Journal of Environmental Science and Technology

ISSN 1994-7887

OPEN ACCESS Journal of Environmental Science and Technology

ISSN 1994-7887
DOI: 10.3923/jest.2023.20.27

Review Article

A Review on Emerging Trends of Reusing Natural Fiber Reinforced Composite with Plastic Waste

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Abstract

This review explores the abundance of "natural waste fibers" in India, like jute, coir, sisal, pineapple, etc. These fibers are eco-friendly and non-abrasive due to their low cost, low density, acceptable specific properties, enhanced energy recovery, CO_2 neutrality and biodegradability. Repurposing these fibers to strengthen polymers is an environmentally friendly choice. However, natural fibers tend to absorb water due to their high hydroxyl content, which negatively affects composite strength. Despite this, recent efforts have focused on combining waste natural fibers with plastics to enhance mechanical properties and reduce environmental impact. By leveraging the advantageous qualities of both materials, composite materials that offer strength, sustainability and cost-effectiveness can be created. The review emphasizes the potential of utilizing abundant natural waste fibers in India, particularly in polymer composites. It recognizes its eco-friendly and non-abrasive nature while addressing water absorption challenges. The fusion of natural fibers and plastics presents an opportunity for environmentally friendly and economically viable composites.

Key words: Composite, plastic, polymer, reinforced, waste, natural fibers

Citation: Rohit, K. and T. Thakre, 2023. A review on emerging trends of reusing natural fiber reinforced composite with plastic waste. J. Environ. Sci. Technol., 16: 20-27.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Natural fiber-reinforced polymer composites are composite materials made of natural fibers such as jute, hemp, flax, kenaf, sisal and bamboo and polymer matrices such as polyethylene, polypropylene and polystyrene. These composites offer several advantages over traditional materials such as high strength, low weight and biodegradability. Additionally, natural fibers are renewable resources that can be grown locally, reducing transportation costs and carbon footprint[1].

Emerging trends in natural fiber-reinforced polymer composites

Nanocellulose-reinforced polymer composite: Nanocellulose is a renewable and biodegradable material derived from natural fibers such as wood, cotton and hemp. It has high strength and stiffness and can be used to reinforce polymers such as polystyrene and polypropylene. Nanocellulose-reinforced polymer composites have the potential to replace traditional composites made of glass or carbon fibers[2].

Biodegradable polymer composite: Biodegradable polymers such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA) are derived from renewable resources such as corn starch and vegetable oils. These polymers can be reinforced with natural fibers to create biodegradable composite materials. These composites have potential applications in packaging, agriculture and automotive industries[3].

Hybrid composites: Hybrid composites are made by combining natural fibers with other types of fibers such as glass, carbon or Kevlar. These composites have improved mechanical properties compared to pure natural fiber composites and can be used in applications where high strength and durability are required[4].

Despite being considered a potential substitute for synthetic fibers, natural fibers face several challenges and limitations. One key issue is the absence of significant technological advancements in the production of raw materials for natural fibers. This hampers the overall efficiency and rate of production[4]. Additionally, there is a lack of improved equipment for processing natural fibers, further impeding their widespread use[5]. Another concern relates to the compatibility of the surface functional groups of natural fibers with the functional groups of existing hydrophobic resin systems. This incompatibility poses difficulties in achieving strong bonding and optimal performance in different environments. Furthermore, natural fibers have a temperature threshold between 170 and 200°C, beyond which they can begin to degrade. This limits their utility as reinforcing materials in thermoplastic matrices with high melting points. The breakdown of natural fibers at elevated temperatures can weaken the composite structure and compromise its overall strength. While, natural fibers hold promise as alternatives to synthetic fibres, they encounter challenges such as technological limitations, processing inefficiencies, compatibility issues with resin systems and susceptibility to thermal degradation. Addressing these issues is crucial for maximizing the potential of natural fibers and their composites in various applications.

Many factors affect how differently their mechanical characteristics can vary. Many variables, such as the absence of standardization in processing and surface treatments, have an impact on the variability in their mechanical properties. The disadvantages of using and applying natural fibers have been identified as their low wettability and susceptibility to moisture absorption. The presence of moisture offers leeway for dimensional fluctuations of the end product and this also creates a weakness in the interfacial bond between the fiber and the matrix. Restricted access caused by geographic barriers between countries where natural fibers are grown and countries where they are used as reinforcement in composites production, such as North America, the UK, France, Germany and Spain, is an often-overlooked but significant barrier to the widespread use of natural fibers in composites applications. The global production of plastics. Global production of plastics×CIS-Commonwealth and Independent States. The NAFTA-North American Free Trade Agreement[6] was shown in Fig. 1. Improper fiber orientation and aspect ratio, as those present in natural fiber, resulting in a composite material with low mechanical properties. During manufacture, natural fibers are frequently twisted, which results in poor resin impregnation and mechanical properties. Since the amount of vacancy in natural fibers increases with increased reinforcement, it has been reported that this causes the mechanical characteristics of the resulting composites to decline. The trend of reusing natural fibers with plastic materials has gained a lot of attention in recent years due to its potential to reduce waste and promote sustainability. This approach involves mixing natural fibres, such as jute, hemp, or flax, with plastic materials, such as polypropylene or polyethylene, to create composite materials that can be used in various applications, including packaging, construction and automotive industries. One of the significant advantages of using natural fibers in plastic composites is their biodegradability and renewable nature. Unlike synthetic

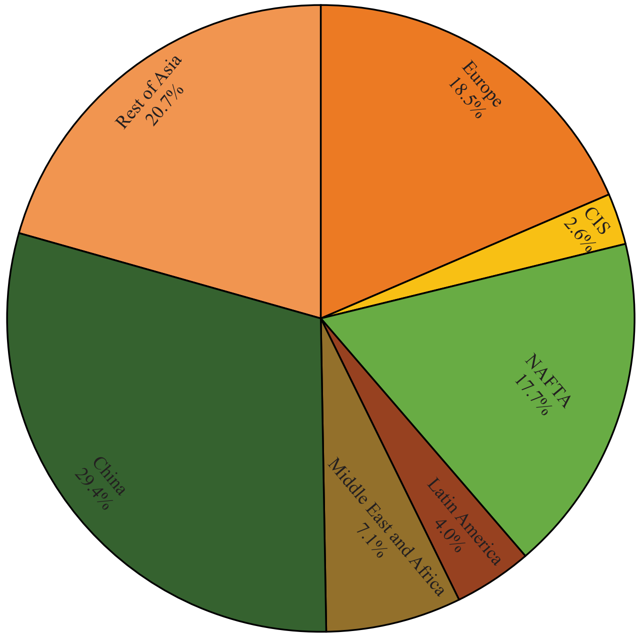

Fig.1: Global production of plastics, global production of plastics × CIS-Commonwealth and Independent States and NAFTA-North American Free Trade Agreement[6]

fibers, which can take hundreds of years to decompose, natural fibers can break down within a few years, making them an eco-friendly alternative. Furthermore, natural fibers have excellent mechanical properties, such as high strength, stiffness and toughness, which can enhance the performance of plastic composites. One example of reusing natural fibers with plastic material is the production of biocomposites, which are composite materials made from a combination of natural fibers, such as hemp or flax and a thermoplastic matrix, such as polypropylene or polyethylene.

Figure 2, the study was conducted by Almeshal *et al*.[7]. The researchers aimed to address two environmental problems: The accumulation of plastic waste and the high carbon footprint of concrete production. By incorporating recycled plastic into concrete, researchers aimed to reduce the amount of plastic waste in landfills and lower the carbon emissions associated with concrete production. The study involved using different percentages of recycled plastic as a partial replacement for sand in concrete mixes. The researchers tested the mechanical properties of the resulting concrete, such as compressive strength, tensile strength and flexural strength. They also evaluated the durability of the concrete by subjecting it to freeze-thaw cycles and acid attacks. The use of recycled plastic as a partial replacement for sand had a positive impact on the mechanical properties of the concrete. Table 1 showed the different types of catalysts used for upcycling of plastic waste material. The researchers found that the compressive strength, tensile strength and flexural strength of the concrete increased with the addition of recycled plastic. They also found that the concrete was more durable and resistant to freeze-thaw cycles and acid attacks. Overall, the study demonstrated the potential of using recycled plastic in concrete production to create more eco-friendly building materials. The researchers suggested that further research should be conducted to optimize the percentage of plastic replacement and to evaluate the environmental impact of the production process.

Dittenber and GangaRao[28] studied that biocomposites made from natural fibers and plastic material have several advantages over traditional composites made solely from synthetic materials, including. Natural fibers can enhance the mechanical properties of the composite, such as strength and stiffness while reducing the weight of the material. Sanjay and Yogesha[29] showed that the use of natural fibers can reduce the environmental impact of the composite by replacing non-renewable materials with renewable resources, as well as reducing the carbon footprint of the material. Rohit and Dixit[30] showed the use of natural fibers can reduce the cost of the composite material, as natural fibers are often cheaper than synthetic fibers. Overall, the reuse of natural fibers with plastic material in biocomposites offers a promising solution

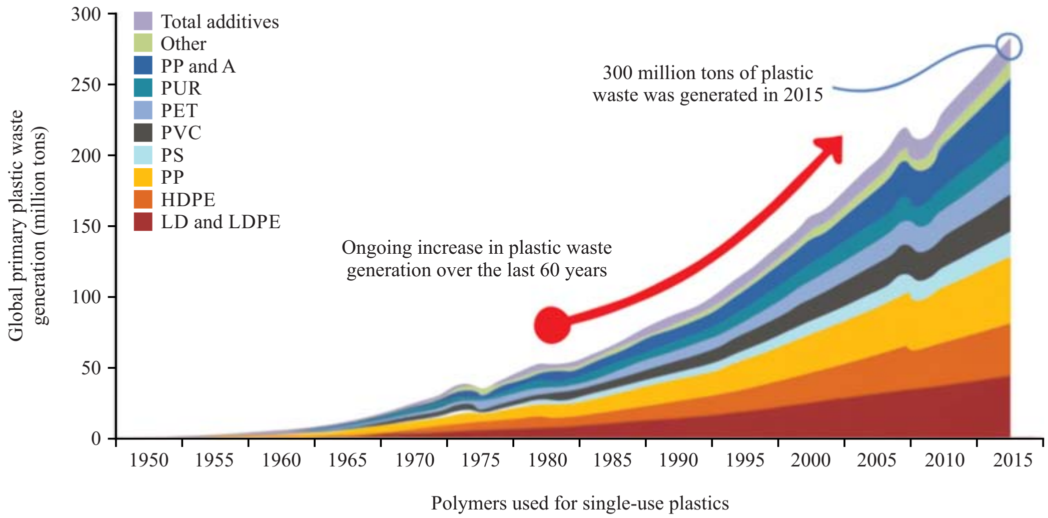

Fig. 2: Global primary plastics waste generation, 1950-2015 (Almeshal *et al.*[7])

Table 1: Different types of catalysts used for upcycling plastic wastes material[8-27]

Starting material (plastic waste)	Final products	(Bio-) catalyst	References
Biological PET PHA, bio	PU	Leaf branch compost cutinase (LCC) and *Pseudomonas umsongensis* GO16	Tiso *et al.*[8]
	Catechol	Bs2Est (chemo-enzymatic depolymerization) and *Escherichia coli* (whole-cell biotransformation)	Kim *et al.*[9]
	Vanillin	Engineered *Escherichia coli*	Sadler and Wallace[10]
	PHB	*Yarrowia lipolytica* Po1f and *Pseudomonas stutzeri* TPA3P	Liu *et al.*[11]
PS	PHA	*Pseudomonas putida* CA-3	Ward *et al.*[12] and Goff *et al.*[13]
PE chemical	PHA	*Pseudomonas aeruginosa* PAO-1	Guzik *et al.*[14]
	Long chain alkylaromatics High-quality	Pt/γ Al_2O_3	Zhang *et al.*[15]
	Liquid products (such as lubricants and waxes) Pt/$SrTiO_3$	Pt/$SrTiO_3$	Celik *et al.*[16]
	Amorphous carbon chips Li-ion battery anodes	H_2SO_4	Villagomez-Salas *et al.*[17]
PC	Aliphatic polycarbonates	TBD: MSA, DMAP	Saito *et al.*[18]
	Poly (aryl ether sulfone)	M_2CO_3	Jones *et al.*[19]
PET	Poly(ester-amide) s	TBD: MSA	Demarteau *et al.*[20]
	Thermoplastic co-polyesters	TBT/Mg$(OAc)_2$	Karanastasis *et al.*[21]
PVC	Porous carbon spheres	TBAB	Wang *et al.*[22]
	Microporous carbon materials	KOH	Liu *et al.*[23]
	Carbon materials	ZnO or KOH	Zhou *et al.*[24]
PP	Magnetic carbon materials	Co$(ac)_2$, Ferrocene, $CuCl_2$	Feng *et al.*[25]
PET, PE, PVC and PP	Graphene	Ni foil	Cui *et al.*[26]
Mixed plastics (PP, PE, PS, PET and PVC)	Carbon nanosheets	Montmorillonite and KOH	Gong *et al.*[27]

PET: Polyethylene terephthalate, PP: Polypropylene, PVC: Poly vinyl chloride, PE: Polyethylene, PS: Polystyrene, PU: Polyurethane, PHA: PolyHydroxyalkanoates, PHB: Polyhydroxybutyrate, PC: Poly carbonates, H_2SO_4: Sulphuric acid, KOH: Potassium hydroxide, M_2CO_3: Carbonate of metal, ZnO: Zinc oxide, TBD: Triazabicyclo dec-5-ene, MSA: Methanesulfonic acid, $CuCl_2$: Cupric chloride, Co$(ac)_2$: Cobalt(II) acetate, TBAB: Tetrabutylammonium bromide, TBT: Tributyltin, DMAP: Dimethylamino pyridine, γ-Al_2O_3: Gamma-alumina and Pt/$SrTiO_3$: Platinum strontium titanate

for creating sustainable materials with improved mechanical properties and reduced environmental impact.

Several studies have been conducted to investigate the properties and applications of natural fiber-reinforced plastic composites. For instance, Gao *et al.*[31] studied the effect of jute fiber content on the mechanical properties of polypropylene composites. They found that increasing the jute fiber content resulted in a significant improvement in the tensile and flexural properties of the composites. Ali *et al.*[32] focused on the development of natural fiber-reinforced polyethylene composites for packaging applications. They reported that the addition of 20% flax fiber improved the tensile strength and modulus of the composites compared to pure polyethylene. According to a study by Ebadi *et al.*[33] natural fiber-reinforced polymer composites have several advantages over conventional materials such as low cost, low density, high specific strength and biodegradability. The study focused on sisal fiber-reinforced polypropylene composites and found that the addition of sisal fiber improved the tensile strength and stiffness of the composites. The study also highlighted the potential of sisal fiber-reinforced composites as a sustainable alternative to conventional materials in various applications. Akindoyo *et al.*[34] studied a comprehensive examination of the mechanical characteristics of composites made from polystyrene reinforced with jute fibers. The investigation revealed that the inclusion of jute fiber resulted in enhanced flexural strength and modulus of the composites. Furthermore, the authors observed that these jute fiber-reinforced composites exhibit promising prospects for utilization in diverse sectors, including the automotive and construction industries. A comprehensive study on natural fiber. Studies have shown that the addition of kenaf fibers to PP improves the mechanical properties of the resulting composite, including increased tensile strength, flexural strength and impact resistance[35]. Another example is the use of sisal fibers in combination with polyethylene (PE) to create composite materials. Sisal is a natural fiber that is derived from the agave plant. Studies have shown that the addition of sisal fibers to PE improves the mechanical properties of the resulting composite, including increased tensile strength, flexural strength and impact resistance. Wang *et al.*[36] studied the combination of natural fibers and plastic materials in composite materials offers a promising solution for creating sustainable and durable products. The extensive utilization of plastics in various sectors such as packaging, automotive and industrial applications, medicinal delivery systems, healthcare applications, water desalination, land/soil conservation, flood control, housing, communication materials, security systems and more, has been instrumental in driving this surge. The widespread use of plastics in packaging, automotive and industrial applications, medicinal delivery systems, healthcare applications, water desalination, land/soil conservation, flood control, housing, communication materials, security systems and other applications has contributed to this increase. As a result, plastic waste has become a growing concern in the solid waste stream. Plastic waste has indeed become a growing concern in the solid waste stream. According to a report by the United Nations Environment Programme (UNEP), an estimated eight million metric tons of plastic waste enter the world's oceans each year, which not only damages marine life but also affects human health and livelihoods (UNEP, 2021)[37]. Additionally, plastic waste takes hundreds of years to decompose, resulting in long-lasting environmental impacts Furthermore, plastic waste generation is on the rise globally, with a projected increase of 33% by 2050[38]. This trend is driven by factors such as population growth, urbanization and the increasing use of single-use plastics. Hence, addressing plastic waste has become a critical issue for policymakers, businesses and individuals worldwide. Plastic waste has indeed become a growing concern in the solid waste stream, as it has a significant impact on the environment and human health. According to a report by the World Economic Forum, "the amount of plastic waste generated globally is expected to triple from 2015 to 2060", which underscores the need for urgent action to address this issue (The New Plastics Economy: Rethinking the future of plastics, 2016). Moreover, a study published in the Journal Science Advances found that "plastic waste inputs into the ocean have increased by an order of magnitude from 1970 to 2015", with plastic debris now affecting nearly all marine environments[39]. This highlights the urgent need to reduce plastic waste and prevent it from entering our oceans and harming marine life. Plastic waste has indeed become a significant environmental concern globally due to its adverse effects on the environment and public health. In recent years, there has been a growing interest in natural fibers as an eco-friendly alternative to plastic materials. According to Rohit and Dixit[40] the increase in the use of synthetic materials, including plastics, has led to an increase in environmental pollution. Plastic waste has become a significant issue because of its non-biodegradable nature, which means that it remains in the environment for an extended period, leading to the degradation of the soil, water and air quality. Furthermore, plastic waste also poses a threat to wildlife, causing suffocation, strangulation and ingestion. Natural fibers, on the other hand, have many environmental advantages over synthetic materials. They are biodegradable, renewable and have a lower carbon footprint. Moreover, natural fibers have excellent mechanical and physical properties that make them suitable for various applications, such as packaging, textiles and construction materials. According to Pandian *et al.*[41] natural fibers can serve as a viable alternative to synthetic materials, including plastics, due to their sustainability and biodegradability. The authors note that natural fibers such as jute, coir, sisal and hemp are widely available, cheap and environmentally friendly. These fibers have been used in various applications, such as packaging, insulation, textiles and automotive components, to reduce the environmental impact of synthetic materials.

Plastic-reinforced polymer composites (PRPCs) have numerous advantages over traditional materials, including[42-44].

High strength and stiffness: The PRPCs have high strength and stiffness compared to traditional materials such as wood, steel, or concrete. The addition of fibers or particles to the polymer matrix significantly enhances the mechanical properties of the composite material.

Lightweight: The PRPCs are lightweight, making them ideal for use in applications where weight is a critical factor.

Corrosion resistance: The PRPCs are highly resistant to corrosion, which makes them ideal for use in harsh environments where traditional materials may deteriorate quickly.

Design flexibility: The PRPCs can be molded into complex shapes and structures, giving designers greater flexibility in creating products with unique geometries.

Durability: The PRPCs are highly durable and have a long service life, which can reduce maintenance costs over time.

Environmental benefits: The PRPCs can be made from recycled materials, reducing the environmental impact of manufacturing.

CONCLUSION

In conclusion, the issue of plastic waste in the solid waste stream has escalated into a significant concern. The persistent nature of plastics, coupled with their escalating production and consumption, has inflicted a substantial environmental toll on our planet. It endangers marine life, waterways and the well-being of both humans and animals. The enormity of this problem has led to a global outcry, demanding concerted efforts to reduce, reuse and recycle plastic waste. It is imperative to enforce policies, initiate programs and foster behavioral changes that encourage responsible plastic usage and disposal, thereby mitigating the adverse effects of plastic waste on our environment. One potential solution to environmental pollution and the conservation of natural resources lies in the adoption of natural fibers as substitutes for synthetic materials, including plastics. Although further research is needed to fully comprehend the extent of their capabilities, mounting evidence suggested that natural fibres can significantly contribute to sustainable development. Consequently, it is crucial for individuals, governments and businesses to take decisive action in minimizing the impact of plastic waste on the environment and safeguard the well-being of our planet. To shift gears, plastic-reinforced polymer composites offer a unique amalgamation of properties that make them an appealing choice for diverse applications across various industries such as aerospace, automotive, marine and construction. These composites possess advantageous characteristics that render them well-suited for a wide range of purposes, showcasing their potential and versatility.

SIGNIFICANCE STATEMENT

The objective of this study was to elucidate the necessity of investigating the emerging trends in reusing natural fiber-reinforced composites with plastic waste and highlight the unique contribution made by the present research in expanding academic understanding of this subject. The purpose of this work was to provide a comprehensive review of the latest developments in utilizing natural fibers and plastic waste in composite materials, focusing on their reusability and sustainable characteristics. The main results of the current study showcased the potential of these composites in various applications, such as automotive and construction industries, offering significant environmental benefits and promoting the circular economy.

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