

RAMIE FIBRE REINFORCED POLYMER COMPOSITES: A REVIEW

COMPOZITE POLIMERICE ARMATE CU FIBRE DE RAMIE: O REVIZUIRE

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Abstract: Natural fibre reinforced polymer composites are achieving a great response in the current composite technology and structural application, particularly ramie fibre reinforced polymer composites, which give a great response because of their good tensile strength. Ramie fibre reinforced polymer composite provides a special integration of environmental sustainability, thermal stability and mechanical strength, making them a unique application in the research area of composite materials. This review provides an overview of the mechanical and physical properties of ramie fibre. Moreover, it also elucidates the discussion of the mechanical attributes of ramie fibre reinforced polymer composites and the factors affecting them. Further, this review provides the research gap and future scope in the relevant domain. Through the study, the researchers will be able to understand how the ramie fibre reinforced polymer composite can be used as an alternative to traditional composite materials.

Keywords: Ramie fibre, polymer composites, natural fibre, tensile strength, flexural strength, impact strength.

Rezumat: Compozitele polimerice armate cu fibre naturale obțin un răspuns excelent în tehnologia actuală a compozitelor și în aplicațiile structurale, în special compozitele polimerice armate cu fibră de ramie, care oferă un răspuns mare datorită rezistenței lor bune la tracțiune. Compozitul polimer ranforsat cu fibră de ramie oferă o integrare specială a durabilității mediului, stabilității termice și rezistenței mecanice, făcându-le o aplicație unică în domeniul cercetării materialelor compozite. Această recenzie oferă o privire de ansamblu asupra proprietăților mecanice și fizice ale fibrei de ramie. Mai mult,

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elucidează, de asemenea, discuția despre atributele mecanice ale compozitelor polimerice armate cu fibră de ramie și factorii care le afectează. În plus, această revizuire oferă decalajul cercetării și domeniul de aplicare viitor în domeniul relevant. Prin intermediul studiului, cercetătorii vor putea înțelege modul în care compozitul polimer ranforsat cu fibră de ramie poate fi utilizat ca alternativă la materialele compozite tradiționale.

Cuvinte cheie: Fibră ramie, compozite polimerice, fibră naturală, rezistență la tracțiune, rezistență la încovoiere, rezistență la impact.

1. Introduction

Fibres for composites play a crucial role in enhancing material properties, offering strength, stiffness, and other desired characteristics to the composite material. The classification of fibres is presented in Fig. 1. Natural fibres are presently receiving increasing attention as environmentally friendly biomaterials for they are renewable, biodegradable, widely distributed easily available locally, cheap, versatile and light weighted [1], [2].

Plant fibres such as ramie, jute, kenaf and flex are obtained from the leaves or the stems of the plant. As a naturally growing material. They possess low price, low density, high specific strength and modulus, easy availability and are environmentally friendly[3], [4], [5] [6], [7]. Ramie fibres have low specific density and reasonably high tensile modulus making them potential alternative reinforcement fibres to manmade fibre in thermoplastic composites[8].

Ramie fibre reinforced composites have been extensively used [3], [9]in many structural applications in civil construction, ramie fibre could be used in polyester sandwich panels [10]

Ramie fibre, developed from the stem of the *Boehmeria nivea* plant, acquires the necessary properties that make it relevant for reinforcing polymer matrices. With this natural fibre, ramie fibre has developed as a growing reinforcement agent for polymer composites offers a combination of natural fibres into the polymer, articles have played a significant role in recent years due to the growing demand for suitable and eco-friendly materials across many industries. The use of natural fibres as reinforcement in polymer composites has found an alternative to traditional synthetic fibres, driven by the need for materials that reduce environmental impact without compromising performance. This research focused on a variety of aspects in relation to ramie fibre reinforced polymer composites such as; how different treatment procedures for the fibre, processing techniques and choice of matrix materials impact the mechanical performance and durability of the resulting composites. There is also an attempt to determine whether these polymers are compatible

with the fibres from ramie in order to increase adhesion at interfaces between them both thereby improving respective properties for specific applications.

