievable by employing certain unique methods and different accessory. These comprises: creep, stress reduction, axial and bending properties, dimensional changes and rheology. However, Thermo-mechanical analysis of bio-composites is limited. The coefficient of thermal expansion of composites made from pineapple leaf/kenaf fiber at 30%, 50% and 70% loading combined with phenolic resin treated with silane coupling agent applying compression molding technique was studied [120]. Results showed that the silane-treated mixed blends showed improved thermal stability compared to pure analogues. Enhanced heat resistance of silanized

30:70 and 70:30 fiber volumes of pineapple leaf/kenaf fiber composites were reported. Enhancements in heat stability of composites were ascribed to outstanding affinity of fiber and matrix that increased mechanical behavior of the treated fiber blended composites.

Comparative investigation of thermo-mechanical properties of bamboo/kenaf/epoxy having differing volume fractions of mixed composites was researched [121]. Report showed enhanced durability was attained through a twisted kenaf mat. Increment in the volume fraction of kenaf fiber gave favorable blend impact at optimal blending volume fraction of 50:50 (bamboo: kenaf). In a related report using banana/kenaf/epoxy composites fabrication was published [122]. They changed the fiber direction to vertical, horizontal and 45^o, varied piling patterns, kept a net filler volume of 40 to 42%. The thermal expansion coefficients were determined in lengthwise orientation. Results showed 45^o oriented banana/kenaf/epoxy gave highest thermal expansion coefficient of 34.61x10^{-6}/^{o}C. Besides, the net span of thermal expansion coefficient of the mixed banana/kenaf/epoxy reached 31-35x10^{-6}/^{o}C. Thermal expansion coefficient of kenaf/epoxy composites contrasted 3% loading of oil palm with the addition of nano-particles, montmorillionite and organomodified montmorillionite via thermo-mechanical analysis method [123]. Decrease in thermal expansion coefficient of filled kenaf/epoxy composites was observed compared to pristine kenaf/epoxy composites. Moreover, higher thermal expansion coefficient was recorded for oil palm nanofiller/epoxy and MMT/kenaf/epoxy compared to OMMT. As well, kenaf fiber and pineapple leaf fiber were added to phenolic resin to fabricate mixed composites [124]. Amidst the developed mixed composites, 30% pineapple leaf fiber/70% kenaf fiber showed improved heat stability. But, discrepancy in 70% pineapple leaf fiber/30% kenaf fiber and 30% pineapple leaf fiber/70% kenaf fiber mixed composites was minimized. Moreover, with a uniform filler amounts lowest heat resistance were achieved for the pristine kenaf and pineapple leaf fiber composites.

5.2. Bionanocomposite

Bionanocomposites are an important class of hybrid materials, comprised of biopolymers and inorganic solids. They exhibit at least one dimension on the nanometer scale. Such biodegradable materials prove to be invaluable gifts to present and future generations thanks to modern science and technology [125]. Nanocomposites comprising of biopolymer together with an inorganic nano functional group verbalize to a disparate category of materials known as “Bionanocomposites”. The term “bionanocomposite” moreso referred to as “Nanobiocomposites”, “green composites,” or, otherwise “biohybrids” [126]. An important element to the development of novel attributes regulating structure of a material at nano-level is its nanostructure. At the 21st century, nanotechnology is in this manner an exceptionally promising area that is needed to exhaustively revamp the ingenious implementation areas in microchip, mineral, as well as biotic resources, energy accumulation, bioengineering [127]. Several resources with different attributes in a particular scope are combined in developing composite. Constituents of composites bound by corporeal conversely blend associations maintaining phenomenal aggregate characters. Normally, attributes of composites are unequalled in several aspects to those of the separate constituents [128]. Nanoengineering is widely detailed as forming, preparing, analysis, application of material system measurement in nanoscale. Nanomaterials are created with enhanced physicothermal distinctive properties [129]. The importance of bionanocomposites is due to their nanoscale dispersion within the dimensions below a thousand nm [130]. Fig. 5 shows the constituents of bionanocomposites.

