Review On Natural Hybrid Composite Materials

Nithin M[1], Akshay Krishna M[2]
Alva's Institute of Engineering & Technology, Moodbidri
mnithin144@gmail.com, akshaykrishna1895@gmail.com, pramodvab@gmail.com
Contact::+91 9353305523, 9606652257

Abstract

One matrix with two or more fibers makes up hybrid composites. Natural, synthetic, or a mix of natural and synthetic fibers can be used to create hybrid composites. Compared to fiber-reinforced composites, hybrid composites can assist us in achieving a superior mix of qualities. The components of a composite that are hybrid can be changed in a variety of ways, which may change the composite's characteristics. The review is significant because it shows that the performance of natural fiber-based hybrid composites is primarily determined by a number of factors, including variations in the volume/weight fraction of the fiber, variations in the stacking order of the fiber layers, treatment of the fiber, and environmental factors.

The effects of chemical treatment, the mechanical and chemical properties of fibers, the properties of various natural and synthetic fiber types for the creation of pure natural composites and hybrid composites based on the combination of natural and synthetic fibers; bio-based resins; various fabrication techniques; and the influence of nanoparticles on composite materialsResearchers are beginning to embrace natural fibers more and more because they are easily obtainable, reasonably priced, easy to produce, biodegradable, and environmentally benign. Compared to mixtures of natural and synthetic fibers, hybrid composites are preferred by more people. Two different natural fibers are combined into a single matrix material to create hybrid composites. According to recent research on natural fiber hybrid composites, the A compound material is known as biodegradable, and as a result a metal matrix composite if it is made of metal fiber, and a polymer matrix material if it is made of polymer

Keywords: *manufacturing methods, chemical treatment, applications, natural and synthetic fibers, hybrid composites, thermosets and thermoplastic resins,*

1. INTRODUCTION

Contemporary technologies, including those related to aviation, undersea, and transportation applications, require a unique combination of material properties that are not available in ceramics or metal alloys. For aircraft applications, structural materials with high specific strength and stiffness are necessary; common materials cannot provide these qualities. With composites, we may intelligently blend multiple materials to offer the required properties. They often have high specific modulus and high specific strength, which are advantageous qualities in a range of industrial applications. Because they have the required qualities, glass fiber polymer composites and carbon fiber polymer composites are used by modern industries as metal alternatives. Each kind has a unique range of applications and limitations[1]. It is anticipated that synthetic fiber composites would eventually give way to natural fiber composites, at least for some applications where a short product life is preferred. The usage of natural fiber composites in the automotive sector has increased dramatically in recent years due to Furthermore, compared to single fiber reinforced composites, hybrid composites offer longer fatigue lifetimes, improved fracture toughness, and decreased notch sensitivity[25]. It was discovered that hybrid composites with an artificial-natural basis that show properties halfway between those of pure natural and pure synthetic fiber-based composites were formed by partially substituting natural fibers for artificial fibers.The usage of natural fibers is expanding rapidly due to their abundance, biodegradability, affordability, and low processing energy consumption [1,2]. Natural fibers can be classified into three categories: plant, animal, and mineral. Since natural fibers from plants are currently receiving a lot of interest from the scientific community and business, that is the main subject of this examination [5].

These fibers differ in diameter, length, and specific gravity, but they share cellulose, hemicellulose, and lignin, which makes them similar chemically. They do, however, barely differ in terms of their mechanical and physical characteristics [9]. Hybrid composites are built of several reinforcing agents within the same polymer matrix in order to boost the composite's features. Combining many reinforcing elements can result in an antagonistic or synergistic effect [10].A matrix and several reinforcements can offer a wider variety of properties than single fiber reinforced composites. The scientific community has therefore closely monitored the hybridization of reinforcing chemicals originating from both synthetic and natural sources.

[12]. After reinforced composites are constructed, testing should be done to ensure that they function in accordance with the necessary industrial requirements [14]. It is crucial to check and validate the properties and performances of the composites, particularly when they are subjected to repeated stresses such as damping. Dynamic mechanical analysis (DMA) is a useful analytical method for analyzing a composite material's properties as a function of temperature, frequency, or time. This methodology has been used for several decades in the field of material engineering and is still regarded as crucial because of its remarkable sensitivity for detection [15]. Many studies have thoroughly investigated the dynamic mechanical characteristics of natural fiber composites in the last few years.

[16–19].

Recent years have seen a large number of academics show interest in employing natural fibers to create hybrid composites due to their abundance, low density, recyclable nature, and exceptional strength [1,2]. due of their attributes, which include their cost, ease of availability in nature, and environmental friendliness, as a support of numerous reinforcement for creative uses. Their resources reduce environmental pollution by absorbing carbon dioxide and preventing the discharge of hazardous gasses [4-6].

One major drawback of using natural fibers as reinforcement in composites is that, due to their hydrophilic character, they cannot be used with hydrophobic matrices. To enhance the composite's overall properties and smooth out any irregularities, the natural fiber surface treatment is required [7, 8].Aside from this, natural fibers are easily exposed to flames; therefore, fire retardants have been added to them to increases their fire resistance.Using different chemical compounds to modify surfaces tends to boost their mechanical and physical qualities. Additionally, altering the composite materials' structure results in additional stability [10, 9]. Materials known as Reinforcement and matrix are two examples of the two or more constituent materials that make up hybrid composites [14, 15]. The material that binds the reinforcement is called a matrix. The materials that are embedded in the matrix are called reinforcements. These provide the composite with its extra strength. The importance of composites lies in their ability to deliver the intended mechanical, chemical, and physical qualities in a better way than their separate constituents [16]. Depending on the matrix, composites are categorized as polymer, ceramic, or polymer. Depending on the type of reinforcement used, these can be categorized as laminate, fibrous, or particle composites. Depending on their availability, reinforcements can be classified as natural or synthetic [15, 17]. A compound material is referred to as a metal matrix composite if it is made of metal fiber, and a polymer matrix material if it is made of polymer [17, 18].