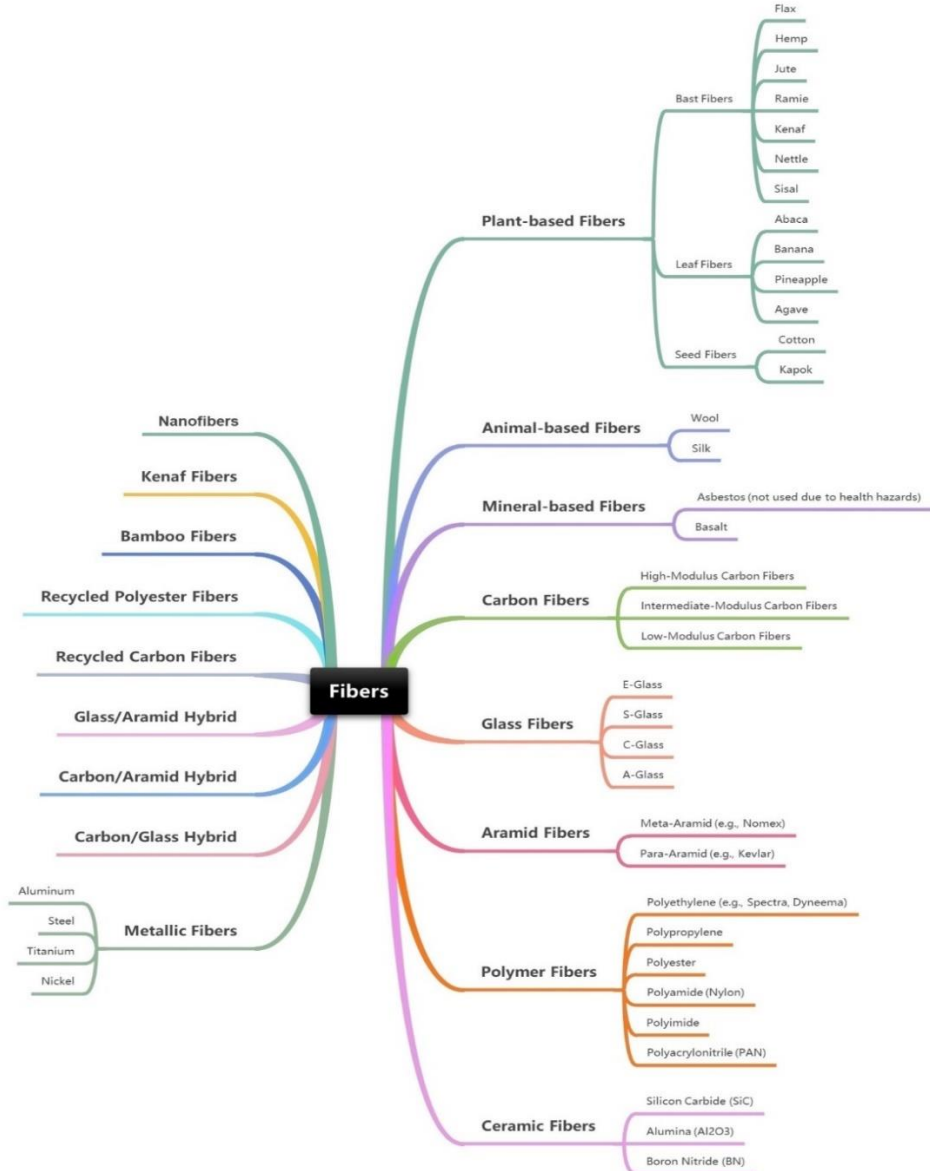


Figure 1. Classification of fibre.

However, much knowledge has been gained in this field, there are still major challenges hindering wider utilization of such materials which include

among others moisture uptake fibre-matrix bonding and cost effectiveness. In order to overcome these issues, the integration of multiple disciplines in a coordinated fashion, such as material science, engineering, and sustainability, must be employed. Furthermore, it is worth investigating whether the ramie fibre reinforced polymer composites exist in the whole production chain with the least possible impact on the environment - from the acquisition of the raw materials to their breaking down to waste and, in the perspective of the time, end-of-life disposal in order to deal with the growing demand for ecologically clean materials. Researching the life cycle analysis provides the enlightening of the environmental impact of these materials which are very crucial for the design and manufacturing phase of products thereby the informed decision-making for proper planning and production.

