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Review of the Utilization of Natural Fibers and Polylactic Acid for Composite Manufacturing

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Abstract-- *Composites made from polylactic acid (PLA) and natural fibers are sustainable, biodegradable materials derived from renewable sources. This review journal examines processing techniques, types of material testing, and the enhancement of the capabilities of natural fiber PLA composites to determine their potential applications as a substitute for conventional materials. From existing research journals discussing PLA and Natural Fiber-based composite materials with applications in various sectors, such as automotive, manufacturing, and healthcare, it is known that the commonly used processing techniques are hot pressing and vacuum bagging to produce homogeneous fiber distribution and strong matrix-fiber bonds. Material testing is performed using tensile tests, elastic modulus, and elongation to evaluate the mechanical properties of the composites. The results also show a 25-35% increase in mechanical performance compared to pure materials, with fiber surface modification that can improve interfacial adhesion. PLA and natural fiber composites provide a sustainable material solution with competitive mechanical performance. Further research is needed to develop eco-friendly fiber surface modification methods and scalable manufacturing techniques to expand industrial applications.*

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1. INTRODUCTION

Recently, the use of composite materials has grown rapidly, and research on composites has increased to develop materials with better mechanical properties [1], [2]. Starting from simple research on the effect of fiber length, concentration of empty oil palm fruit bunch fibers on the mechanical properties of composite materials [3][4], the impact of second phase morphology on mechanical properties [5][6], and the effect of coconut fiber weight fraction on the mechanical properties of composite materials [7][8]. Composites are currently used in various fields, including the automotive industry, manufacturing, aerospace, and health [9]. Their use in different industries is due to their high strength, light weight, and resistance to corrosion and wear [10][11]. However, the dominance of synthetic fiber-based composites, such as glass and carbon fibers, causes serious environmental problems, mainly because these materials are difficult to decompose in nature and have the potential to pollute soil and water, thereby negatively impacting health and ecosystems [12][11].

To overcome this, efforts to improve mechanical properties have also been carried out, including improving mechanical properties by changing the hardener fraction in epoxy resin composite materials [5], alkali treatment and coupling agent on palm oil fibers on the mechanical properties of composite materials [13], then continuing towards research on the degradation of composite materials due to UV rays [1][14] Also research on the effect of the percentage of palm oil fiber content on the Fatigue Life of Axial Loads of Resin Matrix Composites [3]. The large number of studies on the mechanical properties of composite materials is due to the increasingly widespread use of composites, which are replacing metal materials [1][5]. For example, composite polymer materials have almost replaced automotive components, ranging from interiors, dashboards, and steering wheels to bumpers and so on [15][1]. Also, SiC research [16] and the application of composites for automotive components in some of their critical parts [17][18][19], up to applied research.

Among the applied research on composites are research on composite materials for Pelton turbine blades[20][21], research on the application of composites for automotive components such as electric vehicle bodies[22], clutch linings[17], brake linings[18][19], or in the railway sector[23]. In addition, research on the use of composite materials for aircraft structural materials is ongoing, although this is not new and has been pursued for quite some time [24]. However, year to year, it is hoped that the mechanical properties of the materials produced will increase.

Natural fibers are increasingly used as reinforcements in composites due to several main advantages, including their abundant availability, good biodegradability, and competitive physical and mechanical properties for lightweight structural applications [25][11]. In addition, natural fibers are derived from renewable resources, require less energy for production, and can reduce CO2 emissions and the use of hazardous chemicals compared to synthetic fibers [25][11]. Examples of widely used natural fibers include coconut fiber, hemp, bamboo, and other agricultural waste [25][11].

Polylactic acid (PLA) is a biopolymer derived from renewable sources such as corn starch or sugarcane, and can decompose naturally in a relatively short time. PLA offers an attractive alternative as an eco-friendly composite matrix due to its biodegradable nature, low greenhouse gas emissions, and compatibility with various conventional plastic processing techniques [26][27]. The use of PLA as a matrix in natural fiber composites not only improves the mechanical properties of the material but also supports reducing fossil-based waste and accelerating the biodegradation of the final product [26][27].

The main objective of this review journal is to identify the optimal processing techniques, the types of material testing, and improvements in the capabilities of natural fiber PLA composites, and to assess their potential applications as substitutes for conventional materials. Where, in general, the benefits of using this combination include reducing conventional plastic waste, utilizing organic waste, and supporting a circular economy and green industry [27][11]. In addition, surface modification of natural fibers, such as alkalization or the use of Eco-Friendly additives, can increase tensile strength and interfacial adhesion between the fiber and the PLA matrix, thereby improving the overall composite properties [27].