A polymer matrix is used to combine two or more fibers to create hybrid composites. Fiber types that are artificial-artificial, natural-artificial, and natural-natural can all be combined to create hybrid composites. The low cost, high strength-to-weight ratio, and ease of manufacture of hybrid composite materials make them very applicable in the field of engineering.With the help of these hybrid composites, it is possible to combine qualities like strength, ductility, and stiffness that are not possible with single fiber reinforced composites. Comparing hybrid composites to single fiber reinforced composites, the former have reduced notch sensitivity, superior fracture toughness, and longer fatigue lives.[25] Hybrid composites based on artificial fibers provide several benefits, including high specific strength, high toughness, high impact resistance, etc., according to research on different combinations of these materials. Because of high cost, etc., researchers began looking into hybrid composites based on natural fibers. Natural-natural and artificial-natural fibers can be combined to create one of two types of natural fiber-based hybrid composites .Since natural fibers may be treated like composites, they are more durable than synthetic fibers. Additionally, well-designed, premium Glass fiber reinforced composites and natural fiberReinforced hybrid composites have comparable stiffness and strength. It was found that by partially substituting natural fibers for artificial fibers, hybrid composites having an artificial-natural basis and properties halfway between those of pure natural and pure synthetic fiber-based composites may be generated.Researchers discovered that natural fiber composites can have their characteristics improved by the inclusion of additional component[23].

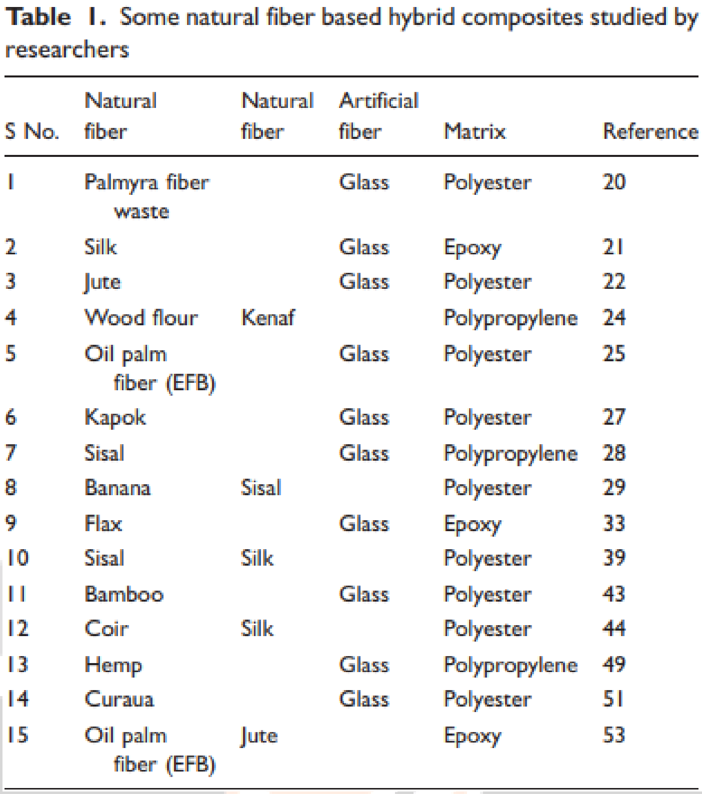

Table 1. Some natural fiber based hybrid composites studied by researchers

S No.	Natural fiber	Natural fiber	Artificial fiber	Matrix	Reference
1	Palmyra fiber waste		Glass	Polyester	20
2	Silk		Glass	Epoxy	21
3	Jute		Glass	Polyester	22
4	Wood flour	Kenaf		Polypropylene	24
5	Oil palm fiber (EFB)		Glass	Polyester	25
6	Kapok		Glass	Polyester	27
7	Sisal		Glass	Polypropylene	28
8	Banana	Sisal		Polyester	29
9	Flax		Glass	Epoxy	33
10	Sisal	Silk		Polyester	39
11	Bamboo		Glass	Polyester	43
12	Coir	Silk		Polyester	44
13	Hemp		Glass	Polypropylene	49
14	Curaua		Glass	Polyester	51
15	Oil palm fiber (EFB)	Jute		Epoxy	53

2.Factors affecting by mechanical behavior of hybrid composites

Volume or weight percentage of fiber is used to express the weight or volume proportion of fibers in a hybrid composite. Numerous investigations have examined the behavior of hybrid composites when the fibers' volume/weight ratio is altered. They have discovered that the mechanical properties may be affected by this modification in both positive and negative ways. The tensile strength of polyester hybrid composites reinforced with glass fibers and bananas varies linearly with the volume percentage of the glass fibers, as demonstrated by Pothan et al. 34. They observed that the delamination of the layers caused a greater volume fraction of glass fiber failure. With an 11% glass fiber volume percentage, the hybrid composites had a higher impact strength. Impact strength decreased[23].

The glass fiber hybridization improved the flexural, impact, and water absorption properties of the hybrid composites. The maximum impact strength and tensile strength in polyester and pine apple leaf fiber composites are 8.6 weight percent, and in polyester and sisal fiber composites, they are 5.7 weight percent.
Compared to bio-fibers, the addition of high modulus glass fibers to the hybrid composites enhanced their tensile strength. Because glass fibers offer a greater resistance to shearing, they have boosted the bio-fiber composites' flexural strength. When the glass fiber loading was increased to 8.6 weight percent, the composite's impact strength significantly increased.

