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A Review on Natural Fibre Reinforcement on Composite Material

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Abstract: The production of eco-friendly and biodegradable fibre-reinforced composite materials has become the subject of extensive research with a view to managing the growing environmental concerns worldwide. In light of this, this review aims to raise awareness regarding the utilization of natural fibres in composite materials, which have been shown to reduce greenhouse gas emissions and carbon footprint significantly. However, despite the numerous benefits of natural fibres, several challenges must be addressed, such as poor compatibility, undesirable interfacial adhesion between natural fibres and matrix, low impact strength, and poor fire resistance. This article briefly assesses the need to meet the demand for eco-friendly materials through prominent modification and processing methods and investigates their properties and applications. Additionally, this article also analyzes the impact of hybridization through a comprehensive comparative analysis. The purpose of this article is to provide a better understanding of the role of natural fibres in reinforcing composites and to emphasize the importance of finding innovative solutions to overcome the challenges associated with their use. In conclusion, this review highlights the potential benefits of using natural fibres in composite materials and emphasizes the need for further research to address the challenges associated with their utilization. This would ultimately lead to the development of sustainable materials that contribute significantly towards reducing the environmental impact of manufacturing processes.

Keywords: Fibre Reinforcement Composites, Natural Fibers, Eco-Friendly Measures, Polymer Composite

1. Introduction

Fibre reinforced polymer composites have been observed to be reaching significant advancement in recent decades to meet the increasing demand for engineering applications. The environmental awareness in directing the eco-beneficial sustainability has urged greater potential in replacing synthetic fibre reinforced polymer composite material to environmentally friendly natural fibres as filler and reinforcement materials associated with a greater focus on hassle free utilization and renewable natural raw materials in the product design [1]. Accordingly, one of the prominent ways in reducing the usage of synthetic fibres for reinforcing purpose needs intensive research on the field of NFRPC to synthesize highly valuable materials. Some of the natural fibres like sisal, jute, hemp, kenaf, flax etc. are under usage as RM (reinforcing material) in recent polymer-based matrices. From the literature it was observed that the emphasis of government on novel environmental regulations to encounter the growing social, ecological and economic awareness and the increasing cost of petroleum resources could be improved with the optimal utilization of natural resources [2]. These NF (Natural Fibres) has a significant role in the reducing the waste disposal issues and thus environmental pollution. The implementation of NFRPC has tremendous advantages like renewability, bio-degradability, low cost, non-hazardous, non-corrosive and manufacturing issues, and flexibility over conventional methods and synthetic fibre composites.

The impact of consumerism on usage of natural fibres is obtaining more attention to enhance the environment with reference to rules and regulations of international and national organisation. The sustainable natural composites could be developed from green fibres like nano cellulose and lignin based carbon fibre particles [3]. These particles are less dense and lighter than the mineral fibres that results in Eco pleasant characteristics which is highly important to aerospace and automotive sectors for decreasing the vehicle weight. Furthermore, natural fibres were highly simple to handle and are non-toxic to human beings. The lignin based cellulose fibres could be effectively developed from annual plants, wood, agroforestry waste, annual plants or industrial by-products like paper or textile production [4]. When the natural hydrophilic fibres are integrated with the hydrophobic matrices, there occurs the formation of weak interphase to compromise the potential mechanical qualities of the composites. Hence this is found be to be an important research aspect to normalize the utilization of natural fibres with significant progress than the mineral fibres. Consequently, multiple solutions has to be activated to develop interphases and to ensure satisfactory combination of the materials. When compared with manmade reinforcements, the natural fibres possess greater range of essential characteristics. Further the plant fibres enables biodegradability and maintains healthy ecology with good performance and low cost [5].

Since we travel in the direction of circular practices, it is significant to possess thorough analysis on the benefits of recycling and reprocessing the natural fibre particles for future applications [6].

The issues needed to be handled with appropriate knowledge. The figure 1 represents the complexities faced in implementing the production of environmentally friendly reinforcement products. The findings of the present review will act as a handy tool in creating novel aspects for functional applications.

1.1 Impacts of Natural Fibre Chemical Treatment

The impact of chemical treatment on the natural fibre has several applications and are processed to decrease the hydrophilic nature of the NF and to increase the fibre strength that leads to the adhesion enhancement between the matrix and fibre. The hydrophilicity of the natural fibre decreases the reinforcement and hence there is an increase in the matrix bond. The following table 1 represents the kinds of chemical treatments in improving the characteristics of NF.