The scope of this review article includes a discussion of PLA-natural fiber composite manufacturing techniques, such as hot pressing, vacuum bagging, and fiber chemical treatment. This review also summarizes research on the mechanical, thermal, and biodegradability characteristics of the composites, as well as the challenges and opportunities for future development. The limitations of this article lie in its focus on the use of natural fibers common in Indonesia and on manufacturing techniques that can be applied in the laboratory to small-scale industries [27].

1.1 Characteristics of Natural Fibers and Polylactic Acid

Natural fiber and polylactic acid (PLA) composites offer sustainable material solutions with mechanical properties that can be continuously improved through various processing methods. Here's an in-depth analysis based on recent research:

1. Structure and Mechanical Properties of Natural Fibers

Natural fibers such as water hyacinth, coconut fiber, bagasse, bamboo, and banana stems generally consist of cellulose, hemicellulose, and lignin. The microfibril structure of natural fibers provides good tensile strength but is anisotropic and hydrophilic, making it easy to absorb water [28][29].
In general:

a) The tensile strength of natural fibers increases after chemical treatment.
b) The elastic modulus of sugarcane fiber reaches 1.07 GPa, the highest among other fibers [30].
c) The combination of fibers (e.g.: 10% sugar cane + 20% banana stem) produces an optimum tensile strength of 21 MPa [29].
d) The hydrophilic nature causes high water absorption, so surface modification is necessary for long-term application [29].

2. Improvement of Mechanical Properties of Natural Fibers

Improving the mechanical properties of natural fibers is done through:d

a) fiber-matrix adhesion by up to 40% and tensile strength and elastic modulus by 20-30% [29][31].
b) Silanization (APTES): Improves hydrolysis resistance and extends the service life of composites [32].
c) Fiber fraction optimization: The optimal composition is generally 30-35% fiber, if it is too high, the quality decreases because matrix penetration is impaired [28].

d) The use of manufacturing techniques, such as hot pressing and vacuum bagging, results in even fiber distribution and low porosity [23].

3. Structure and Mechanical Properties of Polylactic Acid (PLA)

PLA is a biodegradable polymer derived from lactic acid, with a linear chain structure and a crystallinity of 30-50%. PLA is known to have:

a) Tensile strength: 50-70 MPa.
b) Modulus of elasticity: 3-4 GPa.
c) Elongation at break: Low (2-6%), so it tends to be brittle [33].
d) Thermal performance: Stable up to 80°C, suitable for light automotive applications [23][32].

4. Improvement of PLA Mechanical Properties

Strategies for improving the mechanical properties of PLA include:

a) Addition of plasticizer (ATBC 10%): Reduces PLA brittleness by up to 30% and increases flexibility [33].
b) Modification with a chain extender (ESO): increases elongation by up to 15% and improves thermal resistance [32].
c) Reinforcement with natural fibers: Addition of 25-35% natural fibers increases the tensile strength and elastic modulus. For example, PLA-coconut fiber (40% fiber) reaches a tensile strength of 38.7 MPa and an elastic modulus of 3.2 GPa [31].
d) Manufacturing techniques, such as Hot pressing, vacuum bagging, and compression molding, can control fiber distribution, porosity, and composite quality [23][34].

Implementation of the optimal formulation (25-35% natural fiber + PLA modification) produces a composite with a tensile strength of 45 MPa and a production cost 40% lower than fiberglass[31]. Recent developments have shown the potential to reduce the weight of automotive components by up to 28% while maintaining adequate mechanical strength [28].

1.2 Natural Fibers in Composite Manufacturing

Natural fibers are widely used as reinforcing materials in the manufacture of eco-friendly composites. Common types of natural fibers used according to the material you upload include seed fibers such as cotton and kapok, stem fibers such as jute, flax, hemp, and kenaf, and leaf fibers such as sisal, abaca, and pineapple [35]. In addition, local fibers such as bagasse, coconut husk, and water hyacinth fibers also have great potential as composite reinforcing materials due to their abundant availability and high cellulose content [31][28][36].

The advantages of natural fibers over synthetic fibers include their renewable and biodegradable properties, which make them eco-friendly [35][28]. Natural fibers have low density, resulting in lightweight composites that are particularly advantageous for automotive and transportation applications [31]. In addition, the production cost of natural fibers is relatively low due to the abundance of raw materials and the simple extraction process [35]. Natural fibers are also harmless to health and non-abrasive, unlike some synthetic fibers such as glass or carbon fibers [35]. However, the disadvantage of natural fibers is their high hydrophilicity, which leads to water absorption and can reduce fiber-matrix interfacial adhesion and the composite's long-term durability [35][28]. In addition, the mechanical properties of natural fibers tend to vary depending on their source and growing conditions, and their resistance to temperature and the environment is lower than that of synthetic fibers [36][28].