After that, there was no discernible growth. Tensile, flexural, shear, and impact properties of glass/palmyra fiber waste sandwich composites were experimentally evaluate. To create the second set of samples, the proportions of glass and waste fiber were changed while maintaining an overall fiber weight percentage of 60%. The first batch of samples consisted of composite plates composed of 30–70 weight percent fibrous waste (palmyra fiber waste).

Every one of the previously listed mechanical attributes of The hybrid composite with 48% palmyra fiber and 10% glass fiber exhibited a better strengthening effect than the composite with 11% weight percent glass fiber. In an experiment, varied the percentage of glass fiber from 0 to 50% on a silkglass hybrid composite with a total fiber weight fraction of 25%. The hybridization of the composite showed that the properties increased with the weight percentage of glass fiber. Because the hybridized composite contains stronger modulus glass fabric than the unhybridized one, its modulus is found to be higher. Compared to unhybridized composites, a blend of 50% glass and 50% silk performs better. The 50% glass fiber composition of the hybrid composite allows for efficient load transmission from glass to silk fabric. As the amount of glass fiber rose, the flexural strength of the hybrid composite improved because there was more resistance to shearing. Furthermore, it was demonstrated that compared to unhybridized composites, hybrid composites absorbed

less moisture. The reduced water absorption is explained by the addition of water-resistant glass strands, which prevent silk from coming into contact with water. during their tests, they considered the total weight percentage of fiber as glass fibers, Poisson's ratio dropped, the shear modulus was mostly unaltered, and the elastic modulus increased in both the warp and weft directions. The elastic modulus of glass fibers increased due to their high modulus and ability to support loads, howeverBecause of their increased extensibility over jute fiber, Poisson's ratio dropped. By altering the weight proportion of the fibers, efforts are being undertaken to determine the mechanical properties of jute polyester and jute, glass fiber reinforced polyester composites. Up to 25 weight percent of the jute fiber content, the jute-polyester composites demonstrated improved tensile and flexural performances. But when the fiber concentration increased, the features worsened as agglomerates formed and impeded the transfer of stress[18].
Due to the glassHybridization with the kenaf fiber improved the wood flour/polypropylene composite's

tensile characteristics. It was also noted that the enhancement of features was closely linked to a rise in the weight % of kenaf fibers in the hybrid composite. In order to determine the mechanical and physical properties of hybrid composites made of polyester reinforced with glass fiber and oil palm, Abdul Khalil et al.41 conducted study. Up to 45 weight percent of fiber loading can improve tensile properties; however, if fiber content is raised further, a downward trend has been seen due to the production of agglomerates that act as barriers to stress transfer[06].

The tensile capabilities are enhanced by the volume % of glass fiber; however, as the amount of oil palm fibers increases, a reverse trend has been seen because of the poor quality of the connection between the fibers and the matrix. Elongation increased in tandem with an increase in oil palm fiber content in the hybrid composites; however, the opposite trend was observed with an increase in glass fiber content. The flexural and impact characteristics increased up to 35 weight percent of the fiber loading because of fiber–fiber interactions and problems with the fibers' dispersion in the matrix phase. Following then, a downward trend was observed. Since oil palm fibers were added, the amount of glass fiber loading has increased the hybrid composite's hardness, which peaked at 15% of the fiber content before declining. This is due to the polyester matrix's increased hardness. When glass fibers are introduced, the hydrophilic nature of oil palm fibers causes the hybrid composites to absorb less water[05].

3.Stacking sequence of fiber layers

The stacking sequence in hybrid composites represents the fiber layer configuration. Scholars have investigated the effects of varying fiber layer locations on the mechanical properties of hybrid composites. Sabeel Ahmed and Vijayarangan47 investigated the tensile, interlaminar shear, and flexural characteristics of the glass fiber and jute reinforced polyester hybrid composites by varying the layer stacking order. Because glass fibers are more resilient than other materials, the samples with glass fibers at their extremities displayed greater values for tensile strength than the other specimens[03-04].
more robust and rigid than jute fibers. Because the stiffness of the extreme plies mostly determines the flexural strength, specimens with glass layers at the extreme ends and jute layers in the core have higher flexural strengths[02-03].

Glass fibers were used as extreme plies on both sides, which greatly improved the characteristics of the hybrid composites. It was demonstrated that the layering pattern had a greater impact on the flexural
strength and interlaminar shear strength than did the tensile characteristics. Abdul Khalil et al. 48 conducted a comparative analysis of oil palm empty fruit bunch and glass fiber reinforced vinylester hybrid composites, as well as composites manufactured from mechanical and chemical fibers. In comparison to other stacked designs, the hybrid composites with glass fibers at the extremities yielded greater values for the tensile modulus[08].

The tensile behavior of chemical fiber composites was demonstrated to be better than that of mechanical fiber composites due to the presence of lignin in mechanical fibers, which helps to lower bond strength. The hybrid composite with glass fibers in the middle and natural fibers at the extremes showed a higher tensile strength due to sufficient load transfer and robust interfacial bonding. The hybrid composites containing glass fibers at the outer layers have a higher load carrying capability than natural fibers because of this possess more flexural strength and modulus than other layered designs where the extreme portions are made of natural fibers. The impact strength of hybrid composites with natural fibers at the extremities displayed higher values due to their chemical makeup. The presence of lignocellulose caused the water absorption of the hybrid composites to increase as the quantity of natural fibers increased. Gupta49 conducted an experimental evaluation to determine the mechanical properties of glass fiber reinforced composite (GRP) lamina, flax fiber reinforced composite (FFRC), glass-flax-glass hybrid (GFGH), and flax-glass-flax hybrid (FGFH). It was observed that the stacking sequence variation caused the features to vary[09].

