"Matrix and Reinforcement for Biopolymer Composites-A Review"

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Abstract:

Even if a massive amount of petroleum is used to coat countless items in the business sector, the fact that it is not biodegradable is a major drawback. One major replacement for plastics made from petroleum is the use of biodegradable polymers, often known as biopolymers. The qualities of finished plastic goods are greatly enhanced by the addition of natural fiber reinforcement to biopolymer matrices. Researchers have developed biopolymers composites to supply environmentally responsible materials and cut down on carbon emissions. To improve the interfacial bonding with biopolymers and to generate high-performance composite materials that can compete with standard petrochemical-based polymer composites, it is necessary to modify or functionalize natural fibers.

Hybrid composites, created by fusing fibers of multiple sorts together in a matrix, are another popular method for advancing the composites field. Synergistic application and future potential as biopolymer composites in the automotive industry and other expanding sectors are discussed, along with the extraction, processing, and characterization of bio-based materials such as natural fibers and biopolymers.

KEYWORDS

Biodegradable; Biopolymer; natural fiber; interfacial bonding; hybrid composite; automotive sector.

1.0 Introduction

Petroleum-based plastics have become ingrained in our daily lives because of their potential to sub in for a wide range of more conventional materials. Fiber reinforced polymer composites are increasingly used in sophisticated fields like transportation, aerospace, and healthcare. Outside of this monetary sphere, the majority of petroleum-driven materials create an unsustainable ecosystem. Consequently, bio-based materials offer an alternate strategy for creating eco-friendly products.

New materials that are more durable, rigid, and lightweight than those they replaced are always of interest and demand in the construction industry. Fiber reinforced polymer (FRP) composites have been successful in both the scientific and industrial spheres because they outperform more conventional building materials like metals, plastics, and wood in terms of structural efficiency and strength-to-weight ratios. However, there has been growing worry over the depletion and rising costs of petroleum resources that serve as feed-stocks for these polymer matrix materials, despite the fact that these technologies offer remarkable performance.

There has also been a rise in consciousness of the ecological effects of synthetics over their whole life cycles. The scientific community has been tasked with finding ways to lessen humanity's footprint on the planet without sacrificing or diminishing the quality of human life. Increased interest in the creation of novel bio composite materials can be attributed to the potential environmental and economic benefits of using materials based on natural renewable resources.

Substances obtained from live organisms are the basis for bio-based materials. The term "green composite" is used to describe biopolymers that are reinforced with natural fibres. Environmental variables including air, light, heat, or bacteria might break down this biopolymer composite over time.

Products for the construction sector have historically been crafted from wood, metal, concrete, brick, and plastic. Despite their favorable performance features, these materials are frequently ineffective. The use of these products also adds to the global garbage that is increasingly overrunning landfills. However, the widespread use of these materials has been hampered by the relatively incipient state of the material development and lack of knowledge regarding their long-term durability. Bio composites have been used as an alternative to traditional building materials in applications that require minimal load bearing capabilities.

The study that has already been done on bio composites reinforced with natural fibres. The goal of this work was to create a unique bio composite system that is made entirely from renewable resources and is strong enough to be utilized in tertiary load bearing applications, which might be employed in environmentally friendly construction. In order to design a production method that would enable high performance characteristics and the most economical use of the material ingredients, several composite manufacturing techniques were explored. Composites with large fibre volume fractions and good fiber alignment were given extra attention during fabrication since these features were seen as critical for optimal composite performance. To assess these composites' potential as structural materials, we conducted experimental testing to measure their response to a variety of loading circumstances. In addition, the study was able to recommend ways to overcome the present constraints that are restricting bio composite performance and implementation by identifying critical process variables and material parameters that negatively impact performance characteristics.

Natural fibres provide advantages over man-made alternatives such low production costs, low environmental impact, and recyclability. However, natural fibers' high moisture absorption, low processing temperature, and overall quality fluctuation limit their usefulness. Numerous research have reported on the efficacy of functionalizing natural fibers in the production of high-performance goods made from biopolymer composites reinforced with natural fibers. Stiffness and strength in a biopolymer composite are primarily determined by the reinforcing fiber, whereas the biopolymer matrix controls the composite's structure, environmental tolerance, and durability. Biopolymer composites' potential for expansion in global markets is ensured by their use in unique, high-value applications. Some significant global applications have resulted from the attempts to manufacture environmentally friendly composite goods with increased performance, and these efforts are ongoing. This review will focus on commercially available polymers that show promise as future matrices for natural fibre composites, such as cellulose, starch, polylactic acid (PLA), polyhydroxyalkanoate (PHA), etc., and on the production, processing, and applications of biodegradable composites prepared from these polymers. Biopolymers derived from fossil fuels or that are not biodegradable will not be included in this analysis.

The advancement of biocomposite materials is driven by a number of important aspects. First, compared to more conventional materials like metals, GFRP composites, and wood products, bio composite materials offer greater strength and stiffness at lower weights. The low price and relative immunity from economic swings of biocomposite materials are made possible by the seemingly infinite supply of agricultural resources used as feedstock. Bio-based composites made from renewable resources are preferable to traditional FRP composites from a sustainability and environmental protection perspective because they do not contribute to the depletion of the world's natural resources, they require less energy and chemicals to produce [1-4], they emit fewer greenhouse gases and toxins during their production, use, and disposal, and they may be biodegradable, recyclable, or used for energy harvesting upon incineration [1, 3, 4].

2. Literature Review

2.1 A Description of bio composites

The multibillion dollar fiber-reinforced composites market serves a wide variety of end-users and industries, including the transportation, building, maritime, electrical, sporting, appliance, aerospace, and consumer goods sectors. These materials are appealing because of their capacity to mix properties of other materials to make a system that is not present in nature yet is high-performance, easily customized, and efficient. This has led to a rapidly expanding and lucrative industry for composites. Fiber reinforced polymer (FRP) composites have been around since the early 1900s, when cellulose fibers were initially mixed with phenolic resins, and then became a commodity in the 1940s, when glass-fiber reinforced unsaturated polyester was developed [1]. The usage of glass-fibers as reinforcing material in FRP products has steadily increased since then [1]. Figure 1 displays a market share analysis of key end-use industries for glass fiber reinforced polymer (GFRP). As new uses for composites are discovered, it's no surprise that demand is rising.