Various studies have been conducted to utilize natural fibers in composite manufacturing. [28] discussed the potential of water hyacinth fiber as a composite reinforcement, although its mechanical properties still need to be improved through process optimization and fiber pretreatment. [31] showed that the addition of coconut fiber and bagasse in a PLA matrix significantly increased the tensile strength of the composite. [36] examined the effect of banana stem fiber volume fraction as a reinforcement in polymer composites with a resin matrix, showing an increase in mechanical properties.

1.3 Polylactic Acid (PLA) as a Composite Matrix

Polylactic Acid (PLA) is a biodegradable, bio-based polymer belonging to the aliphatic polyester group, derived from renewable sources such as corn, potatoes, and sugarcane [37]. PLA has a low density, relatively low production costs, and good plasticity and stiffness properties, making it a prime candidate as an eco-friendly composite matrix [37][28]. PLA is generally produced by fermenting starch or sugar-based biomass, followed by lactic acid polymerization via ring-opening polymerization to yield a high-molecular-weight polymer [37].

Mechanically, PLA has a tensile strength of 50-70 MPa and an elastic modulus of 3-4 GPa, but a low elongation at break of 2-6%, making it brittle without modification [28]. Thermally, PLA has a melting point of around 150-160°C and a glass transition (Tg) in the range of 60-65°C, which affects its thermal stability in composite applications [28]. PLA can also be degraded biologically through the hydrolysis of ester bonds in the polymer chain, producing lactic acid oligomers and monomers that can be metabolized by microorganisms under aerobic and anaerobic conditions. However, PLA biodegradation requires specific environmental conditions, such as high temperatures and the presence of particular organisms, for optimal degradation [37].

In its application as a composite matrix, PLA is often combined with natural fibers to improve mechanical properties while maintaining its biodegradability [31]. Studies show that adding natural fibers, such as coconut fiber and bagasse, to the PLA matrix can significantly increase the tensile strength and elastic modulus of the composite [31]. In addition, PLA is modified with plasticizers and chain extenders to overcome brittleness and increase its flexibility [28]. PLA can be processed using various standard manufacturing techniques, such as injection molding, hot pressing, and film extrusion, which facilitate its application across automotive, packaging, and medical fields [28].

1.4 Interaction and Reinforcement Mechanism of Natural Fiber–PLA Composites

The interaction and strengthening mechanism of natural fiber–PLA composites are highly dependent on the quality of the interfacial bond between the natural fiber and the PLA matrix. Chemically, hydrophilic natural fibers have hydroxyl groups (-OH) that can interact with the ester groups in PLA, but the difference in the hydrophilic properties of the fiber and the hydrophobic properties of PLA causes weak interfacial adhesion, thus affecting the mechanical properties of the composite [38]. Therefore, improving the fiber-matrix compatibility and adhesion is the primary focus in the development of this composite.

These adhesion enhancement techniques generally involve chemical or physical treatment of the fiber surface. One method frequently used is alkalization with a 5% (w/v) NaOH solution for several hours, which removes dirt, lignin, and hemicellulose from the fiber, thereby increasing surface roughness and reducing the fiber's hydrophilic properties [39][38]. In addition to alkalization, surface modification with citric acid, an eco-friendly material, has been studied to improve fiber-PLA interfacial interaction through a crosslinking effect that strengthens adhesion [38]. Physical techniques such as the use of coupling agents and plasma treatment can also enhance interfacial wettability and adhesion.

Research on the mechanical and thermal properties of composites based on natural fibers and PLA shows significant performance improvements after fiber surface treatment and fiber fraction optimization. For example, research with arenga pinnata fiber combined with PLA shows an increase in tensile strength from 50.5 MPa in pure PLA to 66 MPa in composites with 20% fiber volume fraction, as well as an increase in elastic modulus from 183.2 MPa to 330.4 MPa [40]. Another study using ramie fiber and PLA shows that fiber surface modification via alkalization and citric acid can increase the composite's mechanical strength by reducing fiber hydrophilicity and strengthening the interfacial bond [38]. Thermally, natural fiber-PLA composites maintain the thermal stability of PLA with a slight decrease in degradation temperature due to the presence of natural fibers [38].

Overall, good interfacial interaction between natural fibers and PLA is crucial for obtaining composites with optimal mechanical and thermal properties. Chemical and physical fiber surface treatments have been shown to effectively improve fiber-matrix compatibility and adhesion, thereby enhancing the tensile strength, elastic modulus, and thermal resistance of natural fiber-PLA-based composites.