It was found that in terms of tensile, compressive, flexural, impact, and specific tensile strengths, the stacking arrangement GFGH is superior to FGFH. investigated the effects of changes in the layer stacking order on a hybrid laminate's mechanical properties. Asymmetrical stacking hybrid composites have been found to be less capable than symmetrical hybrid composites. It was unknown how stacking order affected tensile strength. Impact strength values were greater in the hybrid composite that included glass layers next to one another. It was discovered that the harder the composites were, the more glass layers there were on their examined surface and stronger structural integrity. The Examples with sisal in the center and glass around the edges showed Experimental research was done on a natural fiber reinforced hybrid composite made of long abaca and short bagasse fibers acting as reinforcing agents in ortho-type unsaturated polyester (UP) resin. The fabrication and testing of fiber-reinforced plastic laminates employed the same uniform thickness, but the arrangement of the bagasse and abaca fibers in the laminates varied. Two sequences of stacking were designed and evaluated using two bagasse mats positioned 90 degrees apart and sandwiched between three abaca sheets in a cross-ply arrangement. The cross-ply orientation has a lower tensile strength than the parallel orientation. The cross-ply variety can withstand stresses in both transverse and axial directions, making it more suitable for biaxial loading even if it has a lower tensile strength. The stacking sequences CGG and GGC ('C' for Coir and 'G' for glass) showed the highest values of tensile strength, impact strength, and flexural strength. The GGC's mechanical properties specimen were higher than those of the GCG specimen. Furthermore, because glass fibers are stronger than coir fibers, the GGC specimen generated a higher breaking resistance than the CGC specimen. A comparison research comparing composites made of jute fibers, oil palm fibers, and a combination of the two was conducted . They found that the hybrid composites' tensile and flexural characteristics fall between those of epoxy compositesstrengthened with fibers from oil palm and jute. They claimed that the positioning of the high strength fibers affected the hybrid composites' tensile and flexural strengths. The outcomes demonstrated that the mechanical performance of oil palm fiber composites was improved by the addition of jute fibers. Furthermore, the strongest jute fibers are found in hybrid composites with jute layers on the extremities because their strength is higher than that of oil palm fibers[21].

Reinforced hybrid materials are made by joining at least two different types of fibers into a special matrix material. Compared to employing both strands alone in a single polymer lattice, hybridization of two distinct types of filaments with precise lengths and widths provides a few primary focuses. Most studies concentrate on enhancing the properties by hybridizing glass strands with regular filaments. Like affluence, well-being, and protection, they have an average calorific value and cause little stress.In addition, they are thin, modest, and possess exceptional mechanical properties. The enhanced durability and stiffness of composite materials, in comparison to standard materials, make them more useful. Because of their affordability, researchers are drawn to these natural fibers.availability. materials have high-quality fibers added to a matrix material with a modulus. Accordingly, each Each material (fiber and matrix) keeps its distinct chemical and physical properties, and when combined, they offer a combination of properties that would be unimaginable when employed alone. In this case, the fibers are the primary agents for load carrying, and the matrix material works as a load-bearing element around them to protect the fibers from the destructive effects of high humidity and temperature. Thus, Fiber Reinforced Composite Materials (FRCM) is the term used refers to the fact

the fiber provides reinforcements to the matrix Because of the volatility of petroleum oil and its resources, the use of natural-based fillers has advanced significantly over the past few decades. However, there are significant limitations to using natural fillers, particularly in advanced or technical applications (poor thermal stability, extremely combustible, high moisture absorption, change in mechanical properties, etc.). In order to get over these restrictions, more research was done on mixing the natural-based filler with different fillers. The aim was to substitute affordable, biodegradable, and renewable fillers for the synthetic ones. The majority of this evaluation study focuses on fillers that are frequently employed to enhance and/or overcome the drawbacks of natural fillers, hence expanding their technical utility[21].

4.Selection for filler

Fillers can be classified based on where they come from, for example, as natural or synthetic fibers,.The chosen qualities can be directly correlated with the filler choice[06].

Natural fabrics

Because of the volatility of petroleum oil and its resources, the use of natural-based fillers has advanced significantly over the past few decades. However, there are significant limitations to using natural fillers, particularly in advanced or technical applications (poor thermal stability, extremely combustible, high moisture absorption, change in mechanical properties, etc.). In order to get over these restrictions, more research was done on mixing the natural-based filler with different fillers. The aim was to substitute affordable, biodegradable, and renewable fillers for the synthetic ones. The majority of this evaluation study focuses on fillers that are frequently employed to enhance and/or overcome the drawbacks of natural fillers, hence expanding their technical utility[07-08].

Even if they belong to the same family or kind, the chemical makeup changes within various parts depending on the source of the fiber. Their chemical makeup, crystallinity, microfibrillar angle, flaws, and physical characteristics all affect how well they function. For them to reach their full potential, the data based on these parameters is significant. It is acknowledged that, depending on their specific components, natural fibers can degrade in a variety of ways, including biological, chemical, mechanical, thermal, photochemical, and aqueous. For example, hemicelluloses are in charge of biological deterioration,

thermal degradation, and high moisture absorption, while lignin is primarily responsible for UV and fire degradation. One of the main issues preventing their technical applications has been their inherited hydrophilic nature As a result, there is limited
stress transfer between the components of the composite due to the poor interface interaction with hydrophobic polymeric materials. Natural fiber reinforced composites have seen a number of chemical (alkaline, silane, acetylation, benzoylation, acrylation and acrylonitrile grafting, maleated coupling, permanganate, peroxide, and isocyanate treatments) and physical (plasma and corona discharge treatments) modifications aimed at enhancing interfacial adhesion and, consequently, the composite product's overall characteristics. The robust contact between the fibers and the polymer matrix was found to improve the resultant characteristics in these investigations[02].