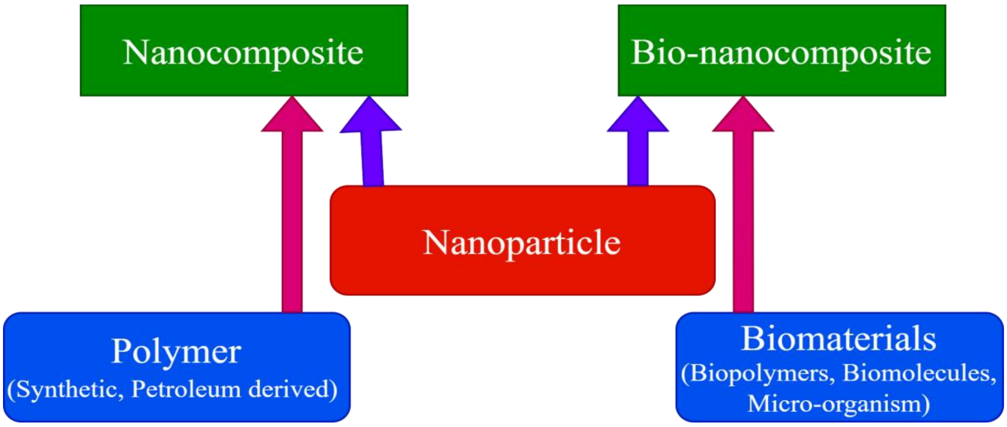

Fig. 5. Constituents of Bionanocomposite

6. Bionanocomposites Preparation Techniques

The following approaches are involved in bionanocomposites preparation as elucidated in flow chart seen in Fig. 6.

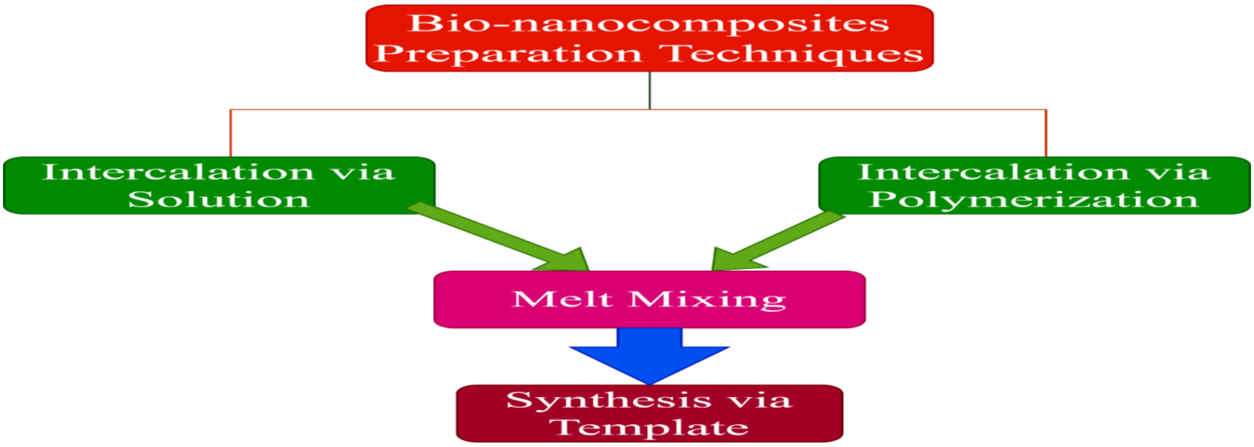

Fig. 6. Flow Chart for Bionanocomposite Preparation

6.1. Intercalation via solution

Here bioprepolymer including cellulose and amino acids are introduced into the solute. Mineral nano fillers such as silicate platelets are distended in water, chloroform or toluene. As biopolymer and nanoparticles are blended in solution polymer chains interpose by replacing liquid inside silicate d-spacing. On liquid discharge interposed contours endures, bringing about the emergence of biopolymer/ layered silicate bionanocomposite [130,131].

6.2. Polymerization via intercalation

The approach involves the spreading of nanoparticle unto a liquid/solution monomer which enables polymer development to take place amid interposed layers. The process of polymerization is carried out via elevated temperature, UV radiation, initiator, or catalyst [130,131].

6.3. Melt mixing

Melt mixing method is the standard technique for concocting layered silicate-polymer bionanocomposites. Numerous merits juxtaposed the solution polymerization whereby polymer is heated to a liquid mass and blended with nanoparticle [130,131].

6.4. Synthesis via template

Here biomolecular cells of microorganisms function to support inorganics created progenitor. Supporting bio-organics nanosized particles are captured by mesoporous matrix. This is a highly versatile simple, easy method and germane for sizeable scale manufacturing. The procedure largely called for soluble polymers ensuing outcome likelihood impurity owing to byproduct (Table 8) [131–133].