1.5 Composite Processing Techniques

A. Some general composite manufacturing techniques

Composite processing techniques are an essential factor that determines the final properties of composite materials, including natural fiber and PLA-based composites. In general, several composite manufacturing techniques are widely used in industry and research. One of the simplest techniques is hand lay-up, where natural fibers are manually arranged on a mold, then soaked in resin, then flattened and compacted with a roller or brush. This method is easy to use and suitable for small-scale production, but it is less precise in thickness control and surface quality. Another similar technique is spray lay-up, in which resin and fibers are simultaneously sprayed onto the mold surface, making the process faster and suitable for more complex shapes [41].

To produce composites with better density and mechanical properties, compression molding is used, consisting of hot and cold compression. In hot compression, the fiber-resin mixture is compressed at a high temperature, for example, 140–150°C, so that the resin hardens quickly and produces a dense, strong composite. Meanwhile, in cold compression, the pressing process is carried out at room temperature, usually for resins that can harden without heat [41], [42]

In addition, there are Resin Transfer Molding (RTM) and Vacuum Assisted Resin Transfer Molding (VARTM) techniques, in which the resin is injected into a closed mold containing dry fibers. In VARTM, the process is assisted by vacuum, allowing the resin to penetrate more uniformly into all fibers and reducing porosity, resulting in a composite with high strength and good homogeneity [41].

For cylindrical or tubular products, the filament winding technique involves winding resin-soaked fibers onto a mandrel according to a specific pattern. Pultrusion, on the other hand, is a continuous production technique in which fibers are pulled through a heated resin and a mold to form a composite profile with a constant shape, such as a rod or plate [41].

As technology advances, composite 3D printing is increasingly used to produce PLA-based components reinforced with natural fibers. This technology enables the creation of highly complex, highly customized shapes with mechanical properties that can be adjusted as needed [41].

Research on the mechanical and thermal properties of natural fiber-PLA-based composites shows that processing techniques significantly influence the final results. For example, in research [42], PLA composites with the addition of cellulose fibers from empty oil palm fruit bunches (OPEFB) processed by hot press at a temperature of 150°C showed that the addition of cellulose fibers up to 15 PHR increased the elastic modulus of the composite from 3.26 GPa (pure PLA) to 3.96 GPa. However, excessive fiber addition (>15 PHR) reduced tensile strength and elongation due to fiber agglomeration and poor interfacial adhesion. From a thermal perspective, an optimal heating process in a hot press can help the dispersion of fibers and resins. Still, the difference in decomposition temperature between PLA and cellulose fibers can reduce the composite's homogeneity and thermal stability [42]. Overall, selecting the appropriate processing technique and controlling process parameters such as temperature, pressure, and time are essential to obtain natural fiber-PLA composites with optimal mechanical and thermal properties. Innovations in processing techniques, such as VARTM and 3D printing, are increasingly opening up opportunities for eco-friendly composite applications across various fields.

B. Manufacturing of composites based on natural fibers and PLA

Table 1.1 List of Previous Research Journals

No	Research Title	DOE / Target Application	Manufacturing Process	Composite Characterization	Engineering Analysis	Environmental impact
1	Optimization of Mechanical Properties of PLA Biocomposites with Arenga Pinnata Fiber [40]	Replacing Conventional Polymer Composite Materials in the Packaging and Automotive Industries with Eco-Friendly and Naturally	1. Arenga pinnata fiber is Cut, Milled, and sifted to a Size of 40 Mesh. 2. The fiber is mixed with PLA (Polylactic Acid) dissolved in dichloromethane (DCM),	- PLA Composite + Arenga Pinnata Fiber (Volume Fraction 10%, 20%, 30%). - Tensile Strength Increased From 50.5 Mpa (Pure PLA) To 56.5	Tensile Strength Increased by 30.7% (From 50.5 to 66 MPa) at 20% Fiber. - Modulus of Elasticity Increased by 80.3% (From 183.2 to 330.4	Biodegradable, made from PLA and natural fibers, can reduce conventional plastic waste and is sourced from renewable agricultural waste, with the potential to reduce CO^2 emissions if used in

