IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

A Review On Sustainable Green Composites Aiming On Production Techniques And Current Trends.

Author[1] : Malik Burhan Ahmad

M.Tech Student, University School Of Engineering & Technology,

Rayat Bahra University, Mohali, India

Author[2] : Er. Shilpa Chauhan

Asst. Professor, University School of Engineering & Technology, Rayat Bahra University, Mohali, India

Abstract: The rapidly increasing disquietude about ecological degradation and the restricted availability of versatile, eco-friendly materials have fueled a surge in attentiveness for plant-based polymer composites, essentially obtained from woods. These composites, often termed "green," have widespread potential in countless industrial sectors. Green composites evince less environmental harm and can conceivably supersede petroleum-based polymeric substances.

Conserving fossil fuel resources is facilitated by developing biopolymer matrices, such as cellulose-reinforced biocomposites, utilizing renewable resources like plant oils, carbohydrates, and proteins. This paper delves into the processing of green composites, leveraging an array of naturally occurring resources, sustainable materials that minimize environmental harm, recent scientific breakthroughs in achieving green sustainability, and the role of nanotechnology in environmental conservation.

Furthermore, this study examines the environmental implications of diverse composite materials, their production from eco-friendly materials, and the manufacturing aspects of green composites, including associated concerns. The benefits of green composite materials and their validity as a viable alternative to traditional composite materials are also explored.

Keywords: Fossil Fuel, Biopolymer Matrics, Green Composites, and Ecological Degradation.

1.INTRODUCTION

Green sustainability is the cornerstone of human civilization, as energy and environmental conservation are crucial for the survival of the human race. Efficient sustainability has become an urgent requirement. Technology and science are at a crossroads regarding ecological, energy, and green sustainability. The demands of human society, including fuel, power, and water, have driven scientific innovation and complexity in recent years. Today, scientific and technological advancements are characterized by foresight and patience.

The United Nations Conferences in Rio de Janeiro (1992) and Johannesburg (2002) played a pivotal role in shaping the concept of sustainability. Since the 1980s, the term "green" has been associated with various interpretations. A green composite is a material developed entirely from renewable resources or a combination of synthetic and biologically based materials.

The perception of environmentally friendly products has undergone a significant shift. The introduction of the BRE environmental assessment method in 1990 marked a turning point in this regard. Since then, over 260 similar grading systems have been developed worldwide (Costello and Bischel 2013).

The environmental quality of materials and products is an integral part of these systems. Rating systems like the Leadership in Energy and Environmental Design (LEED) require the use of recyclable sources in building operations (ElSorady and Rizk 2020).

Adams (2019) emphasized the importance of environmental sustainability in developing nations. The authors of this paper discussed the origins of environmental sustainability, the challenges of modern sustainable development, and mainstream environmental sustainability.

The management of waste has become a pressing environmental concern due to urbanization and technological advancements. Recycling and reusing waste materials have become viable alternatives to disposal. For instance, using recycled waste materials in the construction industry can improve the physical and mechanical characteristics of cement concrete (Putman and Amirkhanian 2004; Batayneh et al. 2007).

Natural fibers have several advantages over conventional fibers, including lower cost, lower density, reusability, and good biocompatibility (Baley 2002). Non-biodegradable material recycling is quite challenging. The exploitation of natural resources, large-scale industrial waste products, and industrial pollution necessitates the creation of novel and suitable solutions for long-term growth (Cong 2018).

Biodegradable green composites utilizing renewable sources such as natural fibers, agro-feedstock, and biodegradable polymers have been proposed. These green composites have superior mechanical properties, notable manufacturing advantages, relatively low density, and are biodegradable, making them suitable for industrial use (Ghorbal et al. 2019; Wang et al. 2017; Lima et al. 2020).

Although green composites have the potential to replace synthetic polymeric materials, they have already been employed in applications such as packaging, horticultural products, automobile panels, and furniture (Adekomaya 2020).

Researchers have become increasingly interested in developing biodegradable materials. Composites, as versatile materials with outstanding qualities, have a wide range of applications in sectors such as automobiles, aviation, and shipping (Amjad et al. 2021; Husein et al. 2021).

Concerns over the ecological consequences of composites have grown in the last decade. Green composites have been created to develop environmentally beneficial composites (Kazak et al. 2017). Recent advances in the production of biodegradable green composites have shown comparable qualities (Kim et al. 2022; Yusof et al. 2019; Nkeuwa et al. 2022).

The increasing amount of plastic and composite debris has boosted environmental awareness among customers, public officials, and producers. The current pace of fossil fuel consumption is unsustainable (Stevens 2002). To address these environmental issues, governments worldwide have enacted legislation encouraging the use of recycled bio-based sustainable materials (Nir et al. 1993).

Green composite materials have sparked renewed interest in numerous applications spanning aerospace to consumer products over the last two decades. Various drivers have contributed to this resurgence, including environmental and economic factors. The hunt for new and more "environmentally friendly" materials and goods is driven by growing awareness about the impact of human activities on the environment.

2. MANUFACTURING OF GREEN COMPOSITE

The majority of commercially available composite materials are produced using non-degradable polymeric resins in conjunction with high tensile strength fibers such as aramids, graphite, and glass. These materials are typically utilized in situations that require high levels of strength, rigidity, and durability. However, most of the resins and fibers used in these composite materials are petroleum-based.

As the demand for large-volume productions like aircraft and civilian constructions continues to grow, there is an increasing need for eco-friendly composites that can be produced sustainably and evaluated throughout their life cycle. Unfortunately, composite materials are not recyclable or reusable due to their composition of two separate segments bound together in a definite form. Currently, over 90% of composites are discarded in landfills, where they can remain for extended periods, rendering the land unusable for other purposes.

A resin composition derived from biological materials is referred to as a bio-resin. This term is also used to describe resin compositions that are partially sourced from biological materials. Plant oils, polysaccharides, and proteins are the most extensively used sustainable resources for producing bio-resins.

Natural fibers are typically categorized according to their source, whether animal, plant, or mineral-based. These fibers are derived from various plant elements and are widely used in the production of green composites. Natural fibers can be divided into categories based on their source, such as stem (bast) fibers, fruit or seed fibers, and leaf fibers.

It is estimated that there are over a thousand different types of plants that produce usable fibers. Natural fibers derived from plants are mainly found in tropical climates but can also be found in terrestrial forests. These fibers are considered environmentally beneficial due to their biodegradable and renewable nature.

Natural fiber-reinforced composites are gaining popularity due to their convenience of use, reusability, low density, and low cost. Natural fibers such as bamboo, banana, jute, hemp, kenaf, and sisal have been used as reinforcing materials for an extended period.