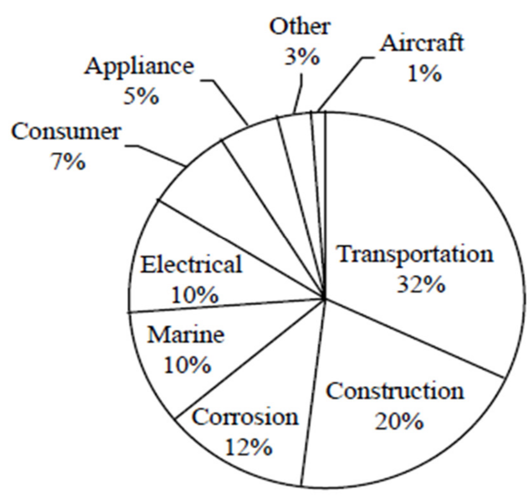

Figure 1: Breakdown of GFRP applications by industry [5]

Growing knowledge of the environmental impacts of making, using, and disposing of synthetic materials has contributed to rising economic concerns about the depletion of petroleum supplies in recent years. The Energy Policy Act of 2005 (U.S. Public Law 109-058), the Biomass Research and Development Act of 2000 (U.S. Public Law 106-224), the Farm Security and Rural Investment Act of 2002 (U.S. Public Law 107-17), and presidential executive orders 13134 (Developing and Promoting Bio based Products and Bioenergy, August 12, 1999) and 13101 (Greening the Government Through Waste Prevention, Recycling, and Energy Efficiency, October 22, 2009) have all contributed to this trend.

Government initiatives and public awareness campaigns have bolstered the push for research into eco-friendlier materials to replace conventional ones like glass and composites made from petroleum. Bio composites and other renewable natural materials have been the primary focus of this study.

Bio composites are composites made from one or more eco-friendly ingredients, like biopolymers or natural fibre reinforcements. Depending on the materials used and how well they biodegrade, different types of bio composites offer variable degrees of environmental friendliness. Figure 2 provides a schematic representation of different types of composites in light of the current definition of bio composites. 'Green' composites are those made with both natural fibre reinforcements and biopolymers [6]. These composites can offer the greatest economic and environmental benefits if they are completely biodegradable, which depends on the polymer utilized.

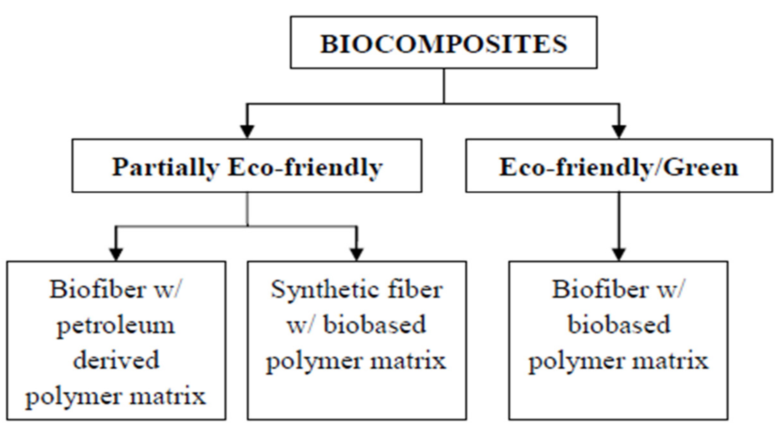

Figure 2: Classification of bio composites based on material constituents

The long-term prosperity and viability of the bio composite materials field depends on their development following a sustainable economic trajectory. The manufacturing procedures for both glass fibres and polymers generated from petroleum are well established, therefore GFRPs may be made cheaply. Most biopolymers are more expensive than petroleum-based polymers at the moment, although this is projected to change as demand rises and technology improves. Natural fibre reinforcements are inexpensive, which can have a positive effect on the total price of the composite. Natural fibre mats use less than a fourth of the energy needed to manufacture a comparable glass fibre mat (54.8 MJ/kg) [6], according to multiple studies that factor in growth, harvesting, and fibre digestion. Most plant fibres also have a density that is roughly 40% lower than glass fibres. When shipping costs are factored in, product weight becomes less of an issue, which is especially helpful in transportation (automotive) applications. As can be seen from the foregoing, there are a number of ways in which bio composites can improve upon the status quo of synthetic composites.

Many studies aim to develop bio composites with superior mechanical properties; however, these materials have not yet reached their full potential due to issues with biopolymer development, fibre property variation, and composite processing. In spite of this, the environmental benefit of bio composites has prompted more work to characterize and improve the properties of already-developed bio composite materials, as well as the development of novel materials. Such developments are expected to pave the way for a bio composites industry that is high-performing, environmentally benign, and economically stable.

2.2 Natural Fiber Reinforcements

Thermoplastic and thermosetting polymers derived from petroleum and natural feed supplies, respectively, can be reinforced with cellulosic fibres. Natural fibres in bio-composites function as the reinforcing phase, elevating the composite material's performance in the same way as traditional composites do. The efficiency of a system can be improved by increasing its mechanical qualities like strength and stiffness while decreasing its weight.

Glass, carbon, and aramid fibres are the most prevalent types of reinforcement used in conventional structural composite materials. The durability and resistance to degradation in the natural environment are major factors in the selection of these fibres.

Research into the development of composites using natural fibrous reinforcement materials, such as those derived from renewable agricultural crops and other fast-growing plants, has been encouraged by growing environmental and economic concerns regarding the manufacture, use, and disposal of these materials.

2.2.1 Advantages of Natural Fibers

Plant-based lignocellulosic materials make up the vast bulk of the natural fibres studied for composite reinforcing. Plant fibres have long been valued for their useful properties. Roping, textiles, tools, and building materials are all examples of uses that have taken advantage of plant fibres' exceptional mechanical characteristics in the past and today. Plant fibres have superior mechanical properties to those of conventional composite fibre reinforcements, and they also have a number of other advantages. The environmental concerns related with the depletion of natural resources are mitigated by the use of these fibres, which are often generated from fast-growing renewable plants and are thus much cheaper and far less sensitive to economic changes. Fibres manufactured from cellulose can have a density that's as little as half that of common reinforcing fibres like glass [15]. As a result, the natural fibre reinforced polymer (NFRP) composites that are produced can be less heavy than conventional composites, leading to more effective systems and lower transportation costs. In comparison to glass fibres, which can cause allergic reactions, skin irritation, and respiratory irritation if breathed due to the production of glass particles during processing, natural fibres are a safer material to work with because they are non-toxic. Also, the machinery needed to process plant fibres is less likely to be damaged since they are less abrasive than conventional fibres.

Compared to composites constructed with glass fibres [5-7], those made with natural fibres are said to have significantly better life cycle assessments (LCA) due to their lower energy requirements and carbon footprints. Plant fibres are carbon neutral because they emit only the same amount of carbon dioxide during deterioration or burning as they took in during their growth [17]. Natural fibre mat production uses less than a fourth of the energy needed to manufacture a comparable glass fibre mat (54.7 MJ/kg) [11]. This includes all stages of production from growth to harvesting to fibre digestion. Patel et al. [3] conducted life cycle assessments (LCAs) for many existing biocomposite systems and found that biocomposites have the potential to provide substantial environmental benefits and make a significant contribution towards an ecologically friendly and sustainable future. Joshi et al. [2] also identified four general drivers for the superior environmental performance of natural fibre reinforced composites compared to glass fibre reinforced composites for automotive applications: (i) the production of natural fibres has a lower environmental impact, (ii) substitution of base polymers by higher volume of natural fibres, (iii) lower energy use during lifecycle as a result of reduced material weight, and (iv) biodegradation. This research concluded that natural fibre composites are preferable to glass fibre composites when considering environmental impact. The advantages of natural fibres over glass fibres are summarized in Table 1.

Table 1: Comparison between natural and glass fibers [2]

	Natural Fibers	**Glass Fibers**
Density	Low	~Twice that of natural fibers
Cost	Low	Low to high
Distribution	Wide	Wide
Energy	Low	High
Renewable	Yes	No
Recyclable	Yes	No
CO2 Neutral	Yes	No
Abrasion to Machines	No	Yes
Health risk when	No	Yes
Disposal	Biodegradable, energy harvesting	harvesting Incineration, land-filled

2.2.2 Disadvantages of Natural Fibers

Some challenges exist in the movement away from traditional fibers like glass, carbon, and aramid towards plant based fibers for composite reinforcement. To begin, conventional fiber reinforced polymers (FRP) are processed and manufactured differently than natural fibers. Since this may necessitate the creation of new machinery and procedures for the production of broad items and fabrics, it may slow down the widespread adoption of natural fiber reinforced composite technology. Furthermore, typical fibers can be manufactured repeatedly with a certain set of qualities. In contrast, natural fibers tend to have more variation in their qualities. Chemical composition and physical structure, for example, are characteristics of a fiber that cannot be changed. The qualities of fibers are more susceptible to variation across batches due to factors like as growth circumstances, harvesting and processing procedures, and even storage. Natural fiber composites have a number of drawbacks, but their susceptibility to moisture is among the most significant. Due to their hydrophilic nature, the fibers absorb water, which can lead to deterioration and swelling, and eventually fiber/matrix interface issues. Bio composite technology can only be effective if their weaknesses are carefully studied and effectively resolved.

2.2.3 Engineering Properties of Natural Fibers

In some circumstances, plant fibres even rival the mechanical qualities of glass fibres. While their tensile strengths fall short of those of glass fibres, their reduced density allows them to achieve similar specific strength values. Selecting natural fibres allows for easy customization of composite qualities, since the fibre elongation to break might fall either above or below the range for conventional glass fibres.

Natural fibres provide low thermal conductivity qualities (between 0.29 and 0.32 /m-K) and superior noise insulation (a hollow tubular structure) [30]. The chemical and physical qualities of natural fibres are crucial to understanding their mechanical properties, as discussed above.

These patterns have been empirically confirmed by multiple study attempts. Based on their examination of a variety of bast, leaf, and fruit fibres, Mukherjee et al. [23] concluded that high cellulose, low fibre angles, and high cell aspect ratios (L/D) in fibres are often connected with high ultimate tensile strength (UTS) and low elongation. Similarly, fibres with low cellulose content, high fibre angles, and low L/D values were shown to have low UTS and high elongation values [23]. However, because fibre strengths are so sensitive to flaws, the association between strength and the aforementioned factors is smaller than it is for elongation and stiffness values [12]. Fibres for composite reinforcement can be better matched to the application needs of the composite if the effect of different chemical and structural factors of fibres on their mechanical properties is understood. Table 2.2 compares some of the mechanical properties of commonly used conventional fibres with those of natural fibres in composite reinforcement. The chemical and physical properties of natural fibres are compared and contrasted in Table 2.3.

Table 2.2: Physical and mechanical properties of natural fibers [14, 23]

Material	Type	Density (g/cm^3)	Diameter (μm)	Tensile Stength (Mpa)	Elastic Modulus (Gpa)	Elong. at break (%)	Price range ($)/kg
Glass	Mineral	2.5-2.55	5-25	1800-3500	70-73	2.5-3.0	1.30-2.00
Flax	Bast	1.4-1.5	20-600	345-1500	27.6-80	1.2-3.2	0.40-1.50
Hemp	Bast	1.45-1.5	25-2000	550-900	550-900	70 1.6	0.40-1.80
Jute	Bast	1.3-1.49	25-200	393-800	10-30	1.16-1.8	0.35-0.55
Ramie	Bast	1.5-1.55	10-25	400-938	44-128	1.2-3.8	0.44-2.50
Kenaf	Bast	1.193	90-100	375-930	22-53	1.5-1.6	0.40-0.55
Coir	Seed/Hair	1.15-1.46	100-460	131-220	4-6	15-40 0	0.25-0.55
Cotton	Seed	1.5-1.6	12-38	287-800	5.5-12.6	7-8	0.44-0.55
Sisal	Leaf	1.33-1.45	50-390	468-700	9.4-38	2-7	0.40-0.70
PALF	Leaf	1.44-1.53	20-80	413-1627	34.5-82.5	1.6-2.4	0.40-0.55
Curaua	Leaf	1.4	-	500-1150	11.8	3.7-4.3	0.6
Hardwood	Wood	0.6-0.9	-	90-110*	11-13*	-	0.44-0.60
Softwood	Wood	0.3-0.7	-	60-90*	8-14*	-	0.44-0.60

*Elastic properties of wood samples at 12% moisture content

Table 2.3: Chemical compositions and structural properties of natural fibers [14, 23]

Type of Fiber	Cellulose (wt. %)	Lignin (wt. %)	Hemicellulose (wt. %)	Microfibril/ spiral angle (degree)	Moisture content (wt. %)	Cell length to diameter ratio (L/D)
BAST						
Flax	71	2.2	18.6-20.6	5-10	8-12	1687
Hemp	70.2-78	3.7-5.7	17.9-22.4	2-6.2	6.2-12	906
Jute	61-71.5	12-13	13.6-20.4	8	12.5-13.7	110
Ramie	68.6-83	0.6-0.7	13.1-16.7	7.5	7.5-17	3500
Kenaf	31-57	8-19	21.5	130	-	-
FRUIT						
Coir	32-43	40-45	0.15-0.25	30-49	8	35
SEED						
Cotton	85-90		5.7	-	7.85-25	1250
LEAF						
Sisal	67-78	8-14	10-14.2	10-22	10-22	100
Pineapple	70-82	5-12.7	-	14	11.8	450
WOOD						
Hardwood	44-50	20-30	20-25	-	3-7	30
Softwood	44-50	20-30	20-25	-	8	164

2.2.4 Fiber Types

The most common classifications of plant fibres used for composite reinforcement are as follows: (1) bast fibres, obtained from the fibrous bundles within the inner bark of a plant stem; (2) leaf fibres, obtained from fibres running the length of plant leaves; (3) seed fibres; (4) reeds and grass stems; (5) fruit fibres; and (6) wood fibres, obtained from the core of trees. Figure 2.4 displays the plant types that have received the most attention for their potential usage in bio-composites. In the subject of natural fibre composite reinforcements, bast and leaf plant fibres have been the primary focus of most studies.