Table 8. Comparing Sources of Natural Fiber, Polymer, Modification and Application

S/N	Natural fiber	Polymer	Modification	Application	Reference
1	Coir	Poly (lactic acid)	Corona	Automobile	[134]
2	Sisal	Epoxy resin	Sodium hydroxide	Advanced application	[135]
3	Jute	Polypropylene	Nano-calcium carbonate	Food packaging	[136]
4	Abaca	Bio-polyethylene	Maleic acid grafted polyethylene	Automobile	[137]
5	Sisal/Banana/Bagasse	Poly (lactic acid)	Sodium hydroxide	Enhanced tribological properties	[138]
6	Sisal	Wasted cotton seed protein	Sodium hydroxide	Food packaging	[139]
7	Flax fabric/Glass fiber	Epoxy resin	Acrylic thermoplastic	Has replaced synthetic polymers in its applications	[140]

7. Bionanocomposites Composition

7.1. Biologically active materials

Plant, animal and microorganism are sources of biomaterials containing mainly cellulose, hemicelluloses and lignin as illustrated in Table 9.

Table 9. Biologically active materials

Cellulose	Chitosan	PLA	starch	Chitin	PHA	Nano particle	Layered silicates	Nano tubes	Orblike particle
Cellulose is a fiber mainly seen in plants and animals. It is a construction material of lengthy fibrous cells and very tough natural polymer. Cellulose nanofibers are intrinsically cheap and ubiquitous material. In addition, they are biodegradabl e and facile of recycling through combustion, and demand reduced power utilization in production. Fundamentall y, two groups of nanoreinforce ments can be derived from cellulose namely microfibrils and whiskers [134,135].	Chitosan is a natural polysacch aride having extensive number of amino (-NH_2) and hydroxyl (-OH) moieties. Chitosan is a straight chain copolyme r synthesize d from the deacetylat ion of chitin; having β (1-4) linked straight chain copolyme r containin g 2-acetamido - 2-deoxy-D-glucopyra nose and 2-amino-2-deoxy-D-glycopyra nos. It has a structure closely identical to cellulose [136]. It has found applicatio ns in medicine including injury dressings and absorbabl e sutures [137].	Poly Lactic Acid (PLA) is among the extensive ly develope d bioplasti cs. It is also called Poly lactide with straight thermopl astic polymer chiefly obtained from sustainab le resources like corns or sugar beets. PLA has multifari ous applicati ons including medical tools, food, packagin g and textiles [141].	Starch is a polysaccha ride having double parts amylose and amylopecti n. Largely starch is useful for storage of energy in plants and microorgan isms. The main sources of starch are potato, maize and tapioca [141].	Chitin is altered cellulose having high molecular weight synthesized from N-acetylglucos amine units. It is extensively employed as functional binder in dyes and fabrics [141].	Polyhydroxyalk anoates (PHA) is associated to a descent of naturally existing water repellant, nontoxic, and eco-friendly polyesters. It is obtainable in a broad kind of shapes and utilized for carbon or energy storage in microorganism in the form of light refracting granules inside the cell [141].	Nanoparti cles in nano sizes exist in spherical, tube and platelets develope d by large particle to form small particle possessin g measure ments in micro or nano size [142].	A layered silicate also referred to as clay minerals is part of type of silicate minerals and phyllosili cate. It comprises of natural and synthetic clays including mica, bentonite, laponite, magadiite , fluorohect orite [142].	There are differe nt kinds of nanotu bes which are availab le but chiefly carbon nanotu bes are used. Nanotu bes are allotrop es of carbon belongi ng to the fulleren e structur al family, having diamet er in a nanosiz e in mm or in cm. Light-weight structur es can be produc ed using carbon nanotu bes-reinfor ced compos ites with a lofty aspect ratio [142].	Mainly in spherica l form obtained through sol-gel techniqu e. Enhance thermal resistanc e, Enhance packagi ng applicati ons, Boost mechani cal characte rs like toughne ss, tensile strength and dimensi onal stability, Strength en properti es of the polymer matrix and Increase porosity [143,14 4].

7.2. Characterization of bionanocomposites (Table 10)

Table 10. Characterization of bionanocomposites

Particle size	Surface morphology	Thermal analysis
The particle sizes of bionancomposites are in nanometer-size dimensions (1-100 nm), elucidated through motic images of particles with the aid of motic microscope or Malvern Zetasizer.	Scanning electron microscopy is applied to investigate the distribution of particle of bionanocomposites.	Differential Scanning Calorimetry (DSC) is employed for the thermal analysis of bionanocomposites. DSC is capable of showing if the nanoparticles are compatibly distributed inside the polymer or not.