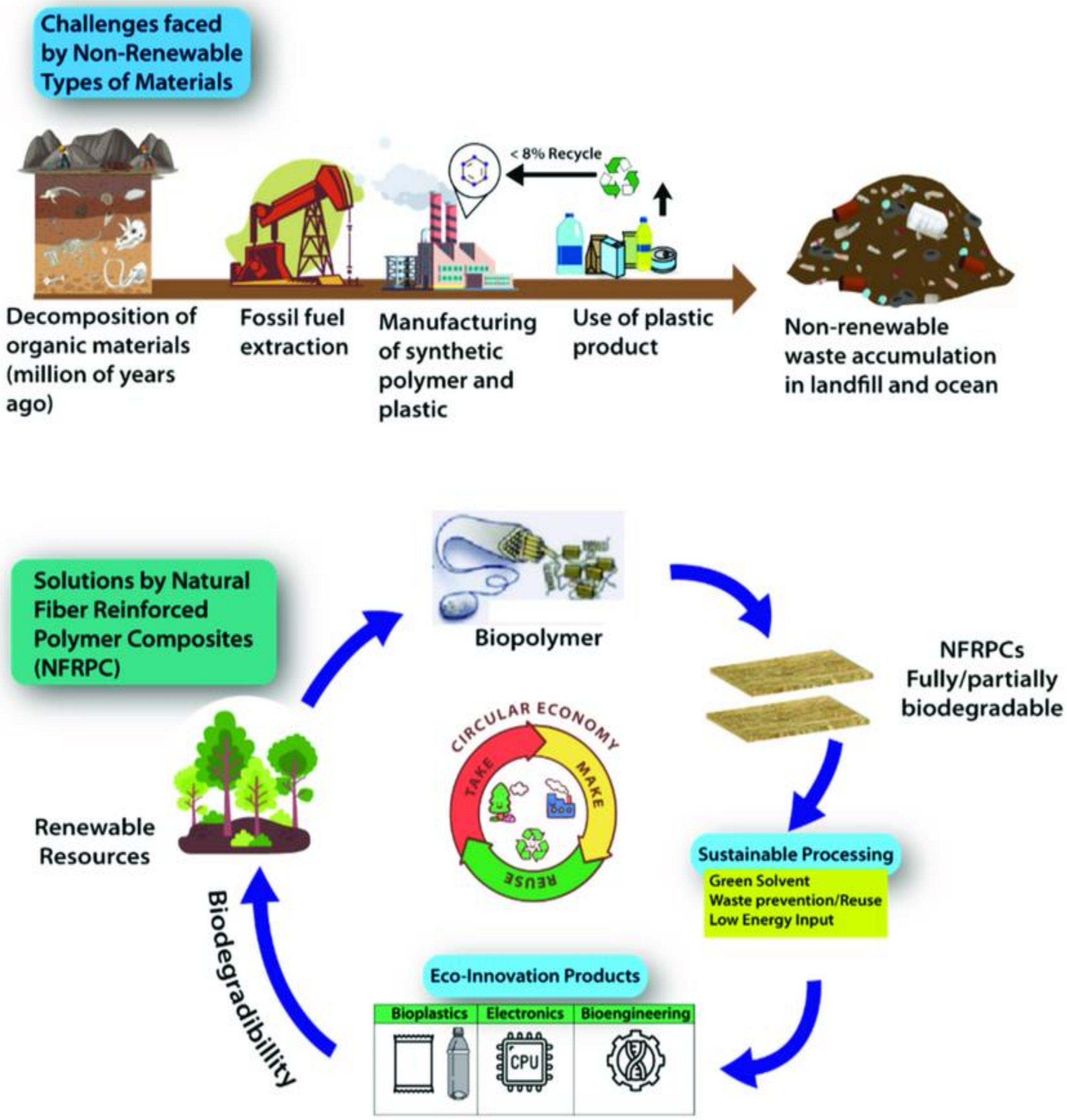

Figure 1. Complexities faced in implementing the production of environmentally friendly reinforcement products [7]

Table 1. Influences of Natural Fibres Chemical Treatment [8]

Chemical Treatment	Fibre	Chemical Reagent Utilized	Method	Application
Maleated Coupling Group	Jute Fibre	Maleic anhydride polypropylene	Fibres are soaked in MAPP in the temperature of 100^{O}C	Greater Mechanical properties
Alkaline	Hemp Jute Sisal Kapok	NaOH	Fibres are treated with NaOH solutions with the temperature of 20 ^{0}C for 48 hours and it will wash by pure distilled water.	Polymer Reinforcement
Saline	Sugar Palm	Saline	Sugar palm fibre composite was soaked with 2% of saline for 3 hours.	Industrial Application
Benzoylation	Sisal Fibre	Benzoyl chloride	---	Industrial Application
Isocyanate Treatment	Pineapple leaf fibre	Toluene solution having poly(phenyl) isocyanate	Fibres were immersed with toluene solutions having PMPPIC for half an hour at the temperature of 50^{0}C	Structural and non-structural application
Acetylation	Banana	Acetyl anhydride	The fibres were dipped with 2-6% of acetyl anhydride at room temperature with 3 hours of duration	Engineering Materials applications
Alkaline hydrogen peroxide	Citrus fibre	Hydrogen peroxide	The fibre was soaked with hydrogen peroxide for 4 hours at 60^{0}C with the duration of 4 hours	Food industry application
Treatment of peroxide	Sisal Fibres	Benzoyl peroxide from acetone	Fibres are slathered with benzoyl peroxide extracts from acetone after the pre-treatment of alkali.	Substitute the wood

2. Effects of Hybridization in Natural Fibre Reinforcement (Nfr)

Hybridization of reinforcements in to natural composite enhances the overall properties of the finished product. When comparing the behaviours of natural/synthetic and completely natural hybrids, there is significant improvement in both the hybridization process. Hence the present study supports the hybridization process as vital factor in developing polymeric composites. The review revealed that the incorporation of natural fibre and inorganics nanoparticles enhanced the tribological and mechanical properties [9]. Further it improves the flame retardancey, thermal stability of the product. Additionally, the hybridization also decreased the water absorption capacity of the bio composite material. The existing research confirmed that the hybridized composite materials gain superior properties with maximum shrinkage resistance with higher superiority. The current review provides insights on the several problems on the development, and mechanical characterization of hybridized natural fibre reinforcement.