Moreover, the natural fibers' biodegradation stability may be enhanced by treatment when subjected to various that, as will be covered in later sections, can be used to overcome and/or enhance the general characteristics of the natural fiber reinforced composites. Proteins make up animal fibers, and fillers formed of minerals include brucite, asbestos, and basalt organic matrix composites (OMCs) fall. The most popular and widely utilized matrix materials are polymer composites. Due to its advantageous mechanical characteristics, which include low mass, high stiffness, and tolerance to high temperatures, polymeric composites' mechanical capabilities can be readily applied to a broad variety of structures. Polymer composites lack the strength and rigidity of metal and ceramic composites; in order to address this issue, composites are reinforced with other materials. It is not necessary to handle polymer composites under high pressure or temperature. Equipping for the creation of composites also requires less complicated machinery[03].

synthetic fillings

Scientific communities have been introduced to a number of artificial or synthetic fillers due to their unique and advantageous properties. Glass and carbon fibers are the most often used synthetic fillers in hybridized composites. Most of these materials are successful in numerous industrial applications, such as large-scale energy generation, construction, entertainment, and many more. Interestingly, the production procedures can be designed so that the final fibers have the properties required for the particular application. Because of this quality, synthetic fillers are superior than natural fillers, which are determined by the kind of environment for harvesting and growth. The cost-to-performance ratio has been played about with by the filler's manufacturers in an attempt to come up with a less expensive production process. Their great tensile strength and tensile modulus, which can range from 50 to 90 GPa for glass fibers, however, outweigh their benefits and have facilitated the creation of commercial items[02].

Additional fillers

While mechanical qualities are the focus of the majority of published research efforts, other physical features, such as flame retardancy, are also quite important. Because natural fibers are more combustible, when they burn, they release smoke and other harmful or corrosive gasses. This makes them less successful in a variety of applications, including home goods and construction. Nanoparticles with flame-retardants can be integrated into the polymeric material to improve the hybrid goods' flame resistance in particular, making their use necessary in environments where fire safety is critical.

However, these fillers also enhance the general characteristics of hybrid composites. The majority of the time, adding flame retardant elements to a composite degrades its mechanical qualities [17]. Consequently, in an effort to combat the latter, research has focused on optimizing these fillers [17]. The incorporation of additional flame-retardant fillers into natural polymer reinforced composites will be covered in this analysis since advanced applications—particularly in the transportation and building/construction sectors—demand their inclusion.

Selection of resins

The hybrid composite product's shape, surface appearance, environmental tolerance, and general longevity are all determined by the resin. Different fillers are frequently used to reinforce thermoplastic and thermoset resins, depending on the processing method [9]. The hybrid composites and the processing methods used Because thermoplastics may be molded into a variety of shapes, they are frequently preferred over thermosets. In contrast to thermosets, the former can be remelted and treated into a new shape. Thermoplastics are typically processed by heating the polymer until it melts and becomes viscous, allowing for fiber impregnation. .. These methods include compression molding, which can be applied singly or in combination, melt mixers, and single- or twin-screw extruders. However, research has also been done on solution casting, which involves dissolving the polymer in an appropriate solution before infusing the fiber(s). The thermoplastic materials polypropylene (PP), polyethylene (PE), polystyrene (PS), and poly vinyl chloride (PVC) have been explored the most.

Thermosets' high tensile strength, high modulus, and chemical stability make them suitable for use in more sophisticated composite applications such wind turbine blades, automotive, and aerospace. Thermoset-based composites are commonly processed using the following techniques: pultrusion, vacuum-assisted resin transfer molding (VARTM), sheet molding compound (SMC), resin transfer molding (RTM), and hand lay-up, which uses less pressure [24].

thermosets have the benefit of including a lot of fibers.

Heat-resistant polymers

Thermoplastics have been a focal point for reinforced composite materials due to their inherent qualities, which include being affordable, lightweight, and easily shaped into many forms. Improving the interfacial adhesion between the matrix and natural fibers has been the focus of extensive research. In order to increase interfacial adhesion, which in turn improves the overall qualities of the resulting composite materials, chemical, physical, and biological treatments are frequently applied to the natural fibers [1, 25]. As previously explained, the chemical treatments might use alkali alone or in conjunction with other processes like acetylation, salinization, and many more. Moreover, coupling agents or compatibilizers are used to enhance interfacial adhesion, which enhances the final composite product's characteristics. Soxhlet extraction and electric discharge (cold plasma and corona) are examples of physical treatments; a biological treatment was recently reported. These kinds of treatments improve the stress transfer between the components of the composite by strengthening the interfacial adhesion between the thermoplastics and plant fibers. The most popular processing methods for thermoplastics, which can be molded into a variety of shapes and turn into a viscous solution when heated, are melt compounding and melt pressing. Extrusion, internal melt mixer, and single/twin-screw extruder are the melt compounding processing processes that can be employed singly or in combination. The primary issue with these methods is the heat they generate, which has the potential to weaken the valuable characteristics of the plant fibers. This has been one of the key factors influencing the choice of polymeric matrix, which needs to melt at a temperature significantly lower than the plant fibers' thermal deterioration. It is interesting to note that adding flame-retardant or very thermally stable synthetic fiber as a second filler can shield these fibers from processing-related thermal deterioration[02]. Polyolefins are the most researched polymers and are utilized in a wide range of applications, from high-end performance to packaging. Polyethylene andpolypropylene are the polyolefins that are studied the most frequently. These polymers have a variety of characteristics that a blend of great strength, low weight, and simple processing. Certain polyolefins can melt at temperatures lower than 200°C, which qualifies them as viable options for the creation of hybridized composites based on natural fibers . Weak interfacial adhesion is the result of the hydrophobic poly-olefin and naturally hydrophilic natural fibers, as was previously indicated. In order to improve adhesion between these parties, there has been a lot of interest in developing alternative methods of their hybridization as a result of the limited stress transmission between these components Reinforced natural-based polymers including polylactic acid (PLA), poly (butylene succinate-co-lactate) (PBSL), thermoplastic starch (TPS), polyhydroxyalkanoates (PHA), and many more have found a home thanks to the much-needed paradigm shifts towards green composites . To improve the overall qualities of the composite materials, interfacial adhesion—which is severely lacking—has been mentioned as one of the main obstacles to be addressed. To increase the interfacial adhesion between these components, several treatments—preferably chemical ones—have been used . discovered that the application of a silane coupling agent produced chemical bonding, which enhanced interfacial adhesion and, ultimately, the material's overall characteristics as a hybridized biocomposite. Hybrid composites based on PLA have been the subject of numerous published investigations. This is because of its characteristics, which are similar to those of synthetic polymers like polystyrene and PP.