		Degradable Materials.	then dried for 5 hours. 3. The mixture is printed using a hydraulic hot pressing machine at a temperature of 200°C and a pressure of 10 tons. Printing Technique, Hot Pressing (ASTM D 1708).	Mpa (10% Fiber) And 66 Mpa (20% Fiber). - Elastic Modulus (Young's Modulus) Increased From 183.2 Mpa (Pure PLA) To 268.8 Mpa (10% Fiber) And 330.4 Mpa (20% Fiber). - At 30% Fiber, Mechanical Properties Decreased Due to the Formation of Voids.	Mpa) at 20% Fiber. - Adding Fiber Up to 20% Significantly Increases Mechanical Ability. - Addition More Than 20% Causes a Decrease Due to Void.	packaging or the automotive industry [43].
2	UTILIZATIO N OF NATURAL FIBER (COCONUT CORN) AS AN ALTERNATI VE COMPOSIT E MATERIAL FOR MOTORCY CLE FRONT FENDER [43]	Automotive , Motorcycle Front Fender	Hot Pressing, Controlled Temperature Mixing, ASTM D638 Molding	Tensile Test: Optimal Strength & Elasticity at 35% Fiber, ANOVA: Significant Composition	Optimal composition : 35% increases strength and elasticity, while too much fiber reduces quality. An economical composite for interiors.	Coconut coir waste is characterized by strength and durability, making it potentially valuable for military applications that require lightweight yet strong materials.

3	Effect of the Addition of Banana Leaf Fiber Against Tensile Strength of Polyester Matrix Sugarcane Fiber Composites [29]	No Application Focus	Hot Pressing, Vacuum Bagging	Tensile Test: Optimum Tensile Strength 21 Mpa (10% Sugarcane + 20% Banana), SEM: Even Fiber Distribution, Minimal Voids	Optimal Combination: 10% Sugarcane + 20% Banana, Tensile Strength 21 MPa. Good Fiber Distribution, Minimal Voids.	Agricultural waste (sugarcane, banana) is utilized, reduces waste burning, has partial biodegradability potential, and is eco-friendly for structural applications.
4	Analysis of Composite Materials with Natural Fiber Reinforcement and Plastic Waste Using a Bar Deflection Tester [30]	Application: Light Automotive	Hot Pressing, Fiber-Resin Mixing	Tensile Test & Modulus of Elasticity: Sugarcane Fiber, Highest Modulus (1.07 GPa), Dimensional Variation Affects Mechanical Properties	Sugarcane Fiber, Highest Modulus (1.07 GPa). Dimensional Variation Affects Mechanical Properties—potential for Lightweight Automotive.	Recycling plastic waste and natural fibers can reduce waste volume, be lightweight for automotive applications (energy efficiency), and provide a renewable fiber source.
5	TENSILE TEST AND IMPACT TEST ON STEM FIBER COMPOSITE BANANAS WITH THE EFFECT OF ADDITIONAL ALKALINE AND WITHOUT ADDITIONAL ALKALINE [44]	As an Alternative Material for Aircraft Components	Hand Lay-Up Technique With Stages, Alkalization Treatment of Banana Stem Fiber Using 5% and 10% NaOH for 2 Hours. Composition: 10% Fiber Volume Fraction, 90% Polyester Resin Unidirectional Fiber	10% Alkalization Best For Tensile Strength (+235%), 5% Alkalization Best For Impact Resistance (+60% Toughness). Testing: ASTM D638-1 (Tensile) and ASTM A370 (Impact)	NaOH Alkalization Significantly Improves the Mechanical Properties of Banana Stem Fiber Composites. 10% Alkalization Provides the Highest Tensile Strength Increase (235.5%), While 5% Alkalization is Optimal	Banana waste is utilized because it is lightweight, can be used as aircraft fuel, is biodegradable, and can undergo an alkali process with minimal chemical waste.

			Orientation with 1% Catalyst Added to Resin Glass Molds Measuring 22 X 17 X 0.4 Cm And 10 X 6 X 1 Cm, Leveling Using A Brush For Even Resin Distribution		for Impact Resistance (60.3% Increase in Toughness). There is a Trade-Off Between Tensile Strength and Impact Resistance, So the Selection of Alkalization Concentration Must Be Adjusted to the Needs of Specific Applications.	
6	Review: Green Composite Manufacturing Techniques and Their Applications [23]	Automotive Application Case Study (Door Panel, Dashboard)	Vacuum Bagging, Compression Molding	Weight Test: 28% Weight Loss; High Temperature Deformation Test: Withstands Up to 80°C	28% Weight Reduction, Deformation Resistance Up to 80°C. Fuel Efficiency Increased, Eco-Friendly.	able to reduce weight by up to 28%, improve fuel efficiency (reduce emissions), produce a biodegradable green composite, and have a low-carbon lifecycle.
7	DEVELOPMENT OF NATURAL FIBER COMPOSITE MATERIALS FOR SUSTAINABLE INDUSTRIAL APPLICATIONS	Fiber Fraction Variation (20%), Application: Armored Vehicle Spall Liner	Hot Pressing	Tensile Test: Tensile Strength 21 Mpa, Armored Application	Tensile Strength 21 Mpa, Application on Armored Vehicles.	for applications in military clothing/sustainable industries, and potentially reducing dependence on fossil-based synthetic materials.

	[32]					
8	Mechanical Properties of Polylactic Acid (PLA) and Palm Oil Empty Fruit Bunch Cellulose Fiber-Based Composites [42]	For Food Packaging, Household Furnishings, and Consumer Products That Require Biodegradable and Sustainable Materials.	TKKS Cellulose Fibers Were Isolated Using Sodium Chloride Solution, Glacial Acetic Acid, and Potassium Hydroxide, Then Mixed With Amorphous PLA 4060D (600g) Dissolved In Acetone (700ml) With Stirring At 600 Rpm. The Mixture With Fiber Variation 0-20 PHR Was Stirred For 2 Hours, Dried For 12 Hours In A Fume Chamber, Cut, And Dried At 60°C For 24 Hours. The Mixing Process Was Carried Out With A Rheomix Rotary Mixer At 150°C, 60 Rpm For 10 Minutes, Followed By Molding With A Hot Press At 150°C	The addition of fiber to PLA decreases the tensile strength (40.20→30.09 MPa) but increases the optimal elasticity at 15 PHR (3.26→3.96 GPa, +21.5%). The strain decreases drastically (4.25→1.21 %), indicating the material becomes stiff but brittle. This trade-off arises from the incompatibility between PLA's hydrophobic properties and the hygroscopic cellulose fibers. The 15 PHR composition is optimal for biodegradable applications requiring high stiffness.	PLA-Fiber Composites Show Optimal Elasticity Improvement at 15 PHR (+21.47%), But With Significant Trade-Offs in the Form of Decreased Tensile Strength (-25.12% at 20 PHR) and Strain (-71.53% at 15 PHR). The Material Becomes Stiffer But Brittle. The 15 PHR Composition Provides the Best Performance for Biodegradable Applications That Require High Stiffness Without Requiring Flexibility.	This combination helps reduce household waste that heavily pollutes coastal and urban environments in Indonesia.

			Through The Stages Of Melting For 9 Minutes Without Pressure, Forming For 2 Minutes With A Pressure Of 1.5 Mpa, Stretching For 1 Minute, Re-Compressing For 2 Minutes With A Pressure Of 1.5 Mpa, And Cold Pressing For 10 Minutes.			
9	Review, Green Composite Manufacturing Techniques and Their Applications in Railways [45]	Development and Application of Green Composites Based on Natural Fibers and Biodegradable Resins for Railway Components, Including Bodies, Interiors, and Supporting Structures. Target: Improving Sustainability, Energy Efficiency, and Reducing Environmental Impacts in	Natural fibers and biodegradable resins are mixed, formed using molding techniques according to component requirements, then dried/heated (hot pressing) at 140°C and 10–50 MPa.	Green Composites Have Good Mechanical Properties, Such as Flexural Strength and Flexural Modulus That Increase with Molding Pressure. Natural Fibers Provide Good Heat and Sound Insulation, are Lightweight, and eco-friendly. Test Results Show Increased Flexural	The mechanical properties of green composites tend to increase with the use of natural fibers and biodegradable resins, especially at high molding pressures. Green composites can reduce weight, increase energy efficiency, and replace conventional materials in the railway	This research can meet the demand in the railway industry, especially for green materials, and reduce material costs by producing materials domestically.

		the Railway Industry.		Strength and Flexural Modulus at Higher Forming Pressures.	sector. Challenges: Production costs and quality standards still need to be optimized.	
10	Increasing the Strength of Mechanical Properties of Natural Fiber Composites Using Water Hyacinth Fiber (Literature Review) [28]	The Use of Water Hyacinth Fiber as a Reinforcing Material in Natural Fiber Composites Has Potential for Structural and Non-Structural Applications	Mechanical and Chemical Extraction, Pretreatment (Alkali, Silane), Fiber Blending with Polymer Matrix (Polypropylene, Polyester, LDPE) Using Mixing and Molding Process	Cellulose Content 29-61%, Hemicellulose 16-29%, Lignin 2.25-18%, Ash 9-11%; Density 0.7–1.22 G/Cm³; Diameter 50–819 Mm; Tensile Strength 105–313 Mpa; Elongation 2.5–14%	Tensile and Impact Strength Increases with Increasing Fiber Volume Fraction; Pretreatment Increases Bonding Strength and Mechanical Strength; Excess Fiber Addition Degrades Mechanical Properties Unless Fiber is Optimally Processed	has an impact on reducing the water hyacinth population, which in some areas is already considered a pest and could replace the main material in automotive structures.
11	Manufacturing of Biocomposite Electric Car Bumpers Reinforced with Random Fibers of Empty Palm Oil Fruit Bunches	Applications of Electric Car Bumper Components	Vacuum Bagging Technique Using TKKS Biocomposite Material and Polyester Resin	Average Tensile Strength 20.21 Mpa, Impact Energy 0.1653 J/Mm², Mechanical Properties That Indicate the Strength and	Bumper Structure Simulation Demonstrates Frontal and Side Impact Force Withstanding Capability with Adequate	It accelerates the development of electric car technology, as this material can be used for electric car bumpers [44].

	and Polyester Using the Vacuum Bagging Method [34]			Toughness of the Material	Safety Factor and Deformation Within Elastic Limits	
12	NATURAL FIBER AS AN ECO-FRIENDLY COMPOSITE MATERIAL [35]	Applications in the Automotive, Construction, and Textile Industries	Hand Lay Up Press Method With Variations in Volume Fraction and Fiber Length	Advantages: Tensile Strength, Flexibility, Sustainability, Lightweight, Biodegradability. Disadvantages: High Water Absorption, Poor Adhesion	Improvement of Mechanical Properties Such as Tensile Strength and Flexibility Through Variation of Volume Fraction and Fiber Length	The development of this type of material will continue to drive the use of many natural fibers and other natural materials in green composite applications, and its impact is vast, shaping our lives and our way of thinking.
13	Analysis of Composite Materials Based on Natural Fibers and Plastic Waste Using Rod Deflection Test [30]	Development of Eco-Friendly Composite Materials for Construction Materials and Lightweight Structures	Material Preparation, Printing, Drying, Testing, Data Analysis	- Highest Modulus of Elasticity in Plastic Fiber (9.57 GPa) - Lowest Modulus of Elasticity in Bamboo Fiber (0.78 GPa) - Flexural Strength and Elasticity Depend on the Type and Number of Fibers	Composites With Plastic Fibers Showed The Highest Elastic Performance, While Bamboo Fibers Showed The Best Strength And Flexural Resistance.	This material will require a lot of plastic waste that was initially difficult to recycle and will be reused until it acquires Eco-Friendly characteristics, thereby significantly reducing plastic waste [45].
14	Development of Natural Fiber Composites	Applications in the Automotive Industry	Chemical (NaOH) and Physical Treatment of	Increased Tensile Strength, Flexural	Significant Improvement in Tensile,	Coconut fiber, often considered waste, will be

	from Coconut Fiber Waste for Sustainable Industrial Applications [11]	(Interior Panels, Dashboards), Construction (Wall Panels, Thermal Insulation), and Other Eco-Friendly Products	Coconut Fiber, Mixing with Polymer Matrix, and Composite Manufacturing Process	Strength, Impact Strength, and Thermal Stability After Chemical Treatment; Increased Fiber-Matrix Adhesion	Flexural, and Impact Strength; Composites Show Great Potential as Eco-Friendly Alternative Materials [3, 4, 6]	transformed into a valuable commodity. Of course, this will affect the economy of coconut farmers and the country's economy [46].
15	Polylactid Acid (PLA) Biocomposite Reinforced with Coir (Coconut Fiber): Evaluation of Mechanical Performance and Multifunctional Properties [31]	Coconut Fiber and PLA Blending Technique Through Mixing and Molding Process (Not Specifically Mentioned)	- Addition of Coconut Fiber Fraction Up to 50% - Tensile and Bending Strength Testing - SEM Morphology Test	- Ultimate Tensile Strength: 56.55 Mpa (Pacb Sample) - Lowest Tensile Strength: 27.09 Mpa (Pace Sample) - Ultimate Bending Strength: 105.61 Mpa (Pure PLA), 100.76 Mpa (Pacb) - Different Elongation at Break Behavior From Other Natural Fibers - There are voids, fibers that experience pull-out, and fiber breaks	- Fiber Addition Increases Tensile and Bending Strength by Up to 20% - Strength Decreases As Fiber Fraction Increases To 50% - Alkali Treatment Increases Cellulose Content, Making Fibers More Flexible and Elastic - Tensile Strength Values Increase Significantly in Certain Composites (E.g., Pacb)	This type of material, with its mechanical properties, can be applied to microcomponents and used in many applications, making them eco-friendly [47].

1.6 Applications, Future Prospects, and Challenges

A. PLA Matrix Composite Applications

Composites based on a Polylactic Acid (PLA) matrix and natural fibers have vast application potential across various industries due to their lightweight, eco-friendly properties, and adequate mechanical strength. In the automotive industry, natural fiber-PLA composites are increasingly used to produce lightweight vehicle interior panels, reducing vehicle weight by 20-30 percent and thereby increasing fuel efficiency and reducing carbon emissions [33]. For example, the development of Ramie Fiber Reinforced-PLA (RFR-PLA) material by the University of Indonesia has been applied to automotive interior bodies and structures, and it has potential for use in fishing boats and household appliances. This material offers the advantages of being more affordable, lightweight, and lower-emitting than synthetic fiber-based materials [48].

In the packaging industry, PLA and natural fiber-based composites offer a biodegradable, eco-friendly alternative to conventional plastics. PLA derived from renewable sources, such as starch or sugar, combined with natural fibers, produces packaging materials with fairly good mechanical properties and faster environmental degradation [33]. This is very relevant to reducing plastic waste that is difficult to decompose and supports the principle of a circular economy in the packaging industry.

In the construction sector, natural fiber-PLA composites are used as alternative materials for wall panels, particleboard, and lightweight insulation materials, offering good thermal and sound insulation properties. The use of these composites also supports sustainable development by reducing the use of petroleum-based materials and lowering the carbon footprint of buildings[33]. Furthermore, the biodegradability of PLA enables easier processing and recycling of composite-based construction waste.

Overall, the application of natural fiber and PLA-based composites in the automotive, packaging, and construction industries holds significant potential to support green technology and sustainability. These materials are continually being developed to improve their mechanical, thermal, and durability properties, meeting stringent industry standards while remaining environmentally friendly.

B. Challenges of developing PLA matrix composite materials

The development of composites based on natural fibers and a Polylactic Acid (PLA) matrix has promising prospects for supporting the sustainability of the manufacturing industry. However, several significant challenges must be overcome for this material to compete with synthetic-based composites. One of the main challenges is the limited mechanical properties of natural fiber-PLA-based composites when compared to synthetic fiber-based composites, such as glass or carbon fibers. This is caused by the nature of natural fibers, which tend to have lower strength and elastic modulus, and by their hydrophilic properties, which lead to less-than-optimal interfacial adhesion with the PLA matrix [32].

In addition, the production costs of PLA-based composites are relatively higher than those of conventional petroleum-based plastics, which is an obstacle to widespread industrial application. These costs include the still-expensive PLA raw materials, as well as the extraction and treatment processes for natural fibers, which require specialized technology to improve fiber-matrix compatibility [49].

The next challenge is the need for further research to improve the compatibility between natural fibers and PLA. Due to differences in the hydrophilic properties of natural fibers and the hydrophobic properties of PLA, interfacial bonds are often weak, so fiber surface treatments, such as alkalization, acetylation, or the use of coupling agents, such as silane and maleic anhydride, are needed to improve adhesion and reduce water absorption [50]. In addition, hybridization methods combining natural fibers with synthetic fibers or nanoparticles can improve the mechanical properties and durability of composites [32]. The development of composites based on natural fibers and PLA faces significant challenges in terms of mechanical properties, production costs, and interfacial compatibility. However, with continued innovation in fiber treatment, matrix formulation, and manufacturing technology, this material has the potential to become a competitive, eco-friendly solution for various industrial applications.

2. Conclusion

Composites made from PLA and natural fibers have proven to be an up-and-coming sustainable material solution. Key findings indicate that the use of natural fibers, such as coconut fiber, bagasse, bamboo, and banana stems, as reinforcements in the PLA matrix can significantly improve the composite's mechanical properties, including tensile strength and elastic modulus. This performance improvement can be achieved through fiber surface treatments such as alkalization or silanization, the use of an optimal fiber fraction of 25–35% on average, and with appropriate manufacturing techniques such as hot pressing and vacuum bagging. Evaluation of mechanical properties is carried out through tensile testing, determination of elastic modulus, and elongation. At the same time, modification of PLA with plasticizers and chain extenders effectively increases flexibility and thermal resistance. The use of this composite has a strategic impact on sustainable industries by reducing dependence on fossil fuels, utilizing Indonesian organic waste, and producing lightweight, economical, and biodegradable materials for automotive, construction, packaging, and medical device applications. This supports the transition towards a circular economy and green industry. Further research needs to focus on eco-friendly surface treatment innovations, the development of scalable manufacturing techniques, the exploration of local natural fibers, and studies on long-term durability and biodegradation. Academic-industry-government collaboration is crucial to accelerate the adoption of PLA and Natural Fiber composite technology at the national and international levels.

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