7.3. Bionanocomposites Application

Bionanocomposite materials are outstanding materials applied for catalysts, gas-separation membranes, contact lenses and bioactive implant devices [145]. Bionanocomposites are employed in the fabrication of scaffolds, implants, diagnostics and biomedical implants and drug-delivery appliances. It is also employed in the cosmetics manufacturing [136]. Centering on the medical area and aggregate utilizations of chitosan based bionanocomposites. He showed the different routes for the production of chitosan nanocomposites using various serviceable material, centering on their implementation precisely in towel manufacturing, drug and gene transportation, injury salve and bio imaging [136]. Produced the reinforced sticking of talc/ZnO nanocomposites on cotton fabric aided using aloevera for biomedical usage mainly applied on baby diaper [146]. Processed and identified the silica nanocomposites for bone administration [147]. Researched on nanocomposite fibers and described its medical usage. They succeeded in changing the calcium alginate fibers with the nanofiliers which generates an option in tissue reconstruction by applying the fibers as bioactive substrates [141]. The production of copper polymer nanocomposites, superb and cheap effective biocide modulating or impeding the development of microorganisms and hindering food causing maladies and healthcare associated infections [142]. Applied in gene transportation for motive of against cancer drug delivery, post-disaster needs assessment (pDNA) transfection, silencing ribonucleic acid (siRNA), camptothecin (CPT) drug and report [143]. It is employed as actuators in man-made tendon [144]. The manufacture of Bosentan nanocomposites employing hydrophobic and hydrophilic graft co-polymer-carrier excellent in improve the solvability disintegration and biological availability. They assembled the graft co-polymer-anchored nanocomposite development via the unattached-emulsion process [148]. Synthesis and characterizing the bionanocomposite films found on soy protein seclude and montmorillonite via melt extrusion. These bionanocomposite films are possibly utilized for packaging of elevated water products like fresh fruits and vegetables to substitute certain of the current plastics including low density polyethylene (LDPE) and polyvinylidene chloride (PVDC) [149]. Generating the cellulose nanocomposites with the aid of nanofibres which are secluded by pineapple leaf fibers. The fabricated composites were used to produce numerous many-sided medical infix. Pineapple leaf fibers obtained from nanocellulose implanted polyurethane has been employed as an appealing and quickly accessible gamut of materials for the production of circulatory prostheses and applied to create coronary spigots and heart vessels in the circulatory system [150,151]. Bionanocomposites mainly appropriate in production of cardiovascular vessels. Used in producing of compostable bags which is biodegradable [152]. Cure osteomyelitis through reconstruction of tissues [153]. Utilizable in symptomatic, drug transportation and tissue reconstruct [154].

8. Drawbacks of Natural Fibers in Bio-composites

Despite the advantages, natural fibers have numerous observable drawbacks limiting their applications in natural fiber polymer composites. High water absorption properties and thickness swelling, low thermal decomposition temperature, flammability, ultraviolet radiation, and poor resistance to microorganisms of natural fibers as juxtaposed traditional polymers hinder advancement and possible implementations. The utilization of natural fibers enhances toughness of bio-composite with increase in fiber loading. However, increase in fiber loading increases fragility, moisture uptake capacity as well as unwanted smell. Further striking impeding variable for employment of bio-composites in structural and non-load-bearing usage is restricted affinity of fibers-polymers. Strength affinity of fibers-polymers impact strength attributes longevity implementation of the bio-composites. Prolonged attributes such as wiggle, jade characters, longevity and duration of life forecast of biopolymer composites is absolutely unspecified and is a great worry. Therefore certain novel procedures and scientific methods should be embraced to investigate the execution of natural fiber polymer bio-composites over its duration of life. It is noteworthy that for mercantile manufacture, the natural fiber polymer bio-composites are made via mercerization, bio-composite mixing, additives, filler inclusion, laminating and certain developed fabrication techniques. Notwithstanding that natural fibers and bio-composites are inexpensive compared to their man-made opposites; certain fabricating processes require a considerable bulk of financial expenditure and energy demand.

8.1. Future Scope of Natural Fiber Bio-composites

In order to overcome these challenging issues, certain vital parts and submissions to be considered in further evaluations of fiber filled plastic bio-composites are:

Surveying, singling-out, and characterization of novel natural fibers that is necessary to expand the implementation of substitute unsafe man-made fibers. Researches on animal fibers reinforced polymer bio-composites are few, despite the fact that animal fibers are recognized to have improved automatic attributes compared to plant fibers. Between presently utilized fiber separation techniques, no separation method has been known as conventional process for a particular kind of fiber. It is also definitely noticed that there is no particular conventional technique for fabricating natural fiber reinforced polymer bio-composites. Initiating modern methods for bio-composite development shortens optimization length, reduces energy and material consumption. Employing natural fiber reinforced polymer composites in diverse disciplines including automotive and construction areas, it is important to conduct standard affirmation and evolve optimized natural fibers owing to its extensively distributed resources and changing attributes. Investigate further regarding influence of reinforcing treated natural fibers in bio-composite to forecast ideal usage to predict possible outcome. Moreover, transformative surface treatment methods require to be studied to embrace approaches which are more inexpensive and biodegradable. However natural fiber-reinforced polymer bio-composites have revealed its execution in automotive, aerospace, electronic and biomedical fields, additional studies is required in medical scaffolds for injury salving process and tissue manufacturing. In automotive fields, natural fiber reinforced polymer bio-composites have created outstanding business emporium for bang for the buck output. As well, value inclusion in other sectors requires be concentrating and encouraging. A significant limitation of bio-composites materials is the complexity in comprehending its longevity. The uncertain permanence coupled with scarce mechanical toughness is a main restricting element in using natural fiber bio-composites for automotive fields. Majority in the mastery regarding the longevity of bio-composites is based on experimental-scale findings. The original character of bio-composites has not been extensively evaluated to check the laboratory outcome and postulations. Novel laboratory methods should be studied to track, assess and direct the longevity and eco-friendliness of natural fiber bio-composites. The study should also target one crucial facet, that is, structural attributes of natural fiber reinforced polymer bio-composites. Production structural bio-composites broaden utilization of bio-composites for different structural implementations. The prolonged permanence of bio-composites requires enhancing and tracking to its wider application in construction areas. Novel methods to perform performance assessment in bio-composites are vital to ascertain influence of eco-system on thermomechanical and longevity of composites. Blending/mixing is a sure method that requires further attention to produce new and efficient bio-composite products. It is a favorable approach to mix natural fibers of different attributes to develop bio-composites with outstanding toughness properties. As bio-composites is an offshoot synergy between characteristics of natural fibers and polymers, development and advancement in component-dependent and independent mixing main field is required. The usage of nanotechnology has given diverse openings for improving attributes of bio-composites. Investigations found nano-crystalline cellulose to be stronger compared to aluminum and steel.

Therefore, producing nanofibers from natural fibers is a propitious area in structural bio-composites implementations.

8.2. Conclusions

Following the previous ten years, there is progressive upsurge in the commercial appeal in natural fiber reinforced polymer bio-composites. Natural fibers on chemical treatment have proved its capability to dominate man-made fibers with its ubiquitous accessibility, inexpensive and biodegradable properties. Amongst the natural materials, kenaf and jute fibers have shown outstanding toughness in bio-composites production and application. Utilization of natural fibers in bio-composite fabrication has advanced agriculture and silk farming, whereby decreases air contamination by mitigating greenhouse impact. Bio-composites are inexhaustible, non-toxic, earth-friendly, environmentally sound, lightweight, facile production, and also have lighter weight and toughness complaint custom-made assuages assorted output demands. Polymer bio-composites implementations relies on multifarious elements including chemical constituents, physical features of fiber and bio-composites, fiber treatment methods, fiber concentration, quantity of added ingredients, technique of fabrication, configuration, fiber-matrix orientation, imperfections, synergy, and environmental factors. Other extensively acknowledged bio-composite advancement method mixing various kinds of filler materials with sole polymer matrix in fabricating greatly prized combined bio-composites. The researchers showed that the bio-composites are harmonious in automotive, construction, biomedical, and food factories possessing multifaceted executions. Prospectively, more studies of natural fiber reinforced bio-composites will possibility take over traditional fossil based polymers. There is potential in the advancement of novel emporiums when these bio-composites become more long-lasting with enhanced performance. This paper is cursory review investigating automatic and thermal behaviors of natural fibers toughened polymeric bio-composites, bio-composites, bionanocomposites and emerging applications. The study proved that bio-composites are propitious resources in emerging appeals for industrial, automotive and scientific advancement. Bio-composites are called 'green materials' because of notable merits including renewability, viability and environmentally friendliness. Fundamentally, a rising consciousness in people as well as contributions from the academia will further advancement in natural fibers reinforced bio-composite materials.

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