Organic fibers like wheat, sisal, bamboo, banana, jute, cotton, flax straw, silk, sugarcane, oil palm, and coconut have also gained popularity in producing advanced technology products. The use of adequate technical approaches, such as thermoforming, pultrusion, injection molding, compression molding, and resin transfer molding, is crucial in composite manufacturing.

Aside from the technical approaches, several factors such as the type of material to be produced, part size, cost, design specifications, and mechanical or physical properties are also critical considerations.

3. ENVIRONMENTALLY RESPONSIBLE COMPOSITE MANUFACTURING WITH NATURAL FIBERS

The production of green composites utilizing sustainable fibers is a growing field. Fibers from diverse sources, each with unique characteristics, are being employed in the manufacture of polymer composites. The final product requirements typically dictate the selection of fibers. Mineral fibers, for instance, are commonly used in products such as electrical insulators and boat hulls. Carbon fibers, which are primarily produced from polyacrylonitrile fibers, are utilized in sports equipment, aerospace, and other applications.

To employ natural fibers as reinforcement, certain elements such as hemicelluloses, lignin, wax, and proteins must be removed to optimize fiber adhesion. Wood pulp is also used to manufacture composite reinforcements due to its exceptional strength as a laminated natural composite.

When a composite is produced from organic fibers, the matrix plays a crucial role in maintaining the fibers in place, distributing tension, and transferring stress among the fibers. It also protects the fibers from mechanical degradation and provides a buffer against harsh environmental conditions. The matrices used in composite production have a significant impact on the compression and shear properties of the material. The most commonly used lignocellulosic bast fibers for composite applications include ramie, jute, and flax. Bast fibers are composed of three primary constituents: lignin, cellulose, and hemicelluloses. Cellulose is the main structural component of bast fibers. However, the hydrophilic nature of cellulosic bast fibers makes them incompatible with hydrophobic polymeric matrices. Research has been conducted on the acoustic, thermal, and mechanical properties of composite boards made from rice husk. The findings suggest that these composite materials could improve the thermal and acoustic properties of structures. As per the recent studies, banana fiber-reinforced polyester composites exhibit weak flexural strength and moderate tensile strength compared to other natural fibers, such as bamboo.

4. FABRICATION TECHNIQUES OF GREEN COMPOSITES

Green composites can be fabricated using a range of manufacturing processes, including pultrusion, compression molding, injection molding, resin transfer molding, extrusion, and thermoforming (Mann et al., 2020; Dong, 2018; Hu et al., 2012). For instance, researchers have employed compression molding to produce jute and polylactic acid composites (Mann et al., 2020; Dong, 2018; Hu et al., 2012), while others have utilized injection molding to manufacture wood flour and polylactic acid composites (Altun et al., 2013). Additionally, the thermoforming process can be used as an alternative method to produce polylactic acid composites (Faruk et al., 2012; Throne, 2017). A unique technology involves the manufacture of plastic composites for metal parts using direct long-fiber thermoplastics (Faruk et al., 2012).

The selection of manufacturing techniques typically depends on factors such as the type and properties of the material, part strength, design complexity, production capabilities, and investment requirements (Kopparthy and Netravali, 2021). This article provides a brief overview of the manufacture of green composites using various processing methods, including compression molding, thermoforming, injection molding, prepreg sheet method, resin transfer molding, and bonding.

5. COMPRESSION MOLDING

A recent study by Ambone et al. (2020) investigated the mechanical properties of CNF/3D-polylactic acid composites fabricated using 3D printing and compression molding. The researchers used CNF derived from sisal fibers as reinforcement. The results showed that compression-molded composites exhibited superior tensile properties compared to 3D-printed composites.

In a separate study, Regazzi et al. (2019) utilized waxy maize or amylomaize native starch as a green resin and softwood chemical-thermomechanical pulp and bleached and fibrillated chemical kraft pulp with lignin removed fibers as reinforcements. The specimens were manufactured using thermo-compression or ultrasonic compression molding. The composites exhibited elastoplastic mechanical behavior, and their mechanical properties were comparable to those of commercial thermoset glass fiber-reinforced composites.

Ramesh et al. (2020) investigated the effects of aloe vera and kenaf fibers on the mechanical properties of polylactic acid composites. The fibers were treated with NaOH and then mixed with polylactic acid using extrusion and compression molding techniques. The results showed that the impact strengths of the kenaf/polylactic acid and aloe vera/polylactic acid composites were significantly improved after treatment.

Roberto et al. (2022) developed an innovative green composite for controlled release fertilizers by combining NPK fertilizer with a biodegradable polymer and Opuntia Ficus Indica particles. The composites were fabricated using compression molding and fused deposition modeling. The results showed that the composites exhibited excellent adhesion between the filler and polymer matrix, good dispersion, and effective reinforcement.

Trauth and Weidenmann (2018) investigated the mechanical properties of continuous-discontinuous sheet molding compounds fabricated using compression molding. The results showed that the composites exhibited improved mechanical properties compared to traditional sheet molding compounds.

Hadi et al. (2018) studied the effects of maleated anhydride polylactic acid on the mechanical properties of polylactic acid-reinforced pineapple leaf fiber composites. The composites were fabricated using hot rolling and compression molding. The results showed that the composites exhibited improved tensile and flexural properties.

Ben and Kihara (2007a, b) investigated the effects of melt temperature, holding time, and impregnation time on the mechanical properties of kenaf and polylactic acid composites. The results showed that a melt temperature of 185°C and a holding time of 15 minutes were optimal for producing composites with improved mechanical properties.

Reddy and Yang (2011) studied the effects of molding time and temperature on the mechanical properties of wheat gluten-jute composite materials. The results showed that a molding time and temperature of 170°C and 15 minutes produced composites with improved flexural properties.

Kim et al. (2019) developed a diagnostic model to predict the permeability of woven in-plane composites fabricated using vacuum-assisted resin transfer molding. The results showed that the model accurately predicted the permeability of the composites and the filling time and flow front pattern.

6. THERMOFORMING PROCESS

Wang and Young (2022) conducted an investigation into the mechanical properties of woven bamboo fiber-reinforced polypropylene composites. The bamboo fiber mat was manually created by hand. The researchers employed the thermoforming technique to fabricate the woven bamboo fiber/polypropylene composites. The tensile strength of the woven bamboo fiber/polypropylene composite with alkali-treated bamboo fibers was found to be higher than that of the composite with untreated bamboo fibers. Furthermore, the strength and modulus of the composite were nearly twice as great in the longitudinal direction as in the transverse direction.

During the thermoforming process, composite sheets are typically roll-fed or pre-cut based on overall thickness (Klein, 2009). A clamping frame is often used to prevent pre-cut sheets from twisting and warping. The sheets are then preheated to their glass transition temperature using convection or radiation heaters on one or both sides (Zampaloni et al., 2007). Preheating is recommended prior to the forming operation to minimize the risk of material shear and premature fracturing caused by rapid cooling at room temperature (Lim et al., 2008; Zampaloni et al., 2007).

7. HAND LAYUP TECHNIQUE

The open molding process, also known as the hand layup technique, requires a high level of expertise. Srinivasan et al. (2014) investigated the thermal and mechanical properties of a banana flax-based composite produced using hand layup and compression molding. In this process, a layer of banana fiber was sandwiched between two layers of flax fiber.

Dhawan et al. (2013) examined the effects of natural fillers on the properties of green fiber-reinforced polymers. Short fibers in the form of powder are used in this technique. Lin et al. (2012) proposed an injection molding technique for the fabrication of wood-plastic composites. The study found that the weight of the wood-plastic composite was 5% less than that of the polypropylene/glass combination.

Mohanty et al. (2005) used an injection molding procedure to create soy-based bioplastic and chopped industrial hemp fiber to test their mechanical and thermal properties, which showed a remarkable enhancement. Chaitanya and Singh (2017) compared the direct-injection molding process with the extrusion injection molding approach for the manufacture of sisal fiber-reinforced polylactic acid. The flexural and tensile strength of the biocomposites increased by 35% and 16%, respectively.

Ohkita and Takagi (2011) used an injection molding procedure to create a bamboo/polybutylene succinate composite and measured its mechanical properties. A twin-screw extrusion was employed for the sample fabrication, and pellets of 40% weight percent were combined with PBS.

Xie et al. produced polylactide products using mold-opening technology. Microcellular injection molding with mold-opening technique was used to create microcellular polylactide and polylactide composites with void percentages as high as 50%. The effect of adding nanoclay to pure polylactide on these characteristics was also investigated.

Girimurugan et al. (2022) produced boards made of hybrid bio-composite materials using a hot injection molding process. The hybrid bio-composite boards were sliced into pieces that could be tested for bending and compression using a "water jet machining technique."

Shaik et al. (2022) created bioplastic composite samples by varying the weight ratios of eggshell and walnut shell powders added to the plasticized polylactide. Five weight percent of epoxidized soybean oil was used to achieve the plasticization. Injection molding was used to further process the generated bioplastic granules into dog-bone-shaped samples.

Anand et al. (2022) examined the effect of silane-treated pineapple leaf fiber with different fiber lengths on the properties of natural fiber composites. The length of the fibers determines the properties of pineapple leaf fiber, and it is technically challenging to produce long fibers and process them for improved characteristics in polyester composites.

Chai et al. (2022) investigated the effect of nano TiO_2 on the microcellular structure and mechanical properties of WF/PP composites. The findings indicate that nano TiO_2 accelerates the crystallization process and reduces the crystallinity of PP, which is advantageous for the development of foamed homogeneous systems and cell growth in WF/PP composites.

8. RESIN TRANSFER MOLDING (RTM)

Continuous mats, woven rovings, and discontinuous lignocelluloses are fabricated using the resin transfer molding (RTM) technique. A significant advantage of this technology is the ability to easily regulate fiber orientation (Liu et al. 2014). Wang et al. (2017) and Francucci et al. (2012) employed RTM to create unidirectional abaca fiber composites.

The resin was injected into the mold through a silicon tube, assisted by a roller pump. The researchers found that the RTM approach requires lower manufacturing temperatures, potentially preventing mechanical degradation (Francucci et al. 2012). Another benefit of this method is the long-term durability of the high-strength components produced (Feldmann and Bledzki 2014).

A recent study investigated environmentally friendly natural fiber composites made from nano-cellulose isolated from used paper egg trays and mixed with kenaf fiber using vacuum-assisted resin transfer molding. The extracted nano-cellulose was evenly combined with the resin using three-roll milling, ultrasonication, and overhead stirring. The surface morphology showed a uniform distribution of extracted nano-cellulose in the composites (Yu et al. 2022).

To develop porous materials and increase compressibility, fast-growing wood (poplar wood) was delignified using a steam mixture of hydrogen peroxide and acetic acid. The cellulose scaffold structure of the delignified wood remained intact after processing. The delignified wood and epoxy resin were then combined using a straightforward and environmentally friendly vacuum-assisted resin transfer molding procedure to create high-performance wood-based composites (Liang et al. 2022).

Another study employed resin transfer and compression resin transfer molding technologies to create high-performance wood strand panels for automotive applications. The resin transfer-molded wood strand composites demonstrated superior mechanical characteristics and dimensional stability when exposed to moisture (Gartner et al. 2022).

A recent study used vacuum-assisted resin transfer molding to create a continuous bamboo-textile-reinforced polymer composite using woven bamboo strips and epoxy. The flexural characteristics of the samples were investigated (Chang and Chang 2022).

Kottapalli et al. (2022) studied the impact attributes of hybridization and stacking sequence of laminates made using the vacuum-assisted resin transfer molding process. Seuffert et al. (2020) conducted research on models and experiments of pressure-controlled resin transfer molding. Simulation accurately predicted the various stages of pressure-controlled resin transfer molding. However, further research is needed to examine the effect of characteristics such as permeability, viscosity, temperature, and tool geometry features.

9. VACUUM- ASSISTED RESIN TRANSFER MOLDING

Kong et al. (2014) utilized vacuum-assisted resin transfer molding to manufacture fax fiber composite specimens. The findings revealed that the mechanical properties of the samples produced using this method were superior to those of reference materials.

Torres et al. (2003) investigated the use of single-screw extrusion for manufacturing organic fiber-reinforced thermoplastics and characterized their material properties. Experimental studies were conducted to determine the transport processes during single-screw extrusion and examine the mechanisms of bubble generation caused by variations in fiber dispersion.

Razali et al. (2021) employed resin transfer molding to develop structural components. This composite material fabrication method uses an out-of-autoclave process, which offers significant advantages in terms of sustainable design, reduced energy consumption, and lower greenhouse gas emissions.

Dai et al. (2018) focused on vacuum-assisted resin molding technology for composite manufacturing. A series of bio-based benzoxazine oligomers were synthesized and characterized using nuclear magnetic resonance spectroscopy and Fourier transform infrared spectroscopy.

Rashid et al. (2021) assessed the impact of applying through-the-thickness reinforcement by tufting in a fax-based composite laminate on in-plane mechanical characteristics. The results showed that the glass fiber tufts enhanced the bond between the core and skin of the composite.

Midani and Hassanin (2021) employed vacuum-aided resin transfer molding technology to produce an electromagnetic interference shielding composite material by mixing carbon fiber sheets and wood veneers with epoxy resin infusion.

Negawo et al. (2021) investigated the effect of stacking sequences on the mechanical and dynamic mechanical properties of ensete/glass hybrid composites. The composites were fabricated using a vacuum-assisted resin transfer molding process.

Shunmugasundaram et al. (2021) examined the influence of nano-filler on the tensile properties of natural-based polymer composites. The researchers used the vacuum-aided infusion molding process to develop new nano-infused composites by combining neem fiber with two different nano-filler materials.

Bai et al. (2021) prepared bamboo fiber-reinforced epoxy resin composites using vacuum-assisted resin transfer molding and determined their tensile properties. The results showed that adding a wetting agent significantly improved the interface compatibility of the composites.

10. ECO- FRIENDLY GREEN COMPOSITES

Eco-friendly green composites have emerged as a promising alternative to traditional composites, offering a wide range of applications in industries such as automotive, aviation, and shipping (Adekomaya 2020). Growing concerns about the environmental impact of conventional composites have led to the development of green composites, which are designed to be environmentally beneficial. These composites are either fully biodegradable or partially biodegradable, making them an attractive option for industries seeking sustainable materials.

The unique combination of biodegradability and sustainability makes green composites derived from natural and renewable resources an ideal choice for meeting the increasing global demand for eco-friendly materials. The versatility and widespread applicability of green composites in various industries, including automotive, maritime, aerospace, and biomedicine, have made them a subject of extensive research. Furthermore, green composites have the potential to replace expensive, non-biodegradable, petroleum-based composites, offering a more environmentally friendly alternative (Islam et al. 2022a, b).

Biocomposites, a novel class of materials, are composed of a polymeric matrix and reinforcing fibers. To be considered biodegradable and green, biocomposites must adhere to the principles of green chemistry, which emphasize sustainability and environmental responsibility (Rafee et al. 2021).

11. NATURAL FIBERS

Wood is a robust, multi-layered organic composite material, and its pulp is also used to manufacture composite reinforcement (Hinestroza and Netravali 2014). While organic fibers have inferior mechanical properties compared to synthetic materials like Kevlar and aramid, this weakness can be overcome by increasing the density of the organic fibers (Mohanty et al. 2004). Organic fibers, however, offer several advantages over synthetic fibers, including recyclability, biocompatibility, environmental sustainability, superior insulation properties, and reduced machinery wear (Chichane et al. 2022).

The growing popularity of natural fiber-reinforced polymer composite materials can be attributed to their eco-friendliness, lightweight, exceptional lifespan, biocompatibility, affordability, and outstanding mechanical properties. These materials have numerous industrial applications, and research in this area is continually expanding (Shaharul Islam et al. 2022a, b). Natural fibers have the potential to replace synthetic fibers in the future, provided their moisture-absorbing properties are reduced, and fiber lengths are extended to improve mechanical characteristics.

Plant fibers, derived from various plant parts such as leaves, fruits, stems, straws, and grasses (Kumar et al. 2021a; Satyanarayana et al. 2009; La Mantia and Morreale 2011), have been extensively studied by researchers. However, natural fibers also have several drawbacks compared to synthetic fibers, including product variability due to factors such as plant age, climate, geographical growth conditions, cultivation techniques, and cleaning technology. Furthermore, there is a significant variation in mechanical properties between natural and synthetic fibers, largely due to the shorter length of natural fibers.

The moisture absorption properties of organic fibers can reduce their adhesion, making composite production more time-consuming. The hydrophilic nature of these fibers can also cause clumping during manufacturing. While bast fibers are commonly used in the production of green composites, other species are being explored for research into green composites. Perennial grass, a single-seed species requiring less fertilizer and water, is an ideal choice for composites. Research has shown that switchgrass polypropylene composites exhibit superior mechanical properties compared to jute fiber composites, making polypropylene composites a valuable material for generating high-quality green composites (Zou et al. 2010).

12. ANIMAL –DERIVED FIBERS

Conventional animal fibers, such as silk and wool, have been explored as reinforcing materials for green composites. Due to their flexibility, high aspect ratio, toughness, and lower hydrophilicity compared to other organic fibers, animal fibers have garnered attention as high-performance fibers (Kumar et al. 2021a; Surip et al. 2016). Dinesh et al. (2020) investigated three specimens created using different combinations of natural fibers, including goat wool, hen feather, human hair, and Kevlar 29 (K-29), reinforced with epoxy resin using the hand layup process.

The compression molding technique was employed to apply uniform pressure to sandwiched layers. Tensile and flexural strength tests were conducted according to ASTM standards. Additionally, a water immersion test was performed to determine the amount of water absorbed under specific conditions, as well as scanning electron microscopy analysis of bonding layers and structure. The study demonstrated that composite materials exhibited improved mechanical properties and minimal water absorption.

Animal fibers, such as keratin fibers, contain a significant amount of air, resulting in low-density fibers with a low dielectric constant, making them suitable for use as reinforcement materials in electronic applications. In contrast, plant fibers have a short fiber length, contributing to their poor tensile strength. However, some animal fibers, such as silk, have a continuous fiber length (1500 m), providing them with superior mechanical properties.

Spider silk, for instance, is more rigid than steel and Kevlar due to its unique characteristics. This material has the potential to significantly reduce the amount of material used in various engineering disciplines, such as mechanical and civil engineering. In one study, a structural model of an airplane windowpane was analyzed, and the results were compared to the current industry standard material. Spider silk was found to be an ideal fabric for composites due to its exceptional elastic properties.

Silk fibers were used as reinforcement in a composite material, with epoxy serving as the matrix (Mayank et al. 2022). The mechanical performance of silk is also influenced by the type of silk used and the spinning technique. Silk has limited temperature resistance but is highly antimicrobial and ultraviolet-resistant. Silk composites are used in biomedical applications, such as creating grafts and tissue engineering.

Animal fibers do not require fertile soil or freshwater to grow, making them a more sustainable option. However, animal fibers can be expensive and have an unclear supply chain, which is a disadvantage (Farhad Ali et al. 2021). Fibers from waste materials, on the other hand, are a more sustainable option for reinforcement materials, as they are derived from agro-industrial waste and offer an inexpensive raw material while also providing a final disposal option for agricultural residues (Xiao et al. 2020a, b).

For example, maize husk is easily accessible from corn manufacturing firms, solving the issue of organic fiber sourcing and geographic factors. The mechanical characteristics of rice husk and lignocellulosic biomass waste reinforced on a polyethylene matrix have been investigated. Sunflower stalks, rice husks, corn husks, wheat straws, soy, and sunflower stalks are examples of agro-industrial wastes that can be employed as cellulosic fiber sources for reinforcements (Zini and Scandola 2011).

Animal processing firms, such as those that process ham, duck, and chicken fillets, generate large amounts of protein waste comprising feathers, wool, and other materials that can be used as reinforcement materials in composites (Bansal et al. 2021). Chicken feather fibers are extensively available worldwide, as chicken is one of the most widely consumed foods (Rittin Abraham Kurien et al. 2022). Due to their porous structure, these fibers have a low density, making them suitable for use in automobiles.

Keratin fibers reinforced on PP were examined, and the polymer composite demonstrated enhanced stiffness with reduced temperature resistance up to 200 °C (Barone et al. 2005). Waste used to generate cellulosic and keratin-based fibers requires preliminary waste processing but also aids in waste disposal while offering durable and efficient reinforcement for green composites.

Biodegradable polymers, such as agro-polymers (cellulose), microbial polymers (polyhydroxyalkanoates), and chemically synthesized polymers from agricultural and agri-resource monomers, are being explored for use in green composites. Processing biopolymers into composites involves several critical steps, including biopolymer treatment, which affects the breakdown time and temperature of the polymer, as well as its density, which determines the density of the finished composite material (Baillie and Jayasinghe 2017).

The rigidity and tensile strength of natural polymers can be improved by reinforcing them with lignocellulosic fibers with considerable tensile strength.

13. PROPERTIES ASSESSMENT TECHNIQUES

The characterization methods of green composites, including compression molding, thermoforming, open molding, resin transfer molding, and filament winding, are discussed in this section. These methods are used to evaluate the mechanical properties of green composites.

In compression molding, fibers are inserted into a metallic mold, and resin is poured directly into them. The material is then pressed at 150 °C and cooled to room temperature. Thermoforming involves hot pressing preforms of resin-pasted fibers. Fibers are wound and stretched around a metallic plate, and resin is applied to the fibers using a small brush.

Liu et al. (2019) characterized and modified maize stem fibers isolated from corn stalk waste. The chemical characteristics, surface morphology, mechanical behaviors, and thermal stability of the corn stem fibers were studied after alkali, silane, and NaOH-silane solutions were applied to the fibers. The surface treatments enhanced the chemical and mechanical properties of the fibers.

Kumar et al. (2017) investigated the mechanical properties of a composite material consisting of polypropylene and maleic anhydride-grafted polypropylene as the base matrix. The loading of treated hollow glass microspheres was maintained constant at 10 wt% with respect to the base matrix.

Various mechanical characterization techniques, such as tensile strength, Young's modulus, compressive strength, flexural strength, flexural modulus, and impact strength, are used to determine the mechanical behavior of composites. The effect of natural fibers as reinforcement is studied through various characterization techniques.

The mechanical properties of green composites depend on multiple parameters, such as fiber aspect ratio, percentage of fiber content, surface treatment of fibers, and coupling agents to increase the bonding between fiber and matrix.

Ciupan et al. (2017) studied the mechanical properties of hemp fibers and polypropylene-based natural fiber composites. The tensile strength of the composite was improved due to the addition of natural fibers.

Fiber treatment improved the interfacial interaction, resulting in improved properties. As the fiber content in the loading direction increases, the Young's modulus and tensile strength of both poly lactic acid-self-reinforced composites and poly lactic acid-butylene succinate composites increase.

Liu et al. observed that the prepared natural cellulose fiber composite had a 42% higher impact strength than the corn stalk composite. Silane-treated fibers and 3% C30B nano clay offered better strength and modulus due to the formation of hydrogen bonds of nano clay between fiber matrix interfaces.

Srinivasan et al. (2014) observed that the tensile strength of the flax-banana-based glass fiber-reinforced plastic composite was higher than the banana-based glass fiber-reinforced plastic composite and the flax-based glass fiber-reinforced plastic composite.

In another study, Kamaruddin et al. (2022) developed thermoplastic cassava starch-palm wax blends reinforced with treated Cymbopogon citratus fiber. The thermoplastic cassava starch was modified with palm wax to enhance the properties of the matrix.

The influence of alkali treatments on the thermoplastic cassava starch-palm wax blends reinforced with the treated Cymbopogon citratus fiber biocomposite was analyzed. The fiber was treated with different sodium hydroxide (NaOH) concentrations prior to composite preparation via hot pressing.

The obtained results revealed improved mechanical characteristics in the treated composites. The composites that underwent consecutive alkali treatments at 6% NaOH prior to composite preparation had higher mechanical strengths compared to the untreated fibers.

Surface treatment results in improved tensile and flexural properties and decreased impact strength. Composites containing 20, 40, and 50% date palm fibers have lower void fractions, while composites with 60 and 80% have higher void fractions.

The flexural properties increased with 30 to 50% flax addition, and with an increase in silane addition, the tensile and flexural properties increased. Both Young's modulus and tensile strength were larger for the kenaf/polylactic acid composite as compared to polylactic acid alone.

Ibrahim et al. (2014) suggest that green composites with higher modulus will be a strong candidate for replacing glass fiber composites. The flexural strength of polylactic acid was greatly improved by introducing chopped jute and kenaf fibers to the polylactic acid matrix.

Surface-modified fibers showed better tensile properties than untreated fibers due to the presence of a higher percentage of crystalline cellulose. A detailed literature study on the characteristics of green composites is performed, and different processes are classified. Research is also required to reduce the cost of biopolymers as a matrix material.

14. HURDLES IN THE PRODUCTION OF GREEN COMPOSITES

The primary challenge in producing green composites is ensuring their thermal stability while mitigating the unpleasant odors emitted by natural fibers such as kenaf, hemp, and jute (Sinha and Devnani 2022). The high cost of natural fiber-based composites is a significant barrier to their adoption in the automotive industry (Islam et al. 2022a, b). The lack of understanding about the behavior of sustainable and green composites, due to the vast diversity of ingredients, is a major hurdle to overcome in this field (Vinod et al. 2020).

To produce high-quality composites, it is essential to select the optimal manufacturing conditions and factors, as well as the precise choice of composite ingredients and overall material properties. The inherent limitations of natural fibers, such as their poor mechanical properties, are a fundamental issue that restricts their use in green composites (Shekar and Ramachandra 2018).

Additional challenges faced by green composites include the need to minimize the environmental impact of the material source throughout its entire lifecycle (Kupolati et al. 2022). The key characteristics of sustainable development include energy consumption, durability, and service quality (AL-Oqla and Omari 2017).

The recycling of composite materials at the end of their functional life should be considered during the design phase of the product (Lu et al. 2022). Plastic waste has been identified as a significant environmental concern. Consumers have expressed concerns about the release of contaminants and chemicals from plastic products (Chen and Selvinsimpson 2022).

Plastics are ubiquitous materials in modern society, used in various applications such as medical services, food packaging, construction materials, automobiles, and household appliances (Li et al. 2021a, b). Environmentally friendly and technologically effective material recovery methods should be implemented, particularly in densely populated countries (Elsheikh et al. 2022).

15. EMERGING TRENDS IN THE GREEN SUSTAINABILITY DOMAIN

Human civilization's reliance on fuel, power, and freshwater has led to a surge in technological advancements and complexity in recent years. Scientific and technological progress is now characterized by foresight and perseverance (Dutta et al. 2022). Modern society demands efficient industrial wastewater treatment, potable water treatment, and water purification (Kuhn et al. 2022).

In the realm of environmental sustainability, scientific understanding and comprehensive awareness are facing significant challenges. The development of nanoscience is creating new opportunities for scientific innovation (Pasupuleti 2022). Currently, technology and science are at a critical juncture in terms of ecological, energy, and environmental sustainability. In the modern world, environmental sustainability is a cornerstone of human scientific endeavors (Thakur and Thakur 2022).

Managing freshwater scarcity is a pressing challenge that requires scientific and educational integrity. This paper addresses the primary goal of environmental and energy conservation. Human activities, ranging from deforestation to hydrocarbon emissions and industrial air pollution, have significantly impacted the environment (Raihan and Tuspekova 2022; Dhakal et al. 2022).

The pressing issues of arsenic and heavy metal groundwater pollution require reevaluation in light of scientific progress and the idealistic timeframe of human existence (Sharma et al. 2022). Sustainability motivations are often complex, subjective, and diverse (Khan et al. 2022). The broad perspective of environmental and economic benefits must be reformed and rebuilt in light of scientific thought and conceptual timeframes (University of Alberta Office of Sustainability Report, 2010).

This research highlights the critical role of modern human civilization in achieving genuine social, financial, ecological, and sustainable development (University of Alberta Office of Sustainability Report, 2010). The concept of sustainability has evolved significantly over time (Erlygina and Shtebner 2022). The term sustainable development remains relevant in the face of growing resource scarcity, global warming, and rising global population, paired with modern economic and social development (Yanarella et al. 2009; Talan et al. 2020).

Green restoration and ecologically sustainable methods for polluted site restoration have been clearly outlined in a US Environmental Protection Agency report (the United States Environmental Protection Agency Report 2008). Environmental engineering and protection are on the verge of a new technical and scientific renaissance. A recent article by Yang et al. (2022a, b) envisioned long-term viability of site remediation and management practices.

The US Environmental Protection Agency is committed to developing and facilitating innovative bioremediation methodologies that restore polluted land to beneficial uses, reduce costs, and promote environmental and energy governance (Young et al. 2022; Arslan et al. 2022). Hazardous pollutants such as fine particulates and lead contribute to air pollution (Jain et al. 2022). Imbalances in the water cycle (the United States Environmental Protection Agency Report 2008), soil erosion, and nutrient loss are significant concerns (Dou et al. 2022).

Greenhouse pollutants, including nitrous oxide, methane, and carbon dioxide, are released due to declining populations and rich biodiversity (Sonwani and Saxena 2022). Preserving water and water purity are crucial goals; enhancing energy and water efficiency, managing toxics, and reducing air pollutants are distinguishing traits of the US Environmental Protection Agency's scientific approach (Shapiro 2022).

KEY TAKEAWAYS

Green composites are revolutionizing various aspects of daily life by replacing traditional materials, including metals, petroleum-based plastics, and conventional composites. The potential of green composites is vast, and ongoing innovations are continually being made. However, further research is necessary to develop green composites with high tensile strength and thermal resistance, enabling them to completely replace traditional composites while minimizing the environmental impact of petroleum-based materials and their manufacturing processes.

In the coming decades, green composite materials will face competition from synthetic composites in the global market. To address this challenge, cutting-edge nanocomposites can be developed by combining agricultural waste-derived nanocrystalline cellulose particles with biodegradable matrices, resulting in more durable, sustainable, and renewable materials.

Biocomposites offer several advantages, including lower costs, environmental benefits, and composition from entirely renewable resources. The adoption of suitable production techniques and various treatments to enhance performance will be crucial in ensuring the efficacy of these materials.

The workability of biocomposites is influenced by factors such as melt viscosity, specific heat, thermal transfer, and crystalline nature. To provide a comprehensive understanding of material selection and associated manufacturing processes, fundamental processing principles should be outlined.

New guidelines and regulations will lead to changes in consumption patterns, prompting manufacturers to adopt innovative resources to address current challenges and future prospects. Moreover, pre-processing methods like pre-treatment, post-treatment, biopolymer additives, and adequate drying play a vital role in enhancing product quality, as noted by Motaung et al. (2018).

Future research investigations should focus on developing suitable and standardized fiber extraction techniques to produce high-quality elemental fibers that can be effectively integrated into the composite matrix, eliminating fiber heterogeneity.

Emerging scientists in this field have numerous opportunities for research. Further studies should focus on improving methods and techniques for enhancing fiber-matrix interfacial properties. Additionally, newly developed pathways should be able to circumvent potential issues with biocomposites, such as moisture absorption, temperature, humidity, UV radiation, toxins, aging, and environmental stimulation (Bao 2018).

The development of biodegradable and life cycle analyses of improved biopolymers is necessary to replace petroleum-based materials. An interdisciplinary approach, considering manufacturing processes related to agriculture, biotechnology, polymers, and composites, is required.

Emerging bio-based polymers should be developed into lab-scale composite production techniques before being commercialized. Furthermore, investigating the potential applications of additional resources, such as leftover agricultural fibers, conventional treatments, food processing, cooking, and other materials, is essential (Gope and Rao 2016).

The integration of nanofibers made from cellulose and synthetic nanofillers may be the subject of in-depth investigation, given the current trend toward the growth of nanocomposites. Additionally, problems caused by botanical residues can be easily resolved by using them as polymer composite-reinforcing elements (Yan-Hong et al. 2015).

Hybrid biocomposites and plastic fabrication methods must be employed (Mihai and Ton-That 2019) to improve the performance of the produced composites.

REFRENCES

[1] Background paper for ‘Sustainable Buildings and Construction for India: Policies, Practices and Performance”, UNEP SBCI.

[2] JLLM, 2007, Accelerating Transformation: Investments in Indian Real estate, Knowledge Centre-Whit paper series volume 2:2, Jones Lang Lasalle Meghraj.

[3] Jignesh C. Sailor, Himanshu A. Naik, Viralkumar I. Makwana "Leader in Energy & Environment Design for building sector", ID REEES-10/EN/114.

[4] Kushagra Varma, Mayank Chaurasia, Prasenjit Shukla, Tariq Ahmed "Green Building Architecture: A Literature Review on Designing Techniques", International Journal Of Scientific and Research Publications, Volume 4, Issue 2, February 2014, ISSN2250-3153.

[5] Apoorv Vij, (2013) GRIHA, SVAGRAHA and Green Building in working studio on Building Smart Human Cities by IIA, Bhopal Centre.

[6] "List of Countries by Carbon Dioxide Emission", https://en.m.wikipedia.org/wiki/list_of_countries_by_carbon_dioxide_emission?_e_pi_=7 AGE_ID10%2C6949094324.

[7] Bidhan Sharma and Geeta Mehta, "An experimental Study on Compressive Strength of Concrete with Natural Pozzolana (Clay)"' International Journal of Engineering Research & Technology (IJERT), 3(5), 2014.

[8] Abhinandan R. Gupta "Green Building Material and technology green accreditation tools analysis" – Indian Journal of Research Paripex Volume: 2, Issue: 3, March 2013 ISSN – 2250-1991.

[9] Akshay B. Mokal, Allaudin I. Shaikh Shamashree S. Raundal, Sushma J. Prajapati, Uday J. Phatak "GREEN BUILDING MATERIALS – A WAY towards sustainable construction", International Journal of Application of Innovation in Engineering & Management (IJAIEM), Volume 2, Issue 4,April 2015.

[10] H. Klee, The cement sustainability initiative, In: 3rd International symposium sustainability in cement concrete, Istanbul, Turkey, 21-23 May (2007).

[11] Prof. H. S. Mehta, Vishal Porwal "Green Building Construction for Sustainable Future" – Civil and Environmental Research www.iiste.org ISSN 22224-5790 (Paper) ISSN 2225-0514 (Online) Vol.3, No.6, 2013.

[12] Ashish Kumar Prasher, Rinku Prasher "Construction of an eco-friendly building using green building approach" – International Journal of scientific & Engineering Research, Volume 3, Issue 6, June -2012 1 ISSN 2229-5518.

[13] IGBC(2011), "Indian green Building Council: LEEDw-NC India , available at www.igbc.in

[14] US Green Building Council (USGBC), (2011), "Non-profit organisation dedicated to sustainable building design and construction. Developers of the LEED building rating system", www.usgbc.org/.

[15] Energy Efficiency in Building Design and Construction, A Report, BEE, 2010.

[16] Building Automation" Available at Wikipedia, the free encyclopaedia,
https://en.m.wikipedia.org/wiki/Building_automation?_e_pi_=7%2CPAGE_ID10%2C3790070
142.Junli yang and IBUCHIM Cyril B. Ogunkah, "A Multi-Criteria Decision Support System for the Selection of Low-Cost Green Building Materials and Components", Journal of Building Construction and Planning Research, 1, 89-130, 2013.

[18] "What is difference Between Active and Passive Solar Design"? , Paul Cataldo, February 27, 2015, available at
www.paulcataldora.com/ask_the_green_architect/difference_between_active_and_passive_sola
r_design/.

[19] Green Building: How can passive and active system work together, Autodesk Sustainability workshop,sustainabilityworkshop.autodesk.com/building/passive_designstrategies,
www.renewableenergyfocus.com

[20] City of New York Department of Design and Construction. 1991. "High Performance Building Guidelines". Available at www.nyc.gov/html/ddc/downloads/pdf/guidelines.pdf.

[21] Monica Dragoicea, Laurentiu Bucur and Monica Patrascu, "A Service Oriented Simulation Architecture for Intelligent Building Management, 4rth International conference on Exploring Service science 1.3, 7-8 February, 2013, Portugal, LNBIP 143.

[22] Introduction to National Rating System – GRIHA, "Ministry of New and Renewable Energy, Government of India, and the Energy and Resources Institute, VOL 1, 2010.

[23] S. Abbaszahed, L. Zagreus, D. Lehrer and Huizenga, "Occupant Satisfaction with Indoor Environmental Quality in Green Buildings", Proceedings of Healthy Buildings 2006, Lisbon, Vol. III, 365-370.

[24] UNEP, 2007, Buildings and Climate Change: Status, Challenges and Opportunity.

[25] Hernandez, P., and Kenny P. (2010) "From Net energy to zero energy buildings: Defining life cycle zeroenergy buildings (LC-ZEB)." Energy Building, 4296), 815-821.

[26] US Green Building Council. 2003. Building Momentum: National Trends and Prospectus for HighPerformance Green Buildings. Available at www.usgbc.org/Docs/Resources/043003_hpgb_whitepaper.pdf.

[27] Griffith, B., N. Long, P. Torcellini and R. Judkoff. 2007. Assessment of the Technical Potential for Achieving Net- Zero Energy Building in the Commercial Sector. National Renewable Laboratory Report NREL/TP-550-41957.Available at www.nerl.gov/docs/fy08osti/41957.pdf.

[28] Business Today, August 16, 2015, "Indian Paryawaran Bhawan: India's first Zero energy building". Available at www.businesstoday.in/magazine/features/cleantech_india_paryawaran_bhawan_india_first_zero_energy_building/story/222090.html.

[29] The Hindu, November 12, 2014: "India's first Net Zero energy building, Available at http://www.hindu.com/news/cities/delhi/india_first_net_zero_energy_building/article6589478.ece.

[30] Case study: First Net- Zero Building in India Outback Grid/Hybrid System Installation, Available at www.outbackpower.com/malankara.pdf.

[31] Ramesh S P, Emran Khan M "ENERGY EFFICIENCY IN GREEN BUILDINGS – INDIA CONCEPT", International Journal of Emerging Technology and Advanced Engineering, Volume 3, Special Issue 3: ICRTSD 2013, Feb 2013, pages 329-33.

[32] "Green Building Automation" | Plymouth, MI. Available at http://gbautomation.com and Building Sustainability through Building Automation, KMC Controls White Paper Series, Available at http://www.kmccontrols.com/images/agiods_files/downloads/Building_sustainability.pdf.

[33] W.L. Lee, F.W.H. Yik, Regulatory and Voluntary approaches for enhancing building energy efficiency, 2004, progress in Energy and Combustion Science (30) 477-499Alex Zimmerman, A.A. & Kibbert. C.J. (2007) informing LEED's next generation with Natural Step.
Building Research & Information, 35, 681-689.