The combination of great strength and stiffness with minimal elongation to break makes these fibres, often known as hard fibres, the most popular in natural fibre composites. Because of their comparatively low moisture uptake, bast fibres swell less in humid settings, leading to better fiber/matrix adhesion [14]. Additionally, bast fibres' large lengths make fibre alignment easier. Based on their inherent qualities, bast plant fibres may be useful as effective composite reinforcements. Flax, hemp, jute, kenaf, and ramie are all potential reinforcement materials for bio composites, thus researchers will soon be analyzing their properties, processing methods, and potential applications.

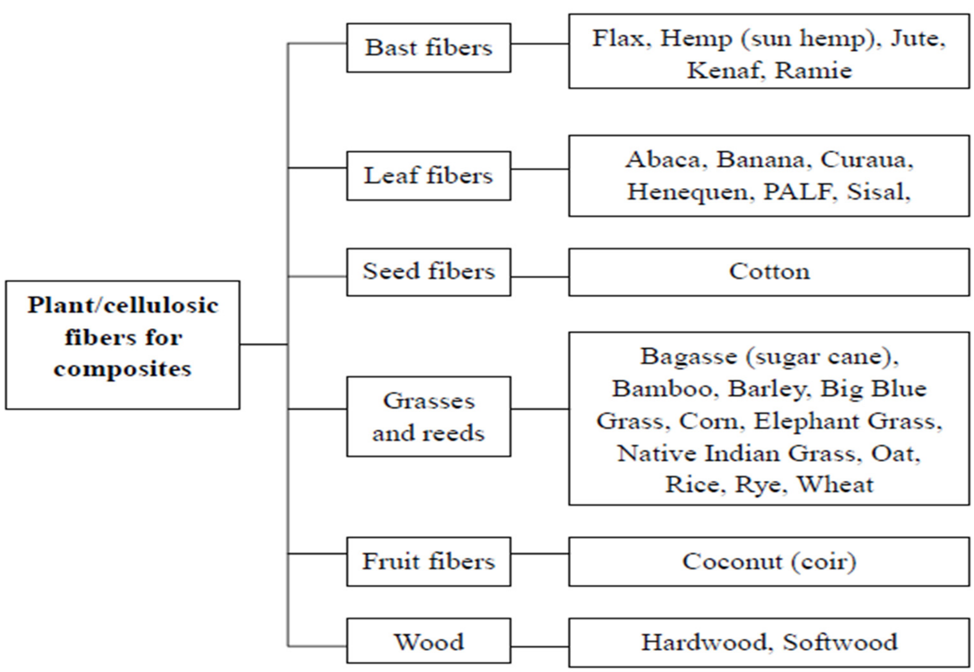

Figure 2.4: Cellulosic fibers and their origins used for natural fiber composites [15]

2.2.4.1 Bast Fibers

The inflexible stalks of bast fiber plants branch out at regular intervals. Stalks have a cambium transition layer between nodes, a phloem composed of small chlorophyll-containing cells and long bast fibre cells, and a thin protective layer made up of the cortex and epidermis [17].

Composite reinforcing efforts focus on the long bast fibers that run longitudinally in the phloem areas, just beneath the bark's protective layer. Diverse bast fiber harvests have diverse stem shapes and sizes, but the fibers themselves all have the same basic structure. Bast fiber crops can provide high yields of the long individual fibres or fibre bundles at a minimal cost.

Since a recent study by Bismark et al. [17] already illustrates the diverse bast stalk and fibre architectures and their qualities. The following sections provide a synopsis of the most popular bast fibres used for natural fibre reinforcements, including information on their sources, physical features, and matching mechanical properties.

2.2.4.1.1 Flax

Flax (Linum usitatissimum L., Linaceae) has been farmed for almost 10,000 years and is primarily grown in temperate areas like southern Europe, Argentina, India, and China. Important items including oil seed, paper and pulp, textile yarns, and fabrics are frequently produced by flax plants. Flax plants can reach heights of 80 to 150 cm in less than 110 days, which is a relatively quick growth rate. The bast fibres are found in bundles between 60 and 140 cm long and 40 to 80 m in diameter, coming from the centre of the plant. Table 2.3 shows further dimensional parameters and chemical contents of flax fibres. One of the strongest and stiffest plant fibres is flax; nonetheless, when subjected to tensile pressures, flax fibres have a comparatively low longitudinal extension to failure [17].

2.2.4.1.2 Hemp

Typically, hemp (Cannabis sativa L., Cannabaceae) is grown in regions with temperate weather like Central Asia and Northern America. Despite being grown for more than 12,000 years, due to its physical similarity to the narcotic substance marijuana, tight legal restrictions have prevented it from being grown. However, although producing less than 1% of the narcotic 9-tetrahydrocannabinol (THC) than marijuana (which generates between 3-20%), hemp cannot be used as a narcotic. Specialty paper, textiles, building materials, polymers and composites, food, medicine, and fuel are just a few of the many items that may be manufactured from hemp plants.

Hemp crops have an advantage over other fibre crops in that they are highly robust and require little to no fertilizer, pesticides, fungicides, or herbicides. Additionally, hemp plants grow quickly, reaching heights of up to 5 m and having bast fibre concentrations between 28 and 46%. The essential fibres range in length from 13 to 25 mm on the 1.8 m or longer fibre strands. Despite being hygroscopic, hemp fibres have a great resistance to moisture deterioration and degrade in water extremely slowly. Because of their low cellular micro fibril angle and high mechanical qualities, hemp fibres have low elongation to break and excellent strength and stiffness [17].