The study on the behaviour of glass and sisal reinforcement depicted that the longitudinal and tensile strength of the composites comprising 20% sisal 80% glass has high effectiveness. Meanwhile the investigation on the hybridization of curaua fibres with glass also found to be more specific. It is also observed the glass fibre / natural fibre hybridization improves the tensile strength with more compatibility. Further it is also recommended that the impact resistance needs to be improves within the mid-layer. A comparative analysis has been performed in another study with different combinations to bear the maximum load. These studies suggested that NFR with appropriate hybridization improves the overall effectiveness of the product.

3. Properties of Natural Fibre Reinforcement

3.1 Tensile strength of NFR

It is commonly known that composites reinforced with natural fibres have mechanical qualities comparable to those of composites reinforced with synthetic fibres. Indeed, fibres with remarkable mechanical qualities, such flax, hemp, jute, and sisal, can rival glass fibres in terms of modulus and strength. These claims likewise hold true for various varieties of natural fibres. Henequen fibre, for instance, has been shown by researchers to have excellent mechanical qualities and is a good fit for thermoplastic resin reinforcement [10]. Furthermore, research has demonstrated that when the fibre volume fraction rises, they display better tensile strength and modulus [11]. It is revealed that compared to the matrix components, the mixed materials exhibited a lower strength and a higher elastic modulus.

A different study [12] examined the tensile characteristics of plastic composites manufactured from waste wood fibre and discovered that the strength of the composites was independent of the amount of fibre. In a similar vein, a study on the mechanical behaviour of polypropylene composites reinforced with kenaf revealed that raising the fibre weight percentage changed the composites' maximum tensile stress and tensile modulus.

3.2 Flexural Strength of NFR

When analysing the composite materials on their determination of structural applications, the consideration of flexural strength is more crucial. These characteristics are significant for ascertaining correlation of natural fibre characteristics. These characteristics lead to considerable improvement in the flexural, tensile and impact strengths. The findings of the study [13] described that alkalised and long fibres possess high flexural strength and modulus. Accordingly, it is also observed that decreased fracture work has been associated with high flexural strength and modulus. In a study performed by [14], it was observed that flexural modulus and strength are the consequences of strong bonding between epoxy matrix and alkali.

3.3 Impact Strength of NFR

Under the author's direction, scientists developed composite materials with increased impact strength by combining sawdust, wood fibre, and polystyrene. The impact strength of the composites was significantly increased, according to the results, when a silicate and an isocyanate component were added to the fibre coating. The study also sought to investigate the effects of length of fibre as well as content on the effect on strength of polyester and short banana fibre-reinforced composites [6]. The results showed that a 40 mm fibre length produced the best impact strength, while adding 40% untreated fibres resulted in a 34% increase. In addition, the influence on strength of green composites containing different proportions of pineapple fibre was tested by the author and contrasted with composites composed of virgin resin [15]. The results showed that a 34% improvement in impact strength was obtained by adding 40% untreated pineapple fibre. These outcomes demonstrate the composites' potential in industrial settings where great impact resistance is essential. Comparably, another study that used both unprocessed and alkali-treated fibres to examine the impact behavior of 35% jute/vinyl-ester composites discovered that the alkali treatment increased crystallinity, eliminated hemicellulose, and improved fibre dispersion [15]. Numerous investigations have been carried out to investigate the impact properties of several fibre-reinforced composite materials which is shown in Table 2. Notably, the impact strength of several composites was significantly increased upon the incorporation of sodium lauryl sulfate (SLS) [16].

As mentioned earlier, the graph (Figure 2) delineates the flexural and tensile strength of diverse types of fibres, as listed in the above table 2. The chart provides a visual representation of the performance of each fibre with respect to its mechanical strength, thereby facilitating a better understanding of its strength properties.

Table 2. Mechanical Properties of NFR composites

Reinforcement	Matrix	Composition (Wt %)	Impact (J/m)	Flexural (MPa)	Tensile (MPa)	References
Banana Fibre and Glass Fibre	Phenol Formaldehyde	0-45	30-40 40	50 73	28 42	[17]
Coconut particle	Epoxy	5-15	---	---	35.48	[18]
Kenaf bast fibre	Poly-Lactic acid	0-50	---	254	223	[19]
Kenaf bast fibre	Thermoplastic polyurethane	10-60	---	32-37	---	[14]
Kenaf derived Cellulose	Poly-Lactic acid	40-60	35.5	63.4-98.8	---	[20]
Kenaf-Bast Fibre	Epoxy Polypropylene	----	20-40	200-240	71.68	[21]
Coconut Spathe and coconut fibre	Polyester	5-15	---	25.6 -67.2	7.9 – 11.6	[22]