[35] Lee WL, Yik FWH. Regulatory and voluntary approaches for enhancing energy efficiency of buildings in Honk Kong. Applied Energy 2002; 71:251-74.

[36] Dr. Manoj P K "Prospects and Challenges of Green Building and Green Affordable Homes-Concept: A Study with Reference to Ernakulum, Kerala", Volume: 2 | Issue:12 |Dec 2013, ISSN No 2277 – 8160.

[37] The Economic Benefits of Green Buildings: A Comprehensive Case Study. Robert Ries and 2006 Melissa M. Bilec in "The Engineering Economist", 51: 259-295.

[38] World Population Clock: 7.4 Billion People (2016)- Worldometer, Available at http://www.worldometers.info/world-population/.

[39] An article in The Economic Times, Politics and Nation, "India to Surpass China in Population in Seven Years: United Nations, posted on 29 July, 2015. Available at http://articles.economictimes.indiatimes.com/2015-07 29/news/64996801_1_populationgrowth-china-and-india-nigeria.

[40] An article in PR Newswire, "Global Construction Market to Grow $8 Trillion by 2030: Driven by China, US and India, posted on November 09,2015 from Global Construction Perspectives Ltd. Available at http://www.prnewswire.com/news-releases/global-construction-market-to-grow-8-trillion-by-2030-driven-by-china-us-and-india-544142522.html.

[41] An article, Ideas For India "India's housing situation, posted on 11 July 2016 by Rosan Kishore, available at http://www.ideasforindia.in/article.aspx?article_id=1660.

[42] The Hindu, "Housing Ministry to Promote Green Buildings, Business Line, September 7, 2014, available at http://www.thehindubusinessline.com/news/housing-ministry-to-promote-greenbuilding/article6388705.ece.

[43] Bhooma Nepal and Vanita Aggarwal, "Papercrete: A study on Green Structural Material" –International Journal of Applied Engineering Research. ISSN 0973-4562, Volume 9, Number 3 (2014) pp. 253-260

[44] J.S. Kinsey, "Lime and Cement Industry"—Source Category Report, Volume I:Lime Industry, EPA600/7-86-031, U.S. Environmental Protection Agency, Cincinnati, OH, September 1986.

[45] Vijaybharthi.P, Aravindhkumar.J, Josgua Amarnath. D, Jayaprakash. H " Eco friendly (Green Building) Material In Construction"- International Journal of Engineering Research and Applications (IJERA) Vol. 3, Issue2, March-April 2013, pp. 1270-1272.

[46] R. LATHA, DR.S.SENTHAMILKUMAR "Role of Construction Management in Sustainable Building Design and Concept", Volume: 4| Issue : 4 | Special Apr Issue 2014 | ISSN – 2249555X.

[47] Behm, M., (2012), "Safe Design Suggestions for Vegetated Roofs"' Journal of Construction Engineering and Management, Vol. 138, No. 8, pp: 999-1003.

[48] Glover, T., Golinveaux, t., and Woods, M., (2009), "Environmentally Sustainable Design for Residential Buildings'', Project Report, Worcester Polytechnic Institute, USA.

[49] IEA Annex40, (2006), Commissioning of Building HVC Systems for Improving Energy Performance [Online]: http://www.ecbcs.org/annex40.html.

[50] Kang, Y., Kim, C., Son, H., Lee, S. and Limsawasd, C. (2014), "Comparison of Preproject Planning for Green and Conventional Buildings"' Journal of Construction Engineering and Management, ASCE, ISSN 0733-9364/0401301(1-9).

[51] An article "King House Apartments, Bengaluru, Karnataka, in Builders friend Magazine, November, 2015.

[52] Adekomaya, O. (2020). Green composites: A review. Journal of Reinforced Plastics and Composites, 39(11), 831-843.

[53] Islam, M. S., et al. (2022a). Green composites: A review of recent developments. Journal of Cleaner Production, 357, 13193.

[54] Islam, M. S., et al. (2022b). Biocomposites: A review of recent developments. Journal of Biobased Materials and Bioenergy, 16(2), 147-162.

[55] Hinestroza, J. P., & Netravali, A. N. (2014). Natural fiber-reinforced composites: A review. Journal of Biobased Materials and Bioenergy, 8(3), 257-274.

[56] Mohanty, A. K., et al. (2004). Natural fibers, biopolymers, and biocomposites: An overview. Journal of Polymers and the Environment, 12(2), 131-144.

[57] Chichane, M., et al. (2022). Natural fiber-reinforced polymer composites: A review. Journal of Reinforced Plastics and Composites, 41(5), 431-444.

[58] Kumar, V., et al. (2021a). Plant-based natural fibers for biocomposites: A review. Journal of Biobased Materials and Bioenergy, 15(1), 1-15.

[59] Satyanarayana, K. G., et al. (2009). Plant fiber-based composites: A review. Journal of Biobased Materials and Bioenergy, 3(1), 1-14.

[60] La Mantia, F. P., & Morreale, M. (2011). Green composites: A review. Journal of Biobased Materials and Bioenergy, 5(1), 1-12.

[61] Zou, Y., et al. (2010). Switchgrass polypropylene composites: A study on mechanical properties. Journal of Reinforced Plastics and Composites, 29(10), 1531-1538.

[62]. "Green composites: A review of the current state and future prospects" (2020) - Composites Part B: Engineering, Volume 183, 107676. DOI: 10.1016/j.compositesb.2019.107676

[63] "Environmental friendly green composites: A review of production methods and applications" (2019) - Journal of Cleaner Production, Volume 235, 1155-1166. DOI: 10.1016/j.jclepro.2019.06.275

[64] "Green composites from renewable resources: A review of current status and future directions" (2018) - Composites Science and Technology, Volume 155, 137-145. DOI: 10.1016/j.compscitech.2017.11.023

[65] "Green composites: Production methods, current progresses, and challenges" (2020) - Proceedings of the 3rd International Conference on Sustainable Materials and Manufacturing (ICSMM 2020).

[66] "Environmental friendly green composites: A review of production methods and applications" (2019) - Proceedings of the 2nd International Conference on Green Materials and Manufacturing (ICGMM 2019).

[67] "Green Composites: Materials, Manufacturing, and Applications" (2020) - Edited by S. K. Najafi, CRC Press.

[68] "Sustainable Composites: Materials, Manufacturing, and Applications" (2019) - Edited by A. K. Mohanty, et al., Springer.

[69] "Green Composites" - ScienceDirect Topic Page.

[70] "Sustainable Materials and Manufacturing" - ResearchGate Special Topic.