The compression approach was used to produce hybridized PLA composites, as reported. Studies using melt pressing were carried out since this processing technique allows for the incorporation of woven fabric and unidirectional fibers in addition to nonwoven random fibers . Additionally, reports of twin-screw extruders and compression molding of bio-polymers were found , whereas melt Solution casting is an additional preparatory technique that provides good dispersion without deteriorating natural fibers[04].

In this instance, the filler is added after the polymer has been dissolved in an appropriate solvent. Water is usually a better solvent because it is less expensive and safe for the environment. It is acknowledged that this process would be costly for industrial production in terms of solvent recovery, and that the number of polymers that can be dissolved in the majority of available solvents is restricted. created a green hybrid composite via solution casting, which is based on fructose as a plasticizer and cassava starch as a matrix. Water was used as an appropriate solvent to reinforce the composite with cassava bagasse and sugar palm fiber (SPF). While natural-based polymers are seen as viable alternatives to polymeric materials derived from fossil fuels, their ecological shortcomings—such as moisture absorption, degradation, and cost—hinder their success in high-performance applications like wind turbine, automotive, and aerospace components. On the other hand, one could argue that because of their brief lifespan, they should be taken into consideration for packaging[08].

Thermosets

Thermosets are distinguished by their special ability to cure and form three-dimensional crosslinked networks. Epoxy resins, phenolic resins, polyurethanes, acrylics, alkyds, furans, polyimides, vinyl esters, and unsaturated polyesters are a few examples of thermosets. As will be covered below, the thermosets that have been explored the most in the context of hybridized composites are epoxy and polyester. The lengthy processing times are the primary cause for concern for thermosets. Additionally, since thermoset-based composites are not very recyclable, new approaches to creating environmentally friendly recycling systems are needed. They can be ground and used again, for instance, as fillers. For a number of years, optimizing the processing temperatures and changing the thermosets' toughness have been the key goals. Furthermore, the processing temperatures (which range from 25 to above 100 °C) are far lower than the temperature at which plant fibers degrade. Table 5 summarizes the methods used for resin impregnation, which include vacuum-assisted resin infused mending, vacuum-assisted transfer molding, vacuum bag resin transfer molding, and manual

layup.
The production of thermoset-based composites for high-end industries like aerospace and automotive frequently uses vacuum-assisted techniques . The benefits of vacuum-assistance strategies, such as minimal preparation costs and comparatively low emissions of volatile organic compounds (VOCs) in comparison to traditional processing methods (e.g. compression molding). One of the processing methods that is typically used to prepare thermoset hybrid composites is hand layup, which is followed by gentle compression during curing; this is because it is less expensive and simpler to implement in a laboratory setting . There have also been reports in the literature on compression molding alone . Epoxy resin, which went on sale in the 1950s, has excellent creep, heat, and solvent resistance in addition to its high strength and stiffness. Their backbones' existence of epoxy groups, or oxirane rings, allows for their identification.Networks that are crosslinked are the outcome of a reaction with a curing or hardening chemical. Interestingly, Compared to the majority of unsaturated polyesters, they shrink less[06-08].

Moreover, compared to other thermosets, less pressure is needed to prepare epoxy composites. It is possible to select the ideal epoxy resin for the particular application or performance from a wide range of viscosities. By altering the type of resin and the curing agent, the former can be customized. It has been used on high-strength structural parts for the automotive, aerospace, and wind turbine industries. This helps reduce fuel consumption (in the case of light vehicles and airplanes) and produce green energy. Numerous investigations have been conducted using the manual lay-up processing method. This technique is sometimes used with light compression, which involves applying some weight while the material cures at room temperature or in the presence of heat. However, Saba et al. [3] and others also used compression molding alone, while also used VARTM.
There are several types of polyester resins, such as unsaturated polyester, vinyl ester, alkyd, and saturated polyester, which are similar to epoxy resins. Out of all these resins, Table 5 lists unsaturated polyester and vinyl ester as the most investigated, especially when it comes to hybrid composites. The type of resin used determines the mechanical and chemical characteristics of the polyester resins[03].

5.Properties of hybrid polymer composites in terms of mechanics

The mechanical properties of composites composed of hybrid polymers are influenced by several factors. The dispersion and distribution of the reinforcements within the chosen polymer matrix, the adhesion of the polymer and reinforcements on the interfacial surface, the large surface area and high aspect ratio of the reinforcements, their mechanical properties, the loading effect, surface modification, and, in the case of natural fibers, the fiber dimension and orientation are some of these variables. Numerous studies routinely report mechanical parameters as a function of size, stress, and fiber treatment. In order to construct polymer composites from both thermosets and thermoplastics, a significant deal of information has been published regarding the evolution of natural and synthetic fibers, as well as the coupling of fibers with nanomaterials and the clarification of their mechanical and thermomechanical properties[01].
. As demonstrated in Table 6, the use of many reinforcing types is warranted since the advantages of one type can counterbalance the disadvantages of another, enhancing the overall properties and performance of the material. Moreover, there is an increasing demand for these materials' development since they meet the requirements of many products, such as door panels and car interiors in transport vehicles. The way hybrid materials behave mechanically can be projected based on a range of material data, such as the reinforcements' volume percentages, test settings, distribution and dispersion, and the mechanical properties of the matrix and the reinforcements (fibers or particles). The Rule of Mixture (ROM) is a widely used method for forecasting the mechanical behavior of hybrid materials. The literature has described a number of ROM-based models for forecasting the mechanical characteristics of hybrid composite materials[06].

reinforcement volume fractions, reinforcement dispersion and distribution, matrix mechanical properties, and other material factors By using reinforcements like fibers or particles, the mechanical behavior of hybrid materials can be anticipated. One popular technique for predicting the mechanical behavior of hybrid materials is the Rule of Mixture (ROM). Several ROM-based models for predicting the mechanical properties of hybrid composite materials have been reported in the literature[09].

Theoretical models Tsai-Pagano, Hirsch, Reuss, and Voigt are among them.

$$E_c = E_f V_f + E_m V_m \qquad (3)$$

where

$$V_f + V_m = 1 \text{ or } V_m = 1 - V_f \qquad (4)$$

$$\therefore E_c = E_f V_f + E_m (1 - V_f) \qquad (5)$$

where E and V are the volume fraction of reinforcement and Young's modulus, respectively. The terms composite, fibers as matrix, and reinforcement are denoted by the subscripts c, f, and m, respectively.

By adding the two systems (polymer composite reinforced with fiber 1 and polymer composite reinforced with fiber 2) and assuming that the strain of the hybrid is equal to that of each system, equation (6) shows how to calculate the Young's modulus (Ehc) of hybrid composites[06].

$$E_{\mathrm{hc}} = E_{\mathrm{c1}} V_{\mathrm{c1}} + E_{\mathrm{c2}} V_{\mathrm{c2}} \tag{6}$$

where Ec1 and Ec2 are the elastic moduli for composites 1 and 2, and Vc1 and Vc2 are the volume fractions of systems 1 and 2, respectively (Equations (7)–(9):

$$V_{\mathrm{c1}} = \frac{V_{\mathrm{f1}}}{V_{\mathrm{t}}} \tag{7}$$

$$V_{\mathrm{c2}} = \frac{V_{\mathrm{f2}}}{V_{\mathrm{t}}} \tag{8}$$

$$V_{\mathrm{t}} = V_{\mathrm{f1}} + V_{\mathrm{f2}} \tag{9}$$

where Vt stands for the total volume fraction of reinforcement. Nonetheless, the Equation was utilized to ascertain the hybrid composites' Young's modulus.

$$E_{\mathrm{hc}} = E_{\mathrm{f1}} V_{\mathrm{f1}} + E_{\mathrm{f2}} V_{\mathrm{f2}} + E_{\mathrm{m}} (1 - V_{\mathrm{f1}} - V_{\mathrm{f2}}) \tag{10}$$

Before applying these formulas, it is important to assume the following: that the load applied is parallel to the direction of the fibers; that the fibers in the hybrid do not interact; and that the fibers are dispersed, spaced, and aligned uniformly throughout the polymer matrix.

Most examinations found that the expected elastic moduli and the actual values agreed. For example, Venkateshwaran et al. found that adding sisal fibers to a hybrid composite reinforced with banana fibers increased the material's tensile strength and modulus to a 50:50 ratio for materials examined in both transverse and longitudinal orientations. The tensile strength and modulus of hybrid composite materials decreased with increasing sisal fiber loadings. Additionally, it was discovered that the tensile modulus that
As was previously mentioned, ROM predicts the elastic modulus of continuous, well-aligned fiber hybrid composites. However, this model does not predict the elastic modulus of a hybrid composite reinforced with discontinuous fibers and small particles. To predict the elastic modulus of poly-propylene hybrid composites reinforced with core fibers and core shell particles, the Tsai-Pagano equation (shown in Equation (11) was applied[10].

$$E_{\mathrm{hc}} = \frac{3}{8} E_1 + \frac{5}{8} E_2 \tag{11}$$

where core fibers and core shell particles, respectively, enhance the composite's elastic moduli, E1 and E2. Tsai-Pagano theory, like ROM, is predicated on the assumption of adequate fiber alignment, dispersion, and distribution, as well as interfacial adhesion between the reinforcements and the polymer matrix. The scientists discovered that applying a force of 5000 MPa to the particles in the core shell produced the best match. Additionally, it was discovered that the predicted and experimental elastic moduli had a similar connection[07].

Conversely, for the hybrid composite prediction's tensile strength (σ), Equation (14) was obtained by applying an equilibrium force (Fhc) to the hybrid cross-section area (A) [92] (Equations (12), (13)). But still:

$$F_{\mathrm{hc}} = F_{\mathrm{f1}} + F_{\mathrm{f2}} + F_{\mathrm{m}} \text{ and } F = \sigma \cdot A \tag{12}$$

Then,

$$\sigma_{\mathrm{hc}} A_{\mathrm{hc}} = \sigma_{\mathrm{f1}} A_{\mathrm{f1}} + \sigma_{\mathrm{f2}} A_{\mathrm{f2}} + \sigma_{\mathrm{m}} A_{\mathrm{m}} \tag{13}$$

$$\therefore \sigma_{\mathrm{hc}} = \sigma_{\mathrm{f1}} V_{\mathrm{f1}} + \sigma_{\mathrm{f2}} V_{\mathrm{f2}} + \sigma_{\mathrm{m}} (1 - V_{\mathrm{f1}} - V_{\mathrm{f2}}) \tag{14}$$

As with tensile modulus, there was agreement between the tensile strength predicted by ROM and the actual tensile strength [01]. For instance, Yusoff et al. [07]
subjected to carbon tetrachloride, both treated and untreated hybrid composites lose weight. However, compared to the untreated hybrid composites, the treated hybrid composites shed more weight for the following reasons:

Chlorinated hydrocarbons hydrolyze polyester, causing alkali group disintegration and crosslinking. The impact of water absorption on the mechanical characteristics of orthophthalic polyester hybrid composites reinforced with curaua and E-glass fiber was examined by Silva et al. 67. The mechanical properties of the non-hybrid composites constructed of curaua natural fibers and the hybrid composites exposed to both seawater and distilled water were assessed. Diffusion rates of distilled water and saltwater have been shown to be equal for up to 330 hours. Chlorinated hydrocarbons hydrolyze polyester, causing alkali group disintegration and crosslinking.
The effects of water absorption on the mechanical characteristics of orthophthalic polyester hybrid composites reinforced with curaua and E-glass fiber were examined by Silva et al. 67. The mechanical properties of the hybrid composites were compared to those of the non-hybrid composites manufactured of curaua natural fibers after they were subjected to both seawater and distilled water. Diffusion rates of seawater have been found to persist for as long as 330 hours. as well as deionized water are equivalent resilience of hybrid composites affixed to glass and textile materials in both freshwater and marine settings

.Variations in the length of the immersion resulted in modifications to the defining parameters' size. The type of fracture was identified by scanning electron microscopy research, which also showed that seawater conditions have different characteristics for fiber pullout, matrix cracking, and crack propagation. It was discovered that under both freshwater and seawater circumstances, the specimen with a higher glass content had a higher critical stress intensity factor. Furthermore, as the immersion period grew, the interlaminar shear and flexural strengths decreased in seawater. Abdul Khalil et al.69 conducted an experimental study using jute and reinforced oil palm fiber[12].

epoxy composites to determine the thickness swelling and water absorption percentage. In comparison to pure oil palm fiber reinforced epoxy composites, they have shown an improvement in the previously described properties by hybridizing the oil palm fiber composite with the jute fibers. When jute layers were positioned at the extremes of the hybrid composites, as opposed to oil palm layers at the endpoints, the characteristics of the composites improved more. It was also demonstrated that the density of the composite, the existence of voids, and the bonding between the fiber
and the matrix are closely related to the capacity to absorb water and swelling of the thickness. Zamri and associates [07].

Conclusion

This study provides an overview of natural fiber-based composites, with a focus on their properties, including flammability, mechanical, thermomechanical, water absorption, and applications. Hybridization gained popularity due to its potential to overcome the obstacles preventing natural fibers from being applied in technical constructions, in addition to the enhanced performance of the products that resulted from it. From an ecological and economic perspective, it is quite likely that a significant portion of natural fibers will be added to standard synthetic reinforced composite products. The quality of the natural fibers, which are contingent upon their maturity and growth conditions, nevertheless introduces variability into the finalcharacteristics of items made using hybrid composites. Research on customization and quality assurance could completely change the way natural fibers are marketed. However, by adding a second filler, either micro- or nano-sized, some of the drawbacks of natural fiber reinforced composites can be addressed.
. By adding flame-retardants, polymers become more flammable and thermally stable, which can lead to new opportunities for high-end technical applications. It is important to note that hybrid composites based on natural fibers open up a competitive market for a range of industrial uses. Additionally, the models are important for forecasting the characteristics of hybrid products, which allows designers to use them to save time and money. predict the resulting properties. In future, the modifications of models in order to include all aspects, such the interaction between the components will perfect the predicted results.

References

1.Materials science and engineering: an introduction, Callister Jr. WD. New York: John Wiley & Sons, 6th ed.

2. Mubarak Khan A, Ruhul Khan A, Haydar Zaman U, et al. Impact of urea and potassium permanganate on enhancing the mechanical characteristics of jute-polypropylene composites. (2010) Fiber Polym 11(3): 455-263.

3. Yang Y, Morii T, Ota T, and others. Mechanical characteristics and hydrothermal aging of polypropylene/jute injection-molded composites. (2011) J Mater Sci; 46: 2678–2684.

4. Beg MDH, Alam AKMM, Quazi Shubhra TH, et al.

Mechanical and degrading properties of composites reinforced with polypropylene and synthetic phosphate glass fiber and natural silk. 45(12) J Compos Mater: 1305–1313.

5. Gupta AVSSKS, Mohana Rao K, Ratna Prasad AV, and others. A research on wildcane grass's flexural characteristics

6. Piao Y, Suardana NPG, and Lim JK. The impact of chemical surface treatment on the mechanical properties of hemp fibers and hemp/PP composites. Phys Mech Mater 2011; 11: 1–8.

7. Thiruchitrambalam M, Manikandan V, Athijayamani A, et al. Mechanical characteristics of polyester hybrid composites bonded with natural fibers. 2010; 14(1); Int J Plast Technol: 104–116.

8. Pattarachaiyakoop N, Ku H, Wang H, and others. An overview of the tensile characteristics of polymