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Exploration of Alternative Materials for Manufacturing Sports Products Using Environment Friendly Plant Fiber Reinforced Polymeric Composites

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Abstract: *This study delves into the investigation of alternative materials for the fabrication of sports products, focusing on environmentally friendly plant fiber reinforced polymeric composites. With a growing concern for sustainability in manufacturing, the exploration of such materials holds promise for reducing the environmental footprint of sports product production. Through a comprehensive analysis of various plant fibers and their integration with polymeric matrices, this research aims to evaluate their mechanical properties, durability, and environmental impact compared to traditional materials. By examining the feasibility and performance of these composites, this study seeks to contribute to the advancement of eco-friendly practices in the sports industry while maintaining product quality and performance standards.*

Keywords: *Alternative materials, Sports products, Environmentally friendly, Plant fiber, Polymeric composites.*

1. Introduction

The sports industry is witnessing a paradigm shift towards sustainability, prompting the exploration of alternative materials for manufacturing sports products. This shift is driven by growing environmental concerns and the need for eco-friendly solutions in production processes. One promising avenue of investigation is the utilization of plant fiber reinforced polymeric composites, which offer a viable alternative to conventional materials. These composites leverage the inherent strength and lightweight properties of plant fibers while reducing reliance on non-renewable resources and minimizing environmental impact. This introduction sets the stage for a comprehensive exploration of the potential of environmentally friendly plant fiber reinforced polymeric composites in revolutionizing the manufacturing landscape of sports products. Through a multidisciplinary approach encompassing materials science, engineering, and sustainability principles, this study aims to assess the feasibility, performance, and ecological benefits of integrating such composites into sports product manufacturing processes.

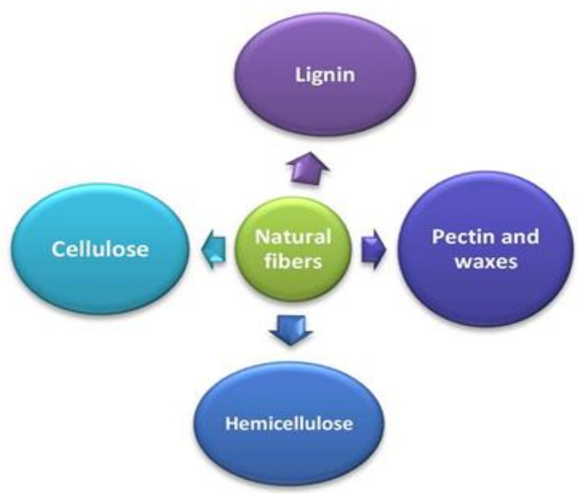

Fig. 1 Constituents of plant fibers

2. Material & Method

Source, Properties, & applications of Natural Fibers:
Kenaf (Hibiscus cannabinus): Kenaf fibers, classified among bast fibers, are utilized in various industries, notably

paper and rope production. These robust fibers, cultivated for approximately 4,000 years across continents, possess remarkable stiffness and resistance to insecticides. Extracted from different parts of the plant, they undergo mechanical processing and chemical or bacterial treatments to isolate them from non-fibrous components. Historically used in textiles and boat construction, kenaf fibers now find application in diverse sectors such as automotive, construction, and packaging, owing to their eco-friendly nature and biodegradability.

Hemp (Cannabis sativa): Hemp, a prevalent plant species primarily cultivated in Europe and Asia, typically reaches heights of 1.2–4.5 meters and diameters of 2 centimeters. Its structure comprises an inner core surrounded by bast fibers, linked to the core by a glue-like substance or pectin. These versatile fibers find application in rope, textiles, garden mulch, various building materials, and animal beddings. Recent advancements have seen hemp being utilized in the fabrication of diverse composites. Harvested hemp plants undergo a mechanical separation process to extract the woody core from the bast fibers. The woody core is subsequently cleaned and sometimes cut to size as needed, while the separated bast fibers are further processed to form yarn or bundles.

Jute (Corchorus capsularis): Jute, a significant natural fiber predominantly cultivated in parts of Asia such as India, Bangladesh, China, and Myanmar, boasts rapid growth, reaching heights of 15–20 centimeters in just four months. The fibers are extracted after approximately four months of cultivation. The retting process, crucial for fiber extraction, can be conducted using either chemical agents like N2H8C2O4 and Na2SO3 or through biological means. In biological retting, harvested stalks are bundled and submerged in water for about 20 days, facilitating the removal of pectin between the bast and wood core and enabling fiber separation. Subsequently, these fibers are dried for further processing.

Flax (Linum usitatissimum): Flax fibers, cultivated since ancient times from the Linum usitatissimum plant, are chiefly utilized in linen production. These fibers, crystalline in nature, can reach lengths of up to 90 centimeters with diameters between 12 and 16 micrometers. Leading producers include the Netherlands, Belgium, and France, with applications ranging from furniture materials to interior decoration accessories. Extraction involves retting and scorching processes, altering fiber properties. Canada stands as the world's largest flax producer and exporter, yielding approximately 872,000 tons annually.

Ramie (Boehmeria nivea): Ramie, a fast-growing plant native to China, Japan, and Malaysia, has been used for centuries in textile production. Its fibers, extracted from the stem, are among the strongest and longest of natural bast fibers. They are employed in various products such as sweaters, upholstery, fishing nets, and marine packings. Ramie fibers also find application in bio-based products for automotive, furniture, and construction industries. Processing methods resemble those of flax linen.

Nettle (Urtica dioica): Nettle, a widely cultivated herbaceous plant comprising numerous species, is prevalent across Europe, Asia, Northern Africa, and North America. Growing up to 2 meters in length, its soft, green leaves typically measure 3–15 centimeters. Characterized by hairy leaves and stems with stinging hairs, nettle is harvested during the flowering period for fiber extraction. This extraction can be achieved through either retting the stalks or decorticating. Common applications of nettle fibers include the textile industry, bioenergy, and animal housing, with recent efforts aimed at scaling up industrial utilization.

Pineapple Leaf (Ananas comosus): The pineapple plant, abundant and easily accessible, yields pineapple leaf fiber as a byproduct post-cultivation. These fibers, known for their good mechanical properties, are extracted manually from the leaves and find applications in automobiles, textiles, mats, and construction. Treated fibers are utilized in advanced applications such as conveyor belt cords and airbags.

Cotton (Gossypium): Cotton, a crucial agricultural crop, is widely utilized for cloth production. Cultivated mainly in tropical and subtropical regions, China, India, and the United States are the top producers. After harvesting, cotton undergoes processing at cotton gins to separate fibers from seeds, sticks, and burrs. Cotton fibers are extensively used in textiles, with emerging applications in industrial composites.

Coconut Fiber (Cocos nucifera): Coconut fiber, extracted from the coconut husk, is notably thick among natural fibers and primarily cultivated in tropical regions like India, Sri Lanka, Indonesia, the Philippines, and Malaysia. Recognized for its strength and lightness, coir fiber is valued for its resilience, weather resistance, and high elongation at break. Widely used in rope, mat, mattress, brush, and upholstery manufacturing, it finds applications in agriculture and construction industries as well.

3. Effect of Treatments on Natural Fibers

Chemical treatments of natural fibers play a pivotal role in enhancing their properties by modifying their microstructure, improving wettability, surface morphology, chemical groups, and tensile strength. This treatment fosters better interfacial adhesion between the fiber surface and polymer matrix, thereby enhancing the thermomechanical properties of composites.

Table 1 Chemical treatments for different natural fibers

Name of the fiber	Chemical reagents used	References
Pineapple leaf	c-aminopropyl trimethoxysilane (Z-6011)	Threepopnatkul et al., 2009
	c-methacrylate propyltrimethoxy silane (Z-6030)	
Green coconut	NaOCl	Alfa
	NaOCl/NaOH	
	Or 202	
	NaOH	
Carica Papaya	NaOH	Saravanakumaar et al., 2018
Kenaf	NaOH	Asumani et al., 2012
	(3-glycidyloxypropyl)trimethoxysilane	Sepe et al., 2018
Hemp	NaOH	Debeli et al., 2018
Ramie	NaOH	Senthilkumar et al., 2019
	NaOH-Saline	
	Silane	
Prosopis juliflora	NaOH	Saravanakumar et al., 2014
	KOH	Paul et al., 1997
	Potassium permanganate (KMnO4)	Arifuzzaman Khan et al., 2009
	Stearic acid	Sisal
Okra bast	NaClO2	Okra
Flax	Methyl methacrylate (MMA)	Kaith and Kalia, 2007

Studies on ramie fibers reveal that treatments with alkaline, saline, or combined solutions lead to improved tensile strength. Chemical treatments effectively reduce the hydrophilic nature of natural fibers while enhancing adhesion with the matrix. Structural and morphological changes observed post-treatment are attributed to the removal of non-cellulosic substances. Remarkable improvements in composite properties, including increased thermal stability, are reported following various chemical treatments of natural fibers.

4. Natural Fibers as Reinforcement for Composites Materials

Over recent decades, significant efforts have been directed towards developing materials with enhanced mechanical and tribological properties across various applications. Traditional monolithic materials are being replaced by fiber-reinforced composites, including those composed of carbon, glass, and aramid fibers, widely used in aerospace, automotive, construction, and sporting industries. However, these materials exhibit drawbacks such as non-biodegradability, non-renewability, and high-energy requirements for production, contributing to environmental harm through the release of significant carbon dioxide emissions during manufacturing processes. Consequently, researchers are exploring natural fiber-reinforced composites as alternatives, aiming to overcome these limitations. Natural fibers, sourced from fruits, seeds, leaves, stems, and animals, are being investigated for their potential to replace synthetic fibers in various applications. Chemical treatments are employed to modify the properties of these natural fibers, enhancing their suitability for composite materials. Additionally, researchers are combining natural fibers with polymers and synthetic materials to create hybrid composites, further enhancing their properties. This concerted effort has led to the development of a diverse range of hybrid composites, demonstrating the promising potential of natural fibers in modern material science.

5. Properties of Natural Fiber Composites

Environmental concerns have prompted researchers to explore new composite materials with multiple natural resource reinforcements through hybridization. This approach combines fillers and natural fibers to enhance the mechanical properties of composites. Various studies have investigated the mechanical properties of natural fiber composites, with factors such as reinforcement volume or weight fraction, fiber orientation, aspect ratio, adhesion between fiber and matrix, alignment, distribution, additives, and chemical treatments influencing mechanical performance. Moisture absorption also impacts mechanical behavior by affecting interfacial bonding between fiber and hydrophobic matrix polymer.

In the automotive industry, asbestos-based brake components are avoided due to carcinogenic risks, leading to the exploration of alternative materials like ceramic, steel, alumina, glass, carbon, and aramid fibers. However, these alternatives are costly and environmentally unfriendly. Xin et al. evaluated treated sisal fiber reinforced composites as substitutes for asbestos-based brake pads, finding comparable frictional properties and recommending treated sisal as an ideal substitute.

Table 2 Properties of natural fibers (Pandey et al., 2010; Ku et al., 2011; Komuraiah et al., 2014; Gurunathan et al., 2015)

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Jute	1.23	325–770	37.5–55	2.5
Flax	1.38	700–1,000	60–70	2.3
Hemp	1.35	530–1,110	45	3
Ramie	1.44	915	23	3.7
Banana	1.35	721.5–910	29	2
Bagasse	1.2	290	17	1.1
Henequen	1.4	500	13.2	4.8
Pineapple	1.5	1,020–1,600	71	0.8
Kenaf	1.2	745–930	41	1.6
Coir	1.2	140.5–175	6	27.5
Sisal	1.2	460–855	15.5	8
Abaca	1.5	410–810	41	3.4
Cotton	1.21	250–500	6–10	7
Nettle	1.51	650	38	1.7

Thermal stability is crucial in fiber-reinforced composites, with chemical treatments improving interfacial bonding and enhancing thermal properties. Joseph et al. studied the thermal stability and crystallization behavior of sisal/polypropylene composites treated with various compounds, observing superior thermal properties in treated fiber-reinforced composites. Additionally, increased crystallinity correlates with improved thermal stability, as demonstrated in thermogravimetry analysis of date palm fibers. Electrical properties of composites are influenced by factors such as fiber loading, treatment, and hybridization. Pineapple-reinforced polyethylene composites exhibited enhanced dielectric properties with increased fiber content, while sisal fiber composites displayed electric anisotropic behavior. Chemical treatments like alkali, stearic acid, peroxide, acetylation, and permanganate can alter the dielectric properties by reducing hydrophilicity. Studies on phenol formaldehyde composites modified with banana fiber showed a decrease in dielectric constant with fiber loading and treatment, and further reductions with hybridization with glass fiber.

3. Future Market Trends

In the current market landscape, there is a notable surge in the demand for natural fiber-reinforced polymers, particularly in the automotive and construction sectors. Bast fibers like hemp, kenaf, and flax are increasingly favored for automotive applications, while wood-plastic composites are gaining traction in the construction industry. European markets are anticipated to maintain their dominance in this field due to their strong preference for environmentally friendly composite materials, supported by automotive manufacturers, government regulations, and the growth of small-scale eco-friendly industries. As advancements continue to enhance the performance of these materials, we can expect to see their adoption in new sectors. Although still relatively novel in segments like electrical, electronics, and sporting goods, natural fiber composites hold significant potential to capture substantial market share in the future, driven by their eco-friendly attributes and improving performance characteristics. This trend underscores the growing recognition of the importance of sustainability and environmental responsibility across various industries.

6. Result & Discussion

The chemical treatments of natural fibers play a crucial role in enhancing their properties by modifying their microstructure, improving wettability, surface morphology, chemical groups, and tensile strength. This treatment fosters better interfacial adhesion between the fiber surface and polymer matrix, thereby enhancing the thermomechanical properties of composites (Pandey et al., 2010; Ku et al., 2011; Komuraiah et al., 2014; Gurunathan et al., 2015). Studies on ramie fibers reveal that treatments with alkaline, saline, or combined solutions lead to improved tensile strength. Chemical treatments effectively reduce the hydrophilic nature of natural fibers while enhancing adhesion with the matrix. Structural and morphological changes observed post-treatment are attributed to the removal of non-cellulosic substances.

In the automotive industry, the transition away from asbestos-based brake components due to carcinogenic risks has led to the exploration of alternative materials such as ceramic, steel, alumina, glass, carbon, and aramid fibers. Xin et al. evaluated treated sisal fiber-reinforced composites as substitutes for asbestos-based brake pads, finding comparable frictional properties and recommending treated sisal as an ideal substitute. Thermal stability is crucial in fiber-reinforced composites, with chemical treatments improving interfacial bonding and enhancing thermal properties. Joseph et al. studied the thermal stability and crystallization behavior of sisal/polypropylene composites treated with various compounds, observing superior thermal properties in treated fiber-reinforced composites. Additionally, increased crystallinity correlates with improved thermal stability, as demonstrated in thermogravimetry analysis of date palm fibers. Electrical properties of composites are influenced by factors such as fiber loading, treatment, and hybridization. Pineapple-reinforced polyethylene composites exhibited enhanced dielectric properties with increased fiber content, while sisal fiber composites displayed electric anisotropic behavior. Chemical treatments like alkali, stearic acid, peroxide, acetylation, and permanganate can alter the dielectric properties by reducing hydrophilicity. Studies on phenol formaldehyde composites modified with banana fiber showed a decrease in dielectric constant with fiber loading and treatment, and further reductions with hybridization with glass fiber.

7. Conclusion

In conclusion, chemical treatments play a pivotal role in enhancing the properties of natural fibers, thereby improving their suitability for composite materials. Through modifications to microstructure, wettability, surface morphology, chemical groups, and tensile strength, these treatments foster better adhesion between fibers and polymer matrices, consequently enhancing the thermomechanical properties of composites. Studies on various fibers, including ramie, have demonstrated the effectiveness of chemical treatments in improving tensile strength and reducing the hydrophilic nature of fibers while promoting adhesion with matrices. Structural and morphological changes post-treatment further contribute to the overall enhancement of composite properties. Additionally, in industries such as automotive, the transition away from carcinogenic asbestos-based components has driven exploration into alternative materials, including natural fiber-reinforced composites. These composites, often treated with various compounds, exhibit improved thermal stability and electrical properties, making them promising substitutes in diverse applications. Overall, chemical treatments represent a crucial aspect of natural fiber utilization in composite materials, offering avenues for improved performance and expanded industrial applications.

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