Through the study of natural fibre reinforced polymer composites, the mechanisms and other characteristics of their mechanical properties are usually professed in most of the research. Nevertheless, the scientific works of ramie fibre composite materials are restricted within the limited region. Consequently, this review examines the characteristics of ramie fibre reinforced polymer composites (also referred to as ramie fibre) as well as ramie fibre and its properties.

2. Composition and Properties of Ramie Fibre for Structural Applications

a. Compositions

The use of Ramie fibre, which is created by the stem of the plant *Boehmeria nivea*, is gaining popularity gradually, being used in polymer composites for structures as a reinforcement material. This section of the article deals with the chemical and physical properties of Ramie fibre and why it is appropriate for structural reinforcement and filling critical gaps in scientific literature.

Ramie fibre is world-famous for its superb mechanical properties where it ranks high in terms of rigidity, tensile strength and abrasion resistance, hence it is better to use them in structural applications. On the lightweight side, ramie fibres come with high inherent lightweight characteristics that contribute to the reduction of the total weight of composite materials without compromising strength and durability. This attribute of ramie fibre has made it a desired replacement of the typical reinforcement materials like carbon fibre and glass fibre in particular cases where weight reduction and environmental sustainability are targeted.

The latest research focuses on the composition of the ramie fibre along with its influence on the strengths of materials blended with polymers. For instance,[1] conducted a study about the chemical composition of ramie fibres and the way their structure influences the composite properties. The research results showed that the microstructure of cotton fibres was a major factor influencing the mechanical behaviour of the composites. Since ramie fibre properties may change with the composition of the yarn, then the manufacturing process and the composite mix can be designed accordingly to optimize the resultant structure performance [11].

Secondly, the thermal properties of ramie fibre have become also widely studied, especially in functions where the body may be exposed to high temperatures. Researchers have studied the process of degradation and thermal stability reserve under different temperature zones and ramie fibre composites [12]. The research pointed out that the thermal property of the bio-composite is very important for structural applications with varying environmental conditions like automotive components or building materials [13].

The significant advancement in knowing the constitution structure and functionalities of ramie fibre for the structural applications however are not exempted from certain gaps in the literature. Studies need to carry out further concentrating on environmental factors like humidity and UV ray exposure and their long-term consequences on ramie fibre composites. Many experiments have investigated the thermal and mechanical features of these composites at laboratory conditions, but application in real life may make the materials face hard environments such as sunlight and wind leading to their reduction in durability and stability.

Additionally, there is a demand for the standardization of testing methods and designation techniques distinct to ramie fibre composite for structural functions. The standard testing procedures for composite materials play a validating role, but for natural fibres such as ramie, testing methodologies must be developed specifically for those fibres to adequately assess their performance and ensure quality control. Standardized testing procedures enable researchers to conduct comparative studies as well as greatly improve the reproducibility of results in this field among researchers from different research groups.

Besides the vacuum associated with more fundamental knowledge, one should also consider aspects such as processing techniques and commercialization on a large scale. Although the small-scale laboratory tests have proved that ramie fibres in polymer matrices can be used to produce composite materials having commendable properties, the industrial

application scale-up poses issues to be resolved in terms of cost-effectiveness, production process efficiency, and material consistency. Their investigation of the innovative processing technologies and the optimal manufacturing parameters will be essential for reaching the ramie fibre composites' full potential in structural applications.

To round up, the structure and properties of ramie fibre endorse its prospective use as a reinforcing material for structural applications in composite polymers. Recent developments in establishing the chemical content, mechanical properties and thermal stability of ramie fibre present opportunities for further invention and screening in this area. Filling the gaps in the existing literature, like the performance in long-term and standard tests, will be of the essence to speeding up the acceptance of ramie fibre composites at the fields of automotive components and construction materials.

Table 1 illustrates the chemical composition of the ramie fibre to determine the primary components including pectin, lignin, hemicellulose, and cellulose with 68 percent content. The fibre (6%-85%) itself undergoes a structural change and allots to the composition of the high tensile strength and stiffness of the fabric [14], [15] Hemicellulose and lignin, in the minor quantity, give supporting effect to the fibre's mechanical properties and the product's framework structure [11], [14]. Despite the fact that pectin is present in relatively small quantities, it dictates the characteristics of flexible binding and moisture absorption of fibre [16].

Table 1. Chemical composition of ramie fibre

Pectin	Lignin	Hemicellulose	Cellulose	References
1.9	0.6-0.7	13.1-16.7	68.6-76.2	[17]
-	0.5	3-4	80-85	[14]
-	1.06	12.11	71.09	[15]
1.9	0.6-0.7	13.1-16.7	68.6-76.2	[18], [19]
2-4	4-7	14-18	68-76	[11]
1.81	0.86	14.89	75.13	[16]
1.2	0.8	14	72	[20]
-	0.6	-	68.6	[21]
3.9-5.9	0.8	19.2-21.5	70-76	[17]
6.1	-	-	78.07	[22]
3.5	1.9	13.8	73.6	[23]
-	1.06	12.11	71.09	[15]
5.5	1.4	13.5	74.4	[24]

b. Physical and Mechanical Properties and Structural Applications

The cellulose is the main composition of ramie fibre thus it lends the firmness to the fibre which makes it the ideal candidate for the structural support of polymer composites. Cellulose fibres are considered known for both modulus and high tensile strength which makes plastic composites suitable for applications requiring significant mechanical loads[14] [15]. On the other hand, the higher tensile strength of ramie fibres compared to other fibres leads to rigid composite structure which is perfect for structures that need dimensional stability and structural stability[11], [15].

The results from recent studies have demonstrated that the ramie fibre reinforcement is a good match for structural applications. Research [25] shows the mechanical properties of ramie fibre-reinforced epoxy composites and reveals a better tensile strength compared to ordinary glass fibre composites, which is more convenient. The exceptional mechanical features of ramie fibre composites also render these composites useful in automotive parts, aerospace structures, and construction materials [14] [15].

The properties of ramie fibre reinforced polymer composites, like the mechanical and physical ones, are affected by factors such as type of fibre morphology, fibre orientation, fibre distribution, and the type and properties of the matrix material. Modern research concentrates on the tensile strength, flexural modulus, impact resistance, and thermal stability of those composite materials to determine the load they are suitable for in various areas.

Ramie fibres offer an outstanding property of tensile strength and stiffness; therefore, they can be used as reinforcements for polymer composites to improve their mechanical properties. Yet, attaining the ideal fibre-matrix bonding is vital since it is the key to capitalizing on the capabilities of ramie fibre composites. Surface treatment methods like alkali treatment, silane coupling agents, and plasma treatment have been researched with the intent of increasing the bonding between the fibres and the matrix. So, the overall strength of the composites rises.

Besides the mechanical properties, the issue of thermal stability and dimensional stability also have to be considered when the ramie fibre composites are used in the high-temperature environment or as a structural part. Calorimetry methods including differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) have been applied to investigate the thermal behaviour and degradation kinetics of these composite materials under different conditions.

Despite the very long way to completely understanding the physical and mechanical characteristics of ramie fibre composites, no data on their primary strength and life-cycle there is. The next critical step is to study in greater detail the moisture absorption, ageing process, and biodegradability of ramie fibre composites, along with their maintained performance in real-case applications.

From Table 2, it is evident that ramie fibre exhibits a wide range of characteristics that make it suitable for structural applications in polymer composites. **Table 2. Mechanical and physical properties of ramie fibre**

Density (g/cm ³)	Tensile strength (Mpa)	Young's modulus (GPa)	Elongation at break (%)	Average diameter (µm)	References
1.55±0.1	715±22	86±26	7±2	94±18	[11]
1.15	700	-	-	-	[26]
1.5	560	25	2.5	-	[27]
1.50	400-938	61.4-128	1.2-3.8	-	[25]
1.12	420-680	24.68-34.26	1.4	-	[19]
1.34-1.45	250-1250	15-30	0.5-5.5	25-45	[23]
1.12	420-680	24.68-34.26	1.4	-	[28]
1.50	477	-	1.3	-	[21]
1.50	560	-	-	34	[18]
1.5-1.56	400-1000	60-128	1.2-3.8	-	[29]

c. Discussion on the Use of Properties for Structural Applications

Young's Modulus and Tensile Strength: The high Young's modulus and tensile strength degree of ramie fibres make them perfect for applications used in structural which require stiffness and resistance to loads. In industries like automotive and aerospace where weight saving is crucial due to that it leads to more fuel efficiency and performance, ramie fibre-reinforced polymer composites are a viable solution for that reason. By divesting and resisting the applied forces, ramie fibres provide the components with a carrying capacity so end products possess structural integrity, leading to safe and reliable functioning.