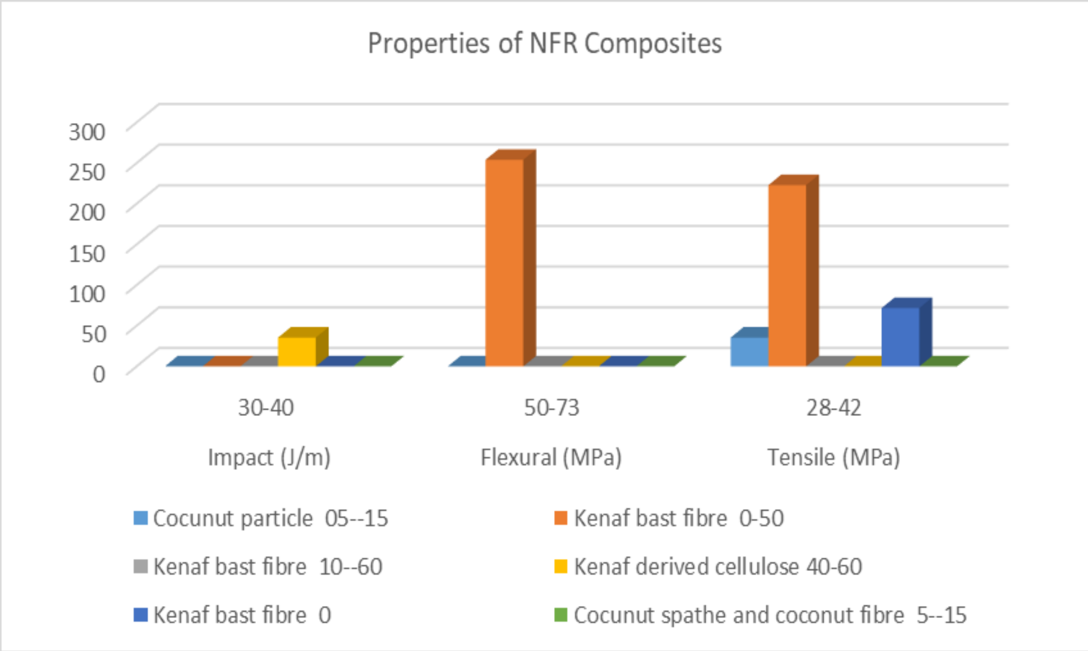

Figure 2. Mechanical Properties of NFR Composites

3.4 Low-velocity Impact Response of NFR

A lot of analytical and experimental research has been done on the low-velocity impact of fibre-reinforced polymers. Research on carbon fibre-reinforced epoxy composite laminates exposed to high impact pressures has been considerable, and glass fibre-reinforced polymeric composite materials are vulnerable to low-velocity impact damage [23]. Further investigation is necessary to fully understand the impact behaviour of composites made of natural fibres.

The consequences of the reaction of hemp-reinforced unsaturated polyester composite samples is the main topic of this investigation. Impact experiments were carried out with different fibre volume fractions in order to examine how reinforcing affected impact characteristics. Using the low-velocity instrumented falling weight impact test method, the impact performance was assessed in terms of load-bearing capacities, energy absorption, and failure modes. The load deformation, load-time, absorbed energy-time, and velocity-time behaviour were all determined [24].

3.5 Hardness Strength of NFR

The study found that, in comparison to the original polymer, a thermoplastic composite material reinforced with pulp fibres had a notable increase in stiffness and strength, with increases of 5.2 and 2.3 times, respectively. In comparison to composites composed of sisal, coir, and E-glass, the researchers discovered that those constructed of Kenaf-maleated polypropylene were more economical, had a higher specific modulus, and had a superior modulus/cost ratio [25]. These results imply that they might be a useful replacement for current materials. The study also looked at the hardness values of several laminates made from polyester hybrid composites reinforced with banana/E-glass textiles and with varied stacking sequences. With a hardness value of 26.72 HV, the investigation discovered that laminate L1, which is composed entirely of glass fibre composite, is the hardest. Conversely, laminate L2, which had a hardness rating of 12.36 HV, was the least hard since it was composed entirely of composites containing banana fibres. The outcomes showed that the toughness of the composites decreased as the number of banana cloth layers increased. In a different experiment, scientists used a polymer matrix and natural Borassus seed shoot fibre to create a novel composite. The researchers noticed that the hardness of the composites reduced as the fibre concentration increased, ranging from 0.116 to 0.305. The group also investigated the mechanical characteristics of composites based on hybrid phenol-formaldehyde reinforced with glass and oil palm fibres. They discovered that combining glass fibres with oil palm fibres led to an improvement in mechanical qualities like flexural strength, tensile strength, and tensile modulus. It did, however, lessen the toughness attribute. A recent study assessed the effects of several parameters on flax fibre-reinforced epoxy circular tubes, including inner diameter, length-to-diameter ratio, and tube thickness [26]. The findings suggest that the flax/epoxy composite tube's ability to absorb energy is mostly determined by the tube's geometry. Multiple plies and laminates of a particular length showed improved energy absorption capacity. Furthermore, using the nano-indentation technique, tests for hardness and elastic modulus were carried out on composites made of polypropylene reinforced with cellulose fibre.

3.6 Water Resistance of NFR

Water absorption studies aim to clarify the effects of moisture on the form, debonding, and strength loss of composite materials. According to the researchers' analysis, the moisture absorption of composites made with kenaf fibre that had been alkali-treated was 3.85% lower than that of composites made with untreated fibre, which absorbed 6.38%. The main cause of the discrepancy was identified as heat exposure's effect on the fibre composites' weight-loss behaviour. Moreover, the researchers noticed that the treated fibres' low hemicellulose content and tiny spaces made it difficult for the composites to retain moisture [27]. By weighing the samples of thermoplastic sugar palm starch/agar blend both before and after absorption, the researchers assessed how well the samples absorbed moisture. Interestingly, the study noted that adding glass fibre to composites reinforced with palmyra enhanced their mechanical qualities and increased their flexibility while reducing moisture absorption.

According to the author's research, sisal-polypropylene composites' strength and water resistance were increased by the addition of glass fibre. They also investigated how unsaturated polyester composites bonded with non-woven hemp fibre absorbed water. The author investigated how different layering sequences affected the result of hybridizing jute/kenaf/E-glass woven fabric composites on water absorption behaviour. The study investigated the effects of applying various chemical treatments and weave ratios of banana fibre to unsaturated polyester composites for reinforcement. The outcomes showed that the mechanical and water-absorption qualities were enhanced by the acrylic acid treatment technique.

The study also looked into how seawater aging affected the characteristics of bio-composites. The results demonstrated that compared to the dry samples, the mechanical impacts of the water-saturated samples were noticeably weaker. In the end, the study demonstrated that natural composites do badly in water. The figure 3 Representation the effect of water on fibre-matrix interface.

3.7 Chemical Resistance behaviour of NFR

An investigation of the chemical resistance of composites is essential to determine if they are suitable for use in chemical and storage tanks. A battery of tests, including subjecting the composite to a variety of acids, alkalis, and solvents, make up the chemical resistance examination. Chemical resistance of composites has been the subject of extensive investigation [29]. The current study examines the tensile characteristics and chemical resistance of natural fibres coated with an epoxy and unsaturated polyester (UP) combination. The findings show that natural fibres, coated or untreated, have outstanding chemical resistance. On the other hand, the blend-coated fibres show reduced water absorption, suggesting improved water resistance. The study also investigates the tensile characteristics and chemical resistance of epoxy composites reinforced with natural fibre. The results indicate that in order to achieve maximal tensile strength in the composites, a critical length of 30mm is necessary.

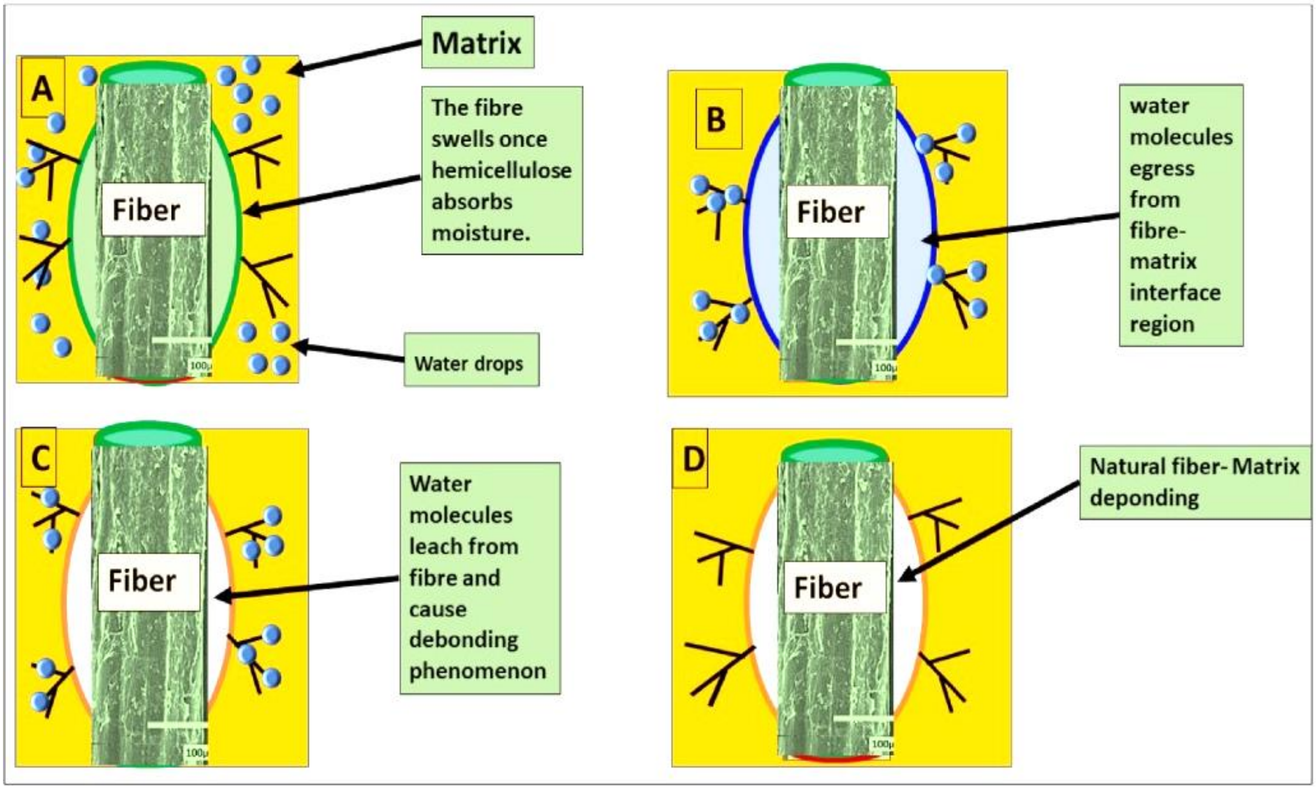

Figure 3. Representation of effect of water on fibre-matrix interface [28]

In summary, the study provides valuable insight into the tensile characteristics and chemical resistance of natural fibre-reinforced composites. These results may have a big impact on how composite materials are developed and used in storage and chemical tanks.