2.2.4.1.3 Jute

Although it originated in the Mediterranean, jute (Corchorus capsularis, Tiliaceae) plants flourish in hot, humid areas and have since spread to the near and Far East. These days, it is primarily grown in the delta created by the Ganges and Bramhaputra rivers in Bangladesh, India, Thailand, China, and Brazil. Jute plants have been used by people from the beginning of time. These annuals have stalk diameters of 2 to 3 cm and reach heights of 2 to 3.5 m. Jute plants, in contrast to flax and hemp, are only grown for their 1.5–3 m long fibres.

These bast fibres come in a wide range of sizes, and despite being robust, they have lower tensile qualities than other bast fibres like hemp and flax. Due to the high lignin concentration, they are also fairly brittle and have a low elongation to break. However, they are quite hygroscopic and sensitive to moisture as well as chemical and photochemical attack, jute fibres are resistant to attacks by microbes [17].

2.2.4.1.4 Ramie

Hardy perennial crop ramie (Beohmeria nivea L. and Boehmeria viridis, Urticaceae) is mostly grown in Indonesia, China, Japan, and India. The plants can be sown and harvested up to six times a year and reach a height of 1.2 to 2.5 m. Ramie fibres are largely employed in the textile industry because they are robust, highly fine (10 to 25 m in diameter), and silk-like. Additionally, they are exceptionally resilient to bacterial, fungal, and insect attack. They are also stable in both alkaline environments and mild acids, unlike flax, hemp, and jute fibres. Due to their high cellulose content, ramie fibres also possess good strength and stiffness qualities [17]

2.2.4.1.5 Kenaf

Hibiscus cannabinus L., a member of the Malvaceae family, is a cane-like annual crop native to Asia and Africa. Kenaf plants grow quickly and can grow from 2.4 to 6 metres tall in just 5 months. Paper, textiles, and composite materials are created from kenaf plants. The stalks of the kenaf plant contain both short and long fibres, although the elementary fibres are quite short, measuring only 1.5 to 6 mm in length. The surface of the fibres is striated, and its shape is asymmetrical. The fibres are also brittle and coarse, which makes processing them challenging. Although their mechanical characteristics are comparable to those of jute fibres, kenaf fibres typically have a lower density than jute due to their lower cellulose content. Since kenaf plants are the newest of the bast crops examined, it is expected that numerous new uses will be discovered for their stalks and fibres. The ability of kenaf to absorb the most carbon dioxide of any plant makes it an effective instrument for lowering atmospheric CO_2 levels [17].

2.3 Biopolymers

Due to the almost limitless uses for these materials in sectors including packaging, automobiles, building supplies, furniture, and consumer goods, the plastics business has been consistently thriving. Because of their strong mechanical qualities and endurance, the majority of these materials historically come from petroleum feedstocks. The last few decades have seen a significant increase in the development of bio composites created from conventional synthetic and petroleum-derived polymers.

The most popular matrix materials used in natural fibre reinforced composites are thermosetting polyester, epoxy, and polyurethane polymers as well as thermoplastic polymers like polypropylene (PP) and polyethylene (PE) and thermosetting polyester. These resins definitely outperform typical glass-fiber reinforced polymer (GFRP) composites in terms of environmental impact by including natural fibre reinforcements; yet, they do little about the issues of depleting petroleum supplies and landfill space.

Since the petroleum supply is not renewable and has recently been proven to be unreliable, the price of these resources has increased significantly. Additionally, since plastics made from petroleum do not dissolve, they must either be burned, producing hazardous pollutants, or dumped in landfills, which are running out of room. Over the past few decades, there has been a surge in research interest in biopolymers, which are roughly categorized as polymers that are biodegradable and/or generated from renewable resources. Scientists' answer to worries about the buildup of non-degradable plastic trash has been the development of biodegradable petroleum-derived plastics. These polymers have given researchers a potential solution to the issues with waste disposal that are frequently connected to standard petroleum-derived polymers, often without sacrificing the extraordinary qualities of non-degradable plastics.

This does not, however, address the problem of growing plastics prices brought on by a lack of fossil fuels. Many researchers have investigated alternative feed supplies for plastics, the majority of which are renewable and agriculturally based, as a result of the unstable petroleum supply and environmental problems associated with its products. The disposal of trash can be handled similarly using biopolymers made from renewable resources, but they also have the added benefit of lowering reliance on oil supplies, which are running out.

Both are undoubtedly beneficial for developing and maintaining the technology of environmentally friendly materials. Only biopolymers with good qualities and biodegradable capabilities were studied for usage as composite matrix materials in this study since it was important to design a biocomposite that optimised properties of environmental friendliness and high performance. In their overview of the state of biopolymer technology, Mohanty and colleagues [20] discussed the structures, synthesis, and characteristics of several of the most widely used biodegradable polymers made from synthetic and renewable resources. However, a number of noteworthy research projects on fresh biopolymer materials for composites have been reported since the time of this review. An overview of the cutting-edge biopolymers technology is presented in Figure 2.5. Below is a summary of the prior review and recent developments in biopolymer technology.

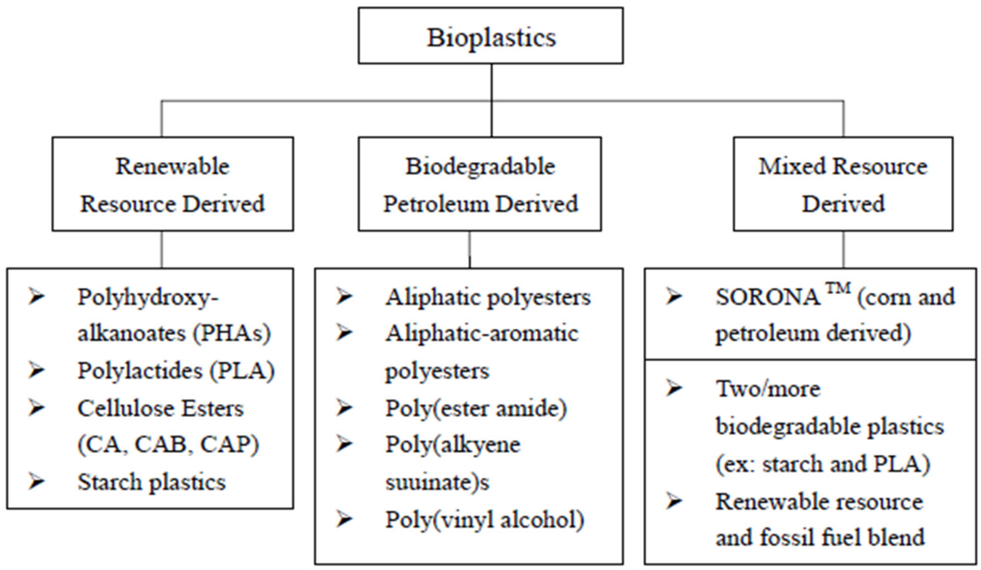

Figure 2.5: Broad classification of materials termed ‘bioplastics’

2.3.1 Biodegradable Petroleum Based Polymers

There are many commercially available biodegradable polymers made from petroleum resources at present [7]. The most well-known biodegradable polymers include, in particular, aromatic polyesters like PCL and PBS, aliphatic-aromatic polyesters like Eastman's Eastar Bio® and BASF's Ecoflex®, and polyester amides like Bayer's BAK 1095 and 2195 [1]. When used in place of conventional polymers, these biodegradable polymers have mechanical qualities that are comparable to those of regular petroleum-derived polymers. When choosing these polymers for a particular application, it is crucial to take into account the processing conditions because they can be very different.

A tough and semi-rigid thermoplastic polymer having a modulus in the range of low- and high-density polyethylene is poly(-caprolactone, or PCL) [7]. PCL is easily melt processed because of its low viscosity, low melting point (60°C), and glass transition temperature of -60°C. Due to its low melt temperature, other polymers are frequently combined with it. Additionally, PCL has strong resistance to chlorine, solvents, water, and oil.

Highpolymer created PBS, or polybutylene succinates, which are offered for sale under the brand Bionelle®. According to reports, these materials are high molecular weight white semicrystalline thermoplastic polymers with melting points between 90 and 120 degrees Celsius and glass transition temperatures between -45 and -10 degrees Celsius [7]. These polymers are relatively stiff and feature tensile strength characteristics that fall between LDPE and HDPE, respectively, as well as a density of roughly 1.25 g/cm^3.

The Bayer Corporation initially released polyester amides in 1995 under the trade name BAK 1095. Two years later, the injection moulding grade polyester amide, BAK 2195, was released. The mechanical and thermal properties of these polymers are comparable to those of polyethylene, and they are renowned for their great toughness and tensile strain at break. The melting values of the BAK 1095 and 2195 are 125 and 175°C, respectively [1]. These polymers are distinctive in that they degrade aerobically at rates equivalent to other biodegradable materials into water, carbon dioxide, and biomass.

2.3.2 Bio-resource Derived Polymers

It is well known that the United States benefits economically and environmentally from using plastics made from bio based renewable resources. First off, by using renewable resources like agricultural produce, the nation's reliance on imports of petroleum will be lessened. The usage of natural materials also aligns with the growing trend in science and technology towards environmentally friendly substitutes. Over the last ten years, a number of government-sponsored programmes have provided financial incentives to think about using biobased products instead of petroleum-based ones [7]. Aromatic polyesters, such as PHAs from bacterial fermentation and PLA from corn, as well as polymers made from renewable resources like cellulose (cellulose acetates), starches (starch esters), and proteins or oils from plants, such as soybeans, are some of the most advanced bio based plastics technologies. As production and sales rise, the demand for these materials is anticipated to rise by more than 20% annually along with improved economics.

2.3.2.1 Polyhydroxyanlanoates (PHAs)

PHAs are biodegradable polyesters produced by the fermentation of microorganisms. In a fermentation facility, the bodies of bacteria fed with glucose produce PHA polymers. Over one hundred compositions have since been described in the literature [7]. Polyhydroxybutyrate (PHB), a linear semicrystalline polymer, was the first PHA found. In the late 1980s, ICI Zeneca began selling PHAs under the brand name Biopol®. These polymers often have glass transition and melting temperatures that are close to those of PP. PHB has been reported to have a 9°C glass transition, a 175°C melting temperature, a 45 MPa tensile strength, a 3.8 GPa elastic modulus, and a 4% elongation at break [336. The PHB polymers and PHBV copolymers' current and future applications have been examined [37, 38]. Additionally, a review of the particular application of bacterial polyesters in bio composites has been done. They are a potential option for commercialized development due to their ease of biodegradation and processing, but their high cost, poor impact resistance, and tiny temperature difference between melting and degradation have impeded widespread commercial deployment [36].

2.3.2.2 Polylactic Acid (PLA)

The use of PLA polymers is not new. Beginning in the 1930s, Carothers, DuPont, and Ethicon developed the process for producing polyester from lactic acid, the fundamental component of PLA. Before the late 1980s, when agricultural resources could be utilised to more cost-effectively produce PLA's monomer, this material was virtually exclusively used in the biomedical sector [1], PLA was at the forefront of the biopolymer industry.

Because of the low yield and low molecular weight of PLA produced prior to recent years, PLA manufacture was still relatively expensive (>$2/lb). Cargill Dow LLC, however, has created a continuous process recently to boost output and lower the price of lactic acid-based polymers. The peculiarity of PLA is that it performs like PP while processing like PET.

The general features and behaviours of PLA polymers are well understood [39–42]. The rigid thermoplastic polymer polylactide can be completely amorphous or semicrystalline. According to reports, PLA's glass transition temperatures range from 40 to 63°C, while its semicrystalline polymer form's melting temperature ranges from 130 to 230°C. Nevertheless, processing temperatures should be kept below 200 °C to prevent thermal deterioration [43].

For PLA polymers, a variety of mechanical characteristics can be seen. According to Garlotta [41], ultimate tensile strength for high molecular weight PLA ranges from 47.6 to 53.1 MPa, elastic modulus ranges from 3.45 to 4.0 GPa, and elongation at break ranges from 3.1 to 5.8%. In comparison, strength, modulus, and elongation values for PLA polymers with lower molecular weights were found to be around 60 MPa, 1.2 GPa, and 3.1 percent, respectively. The favourable features of PLA are anticipated to boost consumer demand for agricultural goods.

Traditional petroleum-derived polymers can be replaced by PLA biopolymers because of their versatility and the ability to be made entirely from renewable resources like maize.

2.3.2.3 Starch Based Polymers

One of the least expensive biodegradable materials now on the market is starch, which is produced in plants like corn, potato, wheat, and rice. Starch is produced throughout Europe on an annual basis, according to reports from the 1990s, and between 20 and 50 percent of it is used for non-food purposes [4, 47]. When starch is transformed into a thermoplastic substance, it presents an intriguing substitute for petroleum polymers in applications where long-term durability is not necessary. The characteristics and uses of starch and starch-based polymers have been discussed [48–51]. The main ingredient in soluble compostable foams is thermoplastic starch, which is also known by the trade names Bioplast®, Bioflex®, and Biopur®. These products were all created by the German company BIOTEC.

This occurs as a result of the water sensitivity and quick degradation of starch polymers. For longer-term applications, starch is consequently frequently combined with other natural and synthetic polymers. Additionally, starch-based polymer blends and composites have been evaluated [51]. Under the trade name Mater-Bi, Novamont of Italy manufactures numerous types of biodegradable polymers that are a combination of starch and various synthetic polymers. Mater-Bi polymers have been approved as compostable and have mechanical qualities that are comparable to those of traditional polymers like polyethylene and polystyrene [4].

The USDA's creation of a starch/PVA blend wood glue, which can be used in place of conventional formaldehyde-based resins, which are known carcinogens, is a noteworthy development in starch-based polymers [52]. Although there are more and more uses for starch-based polymers, many biodegradable goods made from starch still have drawbacks as compared to typical thermoplastics because of their highly hydrophilic nature.

2.3.2.4 Soy Based Polymers and Blends

The first soybean crops were cultivated in the US for food in the early 1800s, and they continue to be a significant source of fats, oils, and proteins used in food and animal feed in the country today. Although soybeans have been found to contain up to 55 percent protein, most soybeans only have 20 percent oil and 40 percent protein. Biopolymers made from cross-linked soy oils like epoxidized soybean oil (ESO) have good mechanical characteristics and water resistance, according to Petrovic and collaborators [50]. Wool and Khot [51] describe the mechanical and processing characteristics of different polymers made from soy oil. The qualities of the plant oil based polymers were shown to significantly increase by including different types and quantities of chemical groups, such as anhydride or maleic acid, but they were still frequently below the values for conventional synthetic polymers. These polymers, like synthetic polymers, are unable to degrade quickly at the end of their useful lives; as a result, only non-biodegradable applications can make use of them [51].

The purified versions of soy protein flour, soy protein isolates and concentrates, have also been investigated as potential substitutes for petroleum-derived polymers in the production of packaging materials, adhesives, and plastics. The structure, composition, production and processing techniques, applications, and biodegradability of soy protein-based polymer technologies have all been examined [4, 52]. Injection moulding or compression moulding are frequently used to create polymers made from soy protein. Plasticization and alteration of processing parameters have been used to regulate and optimize the mechanical characteristics and water resistance of soy protein polymers [53]. Additionally, combining soy protein polymers with other polymers can further improve their characteristics. These soy-based polymers use biodegradable polymers with processing windows that are similar to those of soy, such as polyester amide, PCL, PLA, Biomax, and Eastar Bio, as well as natural polymers like starch, cellulose, or lignin. Tensile strength and modulus values for several soy-based polymer blends are reported by Mohanty and coworkers [53] and vary from 10 to 15.5 MPa and 0.22 to 0.27 GPa, respectively.

2.3.2.5 Cellulose Based Polymers

A linear polysaccharide known as biopolymer cellulose is used to make cellulose ester derivatives. Cellulose biopolymer has been thought of as a viable feedstock for the creation of environmentally friendly polymers since it is an easily accessible biomass that can be harvested from wood species and other lignocellulosic plants. Only a few studies have been reported that look at the use of cellulose based polymers as matrix materials in composites, despite the fact that cellulose esters like cellulose acetate (CA) have many current applications, including adhesives, tool handles, eyeglass frames, packaging materials, coatings, and films [18,54-60]. The ability of cellulose esters to biodegrade has been hotly contested. The biodegradability of cellulose acetates with a degree of substitution (DS) less than 2.5, along with a number of other plasticized cellulose esters, has been well proven. Many of these materials are also easily compostable [61].

Since cellulose esters have deteriorate temperatures at or below their melt processing temperatures, they must be plasticized before being employed as thermoplastic matrix materials in fibre composites [4]. Acetates, propionates, and butyrates are frequently used in plasticization processes to produce a variety of cellulose acetate (CA) derivatives, including cellulose acetate propionate (CAP) and cellulose acetate butyrate (CAB). It has been demonstrated that the plasticizer content has a significant impact on the physical, mechanical, and processing features [4, 58, 62-67]. Cellulose esters can either be burned cleanly without emitting toxic byproducts or they can be 'activated' to biodegrade [58].

The most popular methods for processing thermoplastic polymers can be used to process cellulose esters, and the processing temperature is normally between 180 and 240°C. Additionally, these polymers have good dimensional stability, moisture resistance, and chemical and UV light stability. However, they are easily damaged by strong acids or alkalis, and alcohols, esters, ketones, aromatic hydrocarbons, and chlorinated hydrocarbons can dissolve or swell them [58].

2.4 Past, present, and future of bio-composites

Research attempts to create bio composites that can compete with conventional non-renewable materials, like petroleum-derived polymers and synthetic fibre reinforced composites, have increased in recent years. This chapter has discussed a variety of natural fibre and biopolymer materials that can be utilized to create bio composites. There are numerous evaluations of the bio composite technologies that make use of these materials. The utilization of fiber surface treatments for improved fiber/matrix adhesion as well as specific processing methods are important factors for producing superior composite performance. Finally, a summary of the present and prospective future uses for bio composites will be given.

2.4.1 Important factors affecting bio composite performance

When selecting the constituents to be utilized in fibre reinforced polymer (FRP) composites, it is crucial to take their mechanical and physical qualities into account. However, when developing a composite processing system, reinforcing parameters must be carefully taken into account in order to fully leverage the capabilities of composite parts. Similar to those determined as important factors for traditional composite performance, the key reinforcing parameters known to influence the performance of a natural fibre reinforced biocomposite are fibre volume fraction, fibre aspect ratio, fibre dispersion and orientation, and fiber/matrix adhesion.

Before and during the production of composites, it is possible to determine and simply regulate the fibre aspect ratio, or the ratio of fibre length to diameter, and fibre volume fraction. By choosing the appropriate composite manufacturing technology, fibre orientation and dispersion can also be controlled. It is more challenging to manage the fiber/matrix adhesion, however fibre surface changes have showed promise in enhancing the fiber/matrix adhesion and, consequently, effective stress transmission [18].

3.0 Natural Fiber Reinforced Polymer Composites

Composites made of natural fibres reinforced by polymers have hybrid features, combining the best aspects of both natural fibres and polymers. Because of their non-conductive and heat-resistant qualities, phenol- or melamine formaldehyde resins were created and utilised in electrical applications at the turn of the 20th century.

To enhance the mechanical properties of polymer, natural fibre incorporation is becoming a common approach. As the fibres in the composites determine the tensile strength and young's modulus of the materials, mechanical qualities like tensile strength and young's modulus are improved in the finished products (composites) [68].

The automotive industry, where natural fibres are advantageously employed due to their low density and rising environmental pressures, is one of the main areas of recent growth in natural fibre plastic composites globally. Where load bearing capability and dimensional stability under humid and high heat conditions are of secondary importance, natural fibre composites have found applications. For instance, flax fibre reinforced polyolefins are widely employed in the automotive sector today, but the fibre mostly serves as a filler material in interior non-structural panels [69]. It is possible to use natural fibre composites for structural applications, but these materials typically have synthetic thermo-set matrix, which obviously limits their environmental benefits [70, 71].

Due to their high aspect ratio, high specific strength, and high stiffness, plant fibres like hemp, flax, and wood offer a lot of potential as reinforcement in structural materials [72–75]. Other advantages of adopting natural fibres worth highlighting include low cost, environmentally friendly processing, low tool wear, no skin irritation, and good thermal and acoustic insulating qualities [53]. These advantages are in addition to good particular mechanical properties and a beneficial environmental impact. If the matrix material also originates from a renewable resource, a fully biodegradable system may be generated. These materials include lignophenolics, starch, and polylactic acid (PLA), as examples. Some of these systems produce enticing outcomes. For instance, according to Oksman et al. [76], flax fibre composites with PLA matrix can compete with flax/polypropylene composites and sometimes even outperform them in terms of mechanical qualities. According to a recent study [77], composites of poly-L-lactide acid (PLLA) reinforced by flax fibres can exhibit a specific tensile modulus comparable to that of short-fiber composites made of glass and polyester. Glass/polyester composites had a greater specific strength than flax/polyester composites, which was lower than flax/PLLA composites.

Other significant drawbacks that are still present with natural fibre composites are also linked to their limited application. For effective stress transfer, the fibres often exhibit a low capacity to cling to common non-polar matrix materials. Additionally, the fibres natural hydrophilicity makes them prone to water absorption in humid environments. Natural fibre composites have a tendency to absorb a lot of water, which has a negative impact on their mechanical qualities, such as stiffness and strength. The natural fibre is not inert, though. Through chemical, enzymatic, or mechanical changes, the fiber-matrix adhesion can be improved, and the fibre swelling can be decreased [73].

Natural fibre composites have numerous uses in daily life. Jute, for instance, is a popular reinforcement material for composites in India. Buildings, lifts, pipes and panels all use jute fibres in combination with polyester resins [55]. Natural fibre composites can also be a very affordable material for use in building and construction areas (such as walls, ceilings, partitions, window and door frames), storage devices (such as bio-gas containers, post boxes, etc.), furniture (such as chairs and tables), electronic devices (such as the outer casting of mobile phones), toys and other ad hoc applications (such as helmets and suitcases).

A number of studies have been conducted recently to replace standard synthetic fibre with natural fibre composites. For instance, the most popular fibres used to reinforce polymers such polyolefins, polystyrene, and epoxy resins are hemp, sisal, jute, cotton, flax, and broom. Additionally, fibres such as waste silk, banana, oil palm, bagasse, wheat and flax straw, jute, coir, sisal, and jute [79] have shown to be good and efficient reinforcement in thermoset and thermoplastic matrices. However, some elements of the behaviour of natural fibre reinforced composites, such as their visco-elastic, visco-plastic, or time-dependent behaviour due to creep and fatigue loadings, interfacial adhesion, and tribological properties, are still poorly understood. There isn't much information in the literature about the tribological performance of natural fibre reinforced composite material. In this perspective, the production of composite materials for tribo applications has significant promise for long plant fibres such hemp, flax, bagasse and bamboo.

After analyzing the current literature on natural fibre composites, attempts are made to comprehend the fundamental requirements of the expanding composites sector. The inference made from this is that by successfully fusing vegetable natural fibres with polymer matrices, the mechanical properties of the composite as compared to the matrix material are improved. These fillers are affordable, non-toxic, and simple to recycle. They can be obtained from renewable sources. Furthermore, because to their low density and despite their poor strength, they can produce composites with high specific strengths. The fiber's surface must be chemically modified in order to increase the interfacial strength between it and the matrix. After that, the composite will be exposed to various weathering conditions, including steam, saltwater, and subzero conditions. Prior to and during the treatment, the fibres will be characterized using X-Ray Diffraction (XRD) and Fourier Transform Infrared (FTIR) spectroscopy. The composite's mechanical qualities and moisture absorption traits will be assessed.

It is necessary to carry out various tribological tests, such as the solid particle erosion test, the two-body abrasion test, and the abrasive wear test, in accordance with ASTM standards to determine the potential of polymer composites for tribological application.

4.0 Conclusion

Today's environmental concern drives researchers across the globe to investigate natural fibre reinforced polymer composites as a more affordable alternative to synthetic fibre reinforced composites. Researchers have been enticed by the accessibility of natural fibres and the simplicity of manufacturing to experiment with inexpensive locally available fibres, study their viability for use as reinforcement, and determine how well they meet the requirements of high-quality reinforced polymer composite for various applications. Natural fibre is a good renewable and biodegradable alternative to the most prevalent synthetic reinforcement, glass fibre, due to its low cost and high specific mechanical qualities. Natural fibres have environmental and aesthetic appeal, but their use is restricted to non-bearing applications because of their inferior strength to synthetic fibre reinforced polymer composites.

By using stronger structural configurations and arranging the fibres for maximum strength performance, bio composites weaknesses in stiffness and strength can be solved. As a result, in-depth research on the creation and characteristics of polymer matrix composite (PMC) using natural fibres such jute, sisal, pineapple, bamboo, kenaf, and bagasse in place of synthetic fibre was conducted. These plant fibres are renewable, environmentally friendly, inexpensive, lightweight, and have higher specific mechanical performance than glass fibre or carbon fibre.

The unidirectional bio composites created in this review is generally exhibit substantial promise for use as secondary and maybe even major load-bearing materials. The experimentally determined and predicted composite properties are in good agreement with other literature reported values for unidirectional aligned natural fibre composites, and they frequently outperform wood products and conventional glass fibre reinforced composite materials, especially when weight is taken into consideration. Back-calculated effective fibre properties that took into account the impact of void content on composite properties compared favorably with the figures for hemp fibres reported in the literature. Even more potential for these materials to carry heavy loads may be seen in the predicted composite properties utilizing the ROM technique and the effective fibre properties. The results of experimental testing for these materials are encouraging, but various adjustments to the reinforcing properties, void content, and fiber-matrix adhesion are required to optimize the bio composite system. If the composites are to be utilized in load-bearing applications for hemp fibres, investigations on the composites' durability, biodegradability, and long-term behavior are also required.

The composites in this study are preferable from an environmental standpoint because they are totally made from renewable materials, in contrast to the majority of prior bio composite investigations. The ultimate goal for materials used in structural and building applications is to produce composites that are created from renewable resources using environmentally friendly procedures. These could be regarded as precursors to such composites.

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