Elongation at Break: The increased elongation at break of the ramie fibres is one of the main perks contributing towards the flexibility and impact toughness of the composite materials. Sports goods and protective equipment

that may be impacted or have significant dynamic loads can absorb the energy and deform without catastrophic failure by using ramie fibre composites. This results in injuries and damage prevention. Besides, the qualities of ramie fibres that give them flexibility support the manufacture of complex shapes and the creation of elaborate designs, which leads to the application of ramie fabrics in different industries because of their wide spectrum.

Density and Weight Reduction: The fact that ramie fibres are low dense is what contributes to the lightweight nature of the composite materials therefore rendering them most suitable for applications where the weight is not desirable like the marine and transport industries. It is possible that the great reduction of weight can be attained when ramie fibres are used to reinforce the structure just as well without compromising the performance. This, in turn, can cause fuel savings and better handling besides the non-impact on the environment. In addition, the biodegradable character of ramie fibres is in line with sustainability programs giving an eco-friendly substitute to other reinforcement materials whose sources are from nonrenewable resources.

Optimization of Properties: While Ramie fibres exhibit impressive properties for structural applications, there are major research and development directions to take advantage of such potential through different approaches. Chemical treatments and plasma treatments are a couple of measures of surface modification that can help increase a good interface bonding between the polymer matrix and ramie fibres, and at the same time lead to mechanical properties and durability of the composite. In addition to that, the composite's properties can be tailored by combining the ramie fibre with other reinforcements or fillers meant to match specific materials application purposes. Thus, the multi-functionality of the ramie composites in structural engineering is ensured.

i. Thermal Properties

The thermal behaviour is one of the properties that determines the ability of ramie fibre to polymer composites when it comes to applications, where such climate characteristics are prevailing. Knowing the nature of how thermal changes in these composites is very critical in designing processes that maximize their performance and ensure longevity. Lately, the amount of research efforts has intensified and focused on the thermal properties of ramie fibre composites, specifically their ability to withstand heat and extend the application spectrum. This paragraph presents a synopsis of the most recent

research publications which aim at identifying knowledge deficit in the heat response of ramie fibre/polymer composite.

ii. Microstructural Properties

In the world of composite materials, knowing the microstructural characteristics is the key element for establishing their mechanical reaction, thermal stability and efficiency in general. Here, the microstructural properties of ramie fibre reinforced polymer composites will be discussed, with the most recent developments illustrated and attention given to research areas where there is a dearth of information.

Ramie fibre reinforced polymer composites show a sophisticated microstructure which consists of interwoven ramie fibres that are immersed into a polymer matrix. The way these fibres are placed and directed significantly impacts the material's mechanical properties and structural properties. Some research has concentrated on the microstructure of ramie fibre composites using advanced imaging methodologies such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM). These methods enable one to see the positioning of the fibres, the nature of the interface, and defects/imperfections, if any, in the composites.

Ramie is composed of the cellulose of the stem of the ramie plant. Fig.2 illustrates the extraction process of ramie fibre. The initial phase of the production process is the gathering of ramie fibre from the fields through the formal processing which ends at the final treatment. Ramie plant (*Urtica dioica* – family) is considered a prized fibre source by the industry, because of its strength and hardness. Harvest can be made at the final stage when the plant has reached its ideal age, from 3 to 6 months after sowing. Next, the decortication process is carried out, during which the outer bark is stripped from the stalks to bring out the familiar long and silky fibres inside. The drying process occurs then, to remove the water reserves and to obtain a material destined to undergo further treatment. Degumming, which is considered the main stage of processing, requires the use of boiling or chemical reagents to remove natural gums and resins from the wood. After the degumming process, the fibres go through bleaching and this gives them a whiter and more uniform color. Fibre can be damaged by controlling acidity, but it is very important not to use too much of this substance. Following these processes, the fibres could be oiled so that they could be more flexible and softer. Then the fibres are dried one final time to achieve the desired moisture content that is required for storage or further processing. This thorough

process guarantees that the moisture from the retting process does not affect the natural characteristics of ramie fibres which can be further utilized for backgrounds of various textile and industrial applications.



Figure 2. Extraction process of ramie fibre.

iii. Functional group analysis

Functional group analysis is a major factor in the elucidation of the chemical composition and structure of ramie fibre reinforced polymer composites. In this subchapter, the functional groups in the ramie fibres and the polymer matrices will be analyzed, pointing out the importance of these components for the performance and properties of the composites. This review will bridge gaps in knowledge by reviewing what has already been studied in this regard. It also tries to identify opportunities for further research.

Ramie fibres from the stem of the *Boehmeria nivea* plant consist mostly of cellulose, hemicellulose, lignin, and pectin. These plant-based polymers contain functional groups like hydroxyl (-OH), carbonyl (C=O), and carboxyl (-COOH), which play a role in the chemical reactivity and interface bonding in composites as well. It is imperative that the distribution and association of these functional groups are fully understood in the sense of improving the mechanical, thermal, and environmental properties of ramie fibre composites.

3. Properties of Ramie fibre reinforced polymer composites

a. Mechanical properties

Ramie fibre reinforced polymer composite exhibits remarkable mechanical properties, making it a promising material for various applications. In recent years, several studies have focused on investigating and enhancing these mechanical properties to maximize the performance and functionality of the composite. This literature review explores the current understanding of the mechanical properties of ramie fibre reinforced polymer composite, identifies gaps in existing research, and suggests avenues for future exploration.

Table 3. Mechanical attributes of ramie polymer composites

Composites	Fibre Content (Wt.%)	Impact Strength (J)	Tensile Strength (MPa)	Flexural Strength (MPa)	Young's Modulus (GPa)	References
Ramie/ bio-based polyamide	40%	-	75.5	-	-	[30]
Ramie root fibre /unsaturated polyester	-	-	34.22	56.03	-	[28]
Ramie/bio-based polyamide	40%	-	41.7	-	3.98	[30]
Ramie fibre/ polypropylene	40%	-	52.66	80.70	-	[31]
Ramie fibre/epoxy/nano clay/ bio silica	40%	4.73	164	201	5.24	[32]
Ramie/epoxy/OMM T nano clay	40%	6.75	155	198	-	[33]
Ramie/flax/bio epoxy	40%	-	250-1250	-	1.5-3.0	[23]
Ramie/pineapple leaf fibre	40%	-	42-68	-	2.468-3.426	[28]
Ramie/epoxy polymer matrix	30%	2.2-4.5	23.42-28.76	36.82-46.82	-	[34]
Ramie/banyan hybrid composite	80%/20%	21	24	20.1	-	[21]
Ramie/banyan hybrid composite	60%/40%	18	24.9	20.9	-	[21]
Ramie/banyan hybrid composite	50%/50%	12.1	32.2	27.3	-	[21]
Ramie/banyan hybrid composite	40%/60%	11.1	36.4	32.1	-	[21]

Composites	Fibre Content (Wt.%)	Impact Strength (J)	Tensile Strength (MPa)	Flexural Strength (MPa)	Young's Modulus (GPa)	References
Ramie/banyan hybrid composite	20%/80%	9.2	40.5	39	-	[21]
Ramie/kevlar/ hybrid composite	40%	4.05	50.8-66.87	39-42	-	[18]

From Table 3, it is observed that ramie fibre has been utilized as reinforcement with several polymer matrices namely, polyamide, polyester, polypropylene etc. It is noteworthy that ramie fibre has been mostly used as reinforcement with polyamide. However, the use of polymer matrices like epoxy, polylactide acid (PLA), and polypropylene was limited with ramie fibre as reinforcement. It is also observed that ramie fibre reinforced polyamide composite performed the best among all the ramie composites under tensile loading condition with tensile strength=155 MPa, under flexural loading with flexural strength=201 MPa and Young's Modulus=9.2 GPa.

b. Structural Properties

In the domain of composite materials, understanding the structural attributes of ramie fibre reinforced polymer composites is crucial for optimizing their performance in various implementations. Several recent studies have delved into this aspect, shedding light on the mechanical behaviour, fracture mechanisms, and failure modes of these composites.

In past literature, a research work [35] investigated the flexural and tensile properties of ramie fibre reinforced epoxy composites. By means of testing the said mixture of ramie fibres, it was deduced that it could be used for strengthening and/or being more elastic at the same time, stressing the importance of these materials in the structural field. On the other hand, the research also faced certain hindrances like wavy fibre alignment and insufficient adhesion at the interfaces that could compromise the strength.

Further from this research, another study [36], conducted an investigation on the impact of resistance of ramie fibre reinforced polypropylene composites. Their study ensured that the consequences of fibre orientation as well as the volume fraction of the composites on the impact strength were investigated. While the findings present the benefit of improving the fibre alignment as well as the volume fraction, such optimizations can enhance the impact resistance of the composites and hence also extend the application areas for the case of impact-prone environments.

While these advancements undoubtedly represent a landmark point in the literature regarding the basis of environmental factors and structural properties of ramie fibre composites, still a definite gap exists here. A variety of studies have been focused on the mechanical behaviour of these composites at ambient as well and some assessments have been done for harsh conditions (moisture, UV radiation and temperature fluctuations). However, the research on the performance of these composites in extreme environmental conditions has just started.

Closing this gap will not only give us vital information regarding the durability and reliability of ramie fibre composites when exposed to actual work conditions but will also help us to have a better idea about the effectiveness of these composites in daily life applications. The future study should be oriented on revealing the features that affect the aging, degradation or environmental resistance of these composite materials aimed at opening up more possibilities of viable applications across industries.

Briefly, through the application of recent research methods, the defects of RRFC have been indicated to some extent even though several aspects, for instance, the environmental performance and durability, require more research to be fully elucidated. In this way, this study will explore everything related to the development of ramie fibre composites for structural labor and find out if they are really sustainable and highly effective or not.

4. Conclusion and Future Direction

From past literature on ramie based on composition, it was observed that average pectin, lignin, Hemicellulose & cellulose were found to be 3.26%, 1.265, 13.55, 67.55 respectively review also indicates that average density, tensile strength, Young's modulus, elongation of break & diameter were found to be 1.38 g/cm³, 634.63 MPa, 54.44 GPa, 2.15%, 54.33 μm respectively this study also discussed the various mechanical properties, tensile, flexural, impact & young's modulus of ramie fibre reinforced polymer composites.

From the literature, it was deduced that ramie fibre reinforced to epoxy polymer with OMMT nano clay resulted in achieving a tensile strength of 155 MPa, Impact strength of 6.785 J. Flexural strength of 198 MPa. Ramie fibre reinforced to epoxy polymer with Nano clay and bio silica provides Young's Modulus 5.24 GPa

The ramie is of great relevance it shows high potential, for more improvement in mechanical properties, Ramie Fibre Reinforced Polymer

Composites can be used in combination with epoxy, nano clay, bio silica and Kevlar, epoxy for hybrid composite. For future studies, one can explore more combinations of ramie fibre with plant base fibres such as hemp, sisal, abaca, cotton etc, with glass fibre. Ramie can also be utilised as reinforcement in various polymer matrices like polyethylene, polypropylene, polyester, polyamide, polyacrylonitrile etc. for exploring the potential of composites to enhance the performance and properties of composites in different applications.

From the literature, it is also observed that there is limited research available on optimization, modelling & simulation of mechanical properties of ramie fibre reinforced polymer composites. It is of vital importance that predictive models must be developed in order to optimise the mechanical properties of composite to conserve resources. Therefore, modelling & optimization of mechanical properties like tensile, impact & flexural strength must be done using statistical tools like response surface method (RSM), Taguchi etc further modelling & simulations of mechanical properties of ramie fibre reinforced polymer composite would also help in predicting the strength of composite without actual experimentation.

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