3.8 Bio-degradability characteristics of NFR

Biodegradability is a key feature of green composites that helps with their disposal when their useful lives are ended. Even though this feature makes them less durable, it's crucial to manage their biodegradability behaviour to strike the best possible balance between the longevity of the product and the influence on the environment. Numerous research works have examined the biodegradability of different biodegradable plastics, including PVA, PLA, and PHB [30]. In order to treat cancellous bone ruptures, self-reinforced PGA composite rods with adequate mechanical qualities were created for use in fracture treatment. PLA composites bonded with natural fibres were also created, however their biodegradability mechanism was not explained. It is important to remember that the biological degradation of the reinforcing fibre in biodegradable composite matrix materials has no effect on the composite's propensity to break down [31]. Therefore, while assessing the environmental effects of green composites, it is crucial to take the matrix material's biodegradability into account.

3.9 Vibration Damping Properties of NFR

Excessive vibrations in structural materials might result in fatigue cracks and undesired noise. It is imperative to concentrate on creating materials with better vibration-damping capabilities because of this. Green composites are an excellent choice since they have a higher vibration damping capacity than inorganic fibres because they use natural fibres as reinforcements [32]. Numerous parameters like fibre surface treatment, stress, length, and architecture influence these composites' damping properties. For example, flax fibres perform better than carbon fibres because of their increased capacity to absorb shock. Curiously, these composites' water content can also affect how damp they are, resulting in a drop in bending modulus as well as an increase in loss factor.

3.10 Tribological properties of NFR

As solid surfaces move, wear and friction develop, wasting energy and eroding the materials. At high temperatures, phenol formaldehyde composites containing varying amounts of sisal fibre were investigated. Increased wear rates and potential flaws as a result of inadequate fibre dispersion in the matrix were seen with higher fibre concentrations. One important indicator of how various materials behave when there is friction is their coefficient of friction (COF). This metric is extensively employed in diverse industries to evaluate material performance and make well-informed decisions during product design and manufacturing [33]. The friction value in wear testing is usually either a constant value that is reached at the end of the test, or it is a standard for the entire test. Wear can result from mechanical or chemical processes and is defined as the progressive loss of material from one or both contacting surfaces during sliding.In the present research, we looked at the worn textures of neat epoxy (NE) and kenaf fibre-reinforced epoxy (KFRE) blended under different operating conditions. According to our data, the main cause of debonding, which weakens the interfacial link between the fibres and the matrix, is excessive thermal stress. When larger loads are applied, the application of high side force propagates micro-cracks, which can lead to material failure and accelerate wear rate. It can be deduced that in extreme circumstances, like increased loads and velocities, micro cracks predominate as the wear process.

Recent studies have investigated the feasibility of utilizing rice straw and husk of rice dust in the manufacturing process of brake pads. The results show that these bio-waste composites greatly improve the tribological characteristics of the pads, indicating that brake pad formulations can benefit from using them. Furthermore, bio-wastes can lower the polymer composites' wear rate in comparison to plain epoxy [34]. The sugar cane fibre-reinforced composites exhibited a lower rate of wear than the glass fibre-reinforced composites, according to the data. Nonetheless, the glass fibre-reinforced composite demonstrated superior coefficient of friction, with the two types of composites attaining remarkably comparable values. The figure 4 Representation the Tribological properties of NFR.

3.11 Machining Characteristics of NFR

Because they are made to a near-net profile, Natural Fibre Reinforced Composites (NFRCs) require less machining. However, to give these materials their final shape and make it easier to create pieces in intricate assemblies, companies that work with them frequently use machining techniques like trimming and drilling. These machining operations consist of grinding, milling, turning, and drilling. The kind of fibre utilized and its mechanical characteristics have a significant impact on the dependability and quality of machined NFRC components [36]. A number of performance measures, including cutting force, cutting power, particular chopping force, tool wear, tool life, delamination, and roughness of the surface, are used to assess the machinability of non-ferrous ceramics (NFRCs). A number of process variables influence how well-machined the NFRCs' surfaces are. Therefore, in order to achieve the required quality and dependability of machined NFRC components, an in-depth knowledge of the material characteristics and machining settings is crucial.

Figure 4. Parameters affecting properties of NFRPCs [35]

4. Studies on Various Types of Natural Fibre Composites and Reinforcement

Natural fibre-reinforced polymer composites have become increasingly popular due to their high strength, low weight, and environmental sustainability. These composites are created by combining a polymer matrix with natural fibres that act as reinforcement. The selection of natural fibres is critical in determining the mechanical properties of the composite.

There are several types of natural fibres that might be utilized as reinforcement in polymer composites. Pineapple leaf fibre, Bamboo, Jowar, Banana, Jute, Hemp, Flax, and Sisal are some of the most commonly used fibres which is shown in figure 5. These natural fibres can be categorized into six different types based on their origin and properties. Reed fibres, such as wheat, corn, and rice, are obtained from the stems of cereal crops. Leaf fibres, including Abaca, Sisal, and Pineapple, are obtained from the leaves of plants. Bast fibres, such as Jute, Flax, Hemp, Ramie, and Kenaf, are obtained from the stem of the plant [13]. Seed fibres, such as Coir, Cotton, and Kapok, are obtained from the seeds of the plant. Core fibres, including Kenaf, Hemp, and Jute, are obtained from the plant's core. Other types of natural fibres, including wood and roots, are also used in the development of natural fibre-reinforced polymer composites. Jowar fibre, due to its unique properties, is an excellent candidate for use in producing lightweight materials for various sectors, including automobile body building, the housing industry, and the packaging industry. Its low density relative to other natural fibres makes it an ideal choice for these applications. In conclusion, the use of natural fibres in polymer composites offers a sustainable and eco-friendly solution that has a variety of applications across several sectors [37]. Through proper selection and combination of different natural fibres, researchers can develop composites that meet the specific needs of various industries.

5. Recent Advancement in the Natural Fibre Polymer Composites

Natural fibres have benefits and drawbacks and come from either plant or animal sources. Natural fibres are an eco-friendly choice for a variety of applications since they are lightweight, biodegradable, non-toxic, and release less CO2. However, the hydrophilic nature, low breakdown temperature, and limited heat stability of natural fibres limit their applicability in high-temperature settings.

Figure 5. Natural Fibre Composites [38]

Because of their special qualities, natural fibres are still widely used in a variety of industries, such as packaging, building, and automobiles, despite their drawbacks. The inherent flaws in natural fibres, however, may make it easier to incorporate them into composite materials. Natural fibres are less strong than glass fibres and are more prone to absorbing moisture, which can cause the material to deteriorate [39]. Therefore, it is necessary to carefully assess the usage of natural fibres in composites to ascertain their acceptability for certain applications. In order to fully realize the promise of natural fibres, current research is concentrated on improving their mechanical qualities, increasing their moisture resistance, and creating innovative processing methods for natural fibre composites. With the help of these programs, the drawbacks of using natural fibres will be addressed, and high-performing, environmentally friendly materials that can replace conventional composites in a variety of applications will be developed. The scientific community is clearing the path for a time when natural fibres will be an essential part of outstanding performance. Sustainable materials by tackling current issues.

Natural fibres derived from plants and animals offer a distinct set of benefits and drawbacks. On the one hand, they are simple to handle and transport because of their modest weight. They can also naturally degrade without harming the ecosystem because they are biodegradable. They are also non-toxic and release little CO_2, making them a sustainable choice for a range of uses in the environment. Natural fibres, however, have certain drawbacks. Since they are hydrophilic, they have a rapid rate of water absorption. They are also susceptible to high temperatures because to their weak heat stability. They are also inappropriate for usage in high-temperature situations due to their low breakdown temperature.

6. Optimization Using Integrated Artificial Intelligence Platform

Numerous scientific and engineering fields have been profoundly touched by artificial intelligence (AI). Machine learning is a subfield of artificial intelligence that uses statistical and probabilistic techniques to forecast potential outcomes by analyzing historical data. The purpose of this paper is to present an overview of several machine learning algorithms used in order to rank materials, forecast and optimize process parameters, and validate results. The design and optimization of fibre reinforcement in polymer composites has changed as a result of the application of machine learning algorithms, producing composite products with distinctive features.

This paper highlights the critical role that databases and machine learning algorithms play in each step of the process, from raw material selection to end-user application of fibre-reinforced polymer composites. It is impossible to exaggerate the importance of these technologies since they allow businesses to increase operational effectiveness and optimize their production processes. In particular, machine learning algorithms are made to learn from data and produce insights that might help in decision-making. Conversely, databases offer a location for data that can be accessed and utilized by all parties involved in the company [40]. Businesses can gain a competitive edge by improving product quality, cutting expenses, and raising customer happiness by utilizing these technologies. The study highlights that in order to guarantee accurate and dependable results, machine learning techniques and algorithms must be used appropriately. The application of machine learning techniques may have a special impact on the development and optimization of fibre-reinforced polymer composites. This study created a flexible process technique that covers raw material selection to the performance characteristics of the final output, all at the laboratory scale. The technique is controllable by the researcher and highlights the function of machine learning at various polymer composite production phases. The first step involves choosing the fibres, fillers, and matrices according to end-user applications, and an input dataset is used to record the composition of each. Machine learning algorithms can be applied to optimize these compositions. The choice of fabrication technique is made in the second stage, and each technique has its own controlling parameters, including pressure flow rate, flow media, temperature, fibre type, filler size, filler concentration, and other elements. ML algorithms can handle these parameters as input datasets [41]. By doing this, experiment time and expense can be reduced by using the best, most optimal parameters in composite production techniques. Following manufacture, the composites are then characterized for certain qualities. The established approach offers an efficient and effective way to save time and resources while generating optimal outcomes, and it can be used to a variety of situations.

7. Comparative Studies on Existing Experimental Investigation

In our comparative study on NFR reviewed key parameters that affect performance outcomes. As shown in Table.3: Summary of Various Types of Natural Fibre Composites and Reinforcement, Manufacturing Process, and Inferences.

Table 3. Comparative Studies of NFR

S.No	Composites	Manufacturing Process	Inferences	References
1.	Kenaf Fibre- reinforced (PLA Composite)	Extrusion moulding	For flexural and Tensile strength, linear incremental behaviour was attained up to 50%	[42]
2.	Kenaf Fibre-reinforced (Epoxy-Composite)	Vacuum assisted resin transfer moulding	Composite enhanced with the fibre reinforcement, wear performance and frictions.	[43]
3.	Betel nut/ Jute fibre reinforced (Poly propylene composite)	Compression Moulding	After 10% of betel nut converted into Jute, the mechanical strength was enhanced.	[44]
4.	Sisal/Cotton reinforced (Epoxy Composite)	Hand Lay-up Method	When compared the mechanical strength to 10%, 20%, 30% and 50%, then it displayed better mechanical properties of 40% wt reinforced composites	[45]
5.	Coconut Fibre (Epoxy Composite)	Microwave assisted heating	When compared to the convention oven, the microwave oven heating was decreased.	[46]
6.	Basal Fibre reinforced (Furan Composite)	Microwave assisted heating	With the comparison of thermally cured and microwave cured parameters, the penetrated threshold, maximum load and ILSS was greater for microwave-cured composite	[47]
7.	Hemp, jute and linen fibre- reinforced (Polypropylene Composites)	Compression Moulding	The NFR properties of flexural and tensile were maximized by changing the natural fibre emerge with 1.5 wt% of HGM.	[43]
8.	Ecco-bond/ Bexloy Composite	Microwave assisted heating	The epoxy resin compressive strength was greater	[48]
9.	Glass Fibre reinforced nylon 66	Microwave assisted heating	Amalgamation of thermo-plastic oriented composite was carried out. This procedure has the capability to exchange thermosetting resin to thermoplastic composites.	[49]
10.	Kenaf-fibre reinforced natural rubber (Polyurethane composite)	Compression moulding	The natural rubber displayed the highest physical strength with the composite and it also showed the greater damping properties.	[50]

8. Research Gap

Much study has been done in the area of natural fibre including natural fibre hybrid composites. Because composite substances have so many uses, they are frequently used in many industries of manufacture. The mechanical qualities, tribological behavior, machining features, vibrational impact, resistance to chemicals, resistance to water, biodegradable properties as well as thermal investigations of NFRP have all been thoroughly examined thanks to this work. The research effort has investigated the impacts of hybridization and several chemical procedures. Due to their enhanced efficiency and ability to overcome natural fibre materials' drawbacks in a variety of uses, hybrid composites have gained popularity. As a result, novel composites including blends of synthetic as well as natural fibres have been developed, offering a cost-effective and environmentally friendly option.

Moreover, chemical-based procedures can improve the quality of natural fibres, bringing about an advancement in the marketplace. To maintain a clean environment, it is important to remember that chemical preparatory procedures that have enhanced NFPC functioning ought to be used in conjunction with appropriate disposal techniques. Furthermore, adding filler to natural fibre combinations offers further benefits for customizing the composite's qualities, particularly it's tribological along with thermal attributes. This makes NFPR usable in sophisticated settings. Although NFRP performs better, non-homogeneity in the composites is a result of fibre variation and inadequate processing techniques. Future studies should concentrate on lowering natural fibre variances, refining treatment and production methods, and better comprehending the connections among natural materials and the surrounding matrix. This kind of investigation will improve natural fibre composites' durability and enable more effective use of them in a variety of industrial applications.

9. Conclusion

The characteristics and advantages of NFRPC and natural fibres for environmentally friendly uses in industry are examined in this review paper. Through the application of the regenerative economy idea, NFRPC might potentially mitigate the problems associated with materials that are not renewable and develop eco-friendly technologies and goods. NFRPC has the potential to be used in a variety of innovative manufacturing processes due to its durability over time. A wide spectrum of NFRPC research is also included in the study, including programs, adjustments, treatments, and processing methods as well as the path through industry 4.0 for ongoing utilization in industry. Our investigation suggests that certain features that provide particular benefits have an impact on the choice for green materials. For instance, physical characteristics, chemical makeup, crystallized cellulose diameters, microfibrillar angle, flaws, form, and extraction method all affect the attributes of natural fibres. The properties affecting NFRPC performance include structure, contamination, moisture retention, orientation, volume, physical and chemical characteristics, microfibrillar position, flaws, and fibre connection. Plant fibres are recommended as a sustainable alternative to synthetic materials.

The evaluation pointed out that a variety of procedures are employed by researchers to create and handle NFRPC, such as hand layup, hot press, plastic injection, the extrusion, and resin transmit molding (RTM) in conjunction with formed fibre manufacturing practices. To achieve 100% biodegradability, more effort should be put into creating NFRP using coupling agents, components, and frameworks derived from resources that are renewable. A thorough analysis of the breakdown and lifespan of NFRP is needed. Composite effectiveness is able to be predicted using experimental information as well as machine learning techniques like genetic algorithm programming along with neural networks that are artificial. To reduce costs and time, we need to develop models and algorithms for natural fibre composites to create new composites with customized characteristics. The purpose of this article is to provide a deeper understanding of the role of natural fibres in reinforcing composites and to underscore the importance of finding innovative solutions to overcome the challenges associated with their use. In conclusion, this review highlights the potential benefits of using natural fibres in composite materials and emphasizes the need for further research to address the challenges associated with their utilization.

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Authors Contribution Statement

C. Chokkalingam: Conceptualization, Implementation, Experimental Setup, and Data Collection. R. Babuprakash: Literature review and Result analysis. G. Abishek: Drafting, Formatting, and Presentation of Results. B. Balaji: Supervision, Guidance, and Review of Methodology. All authors read and approved the final manuscript.

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Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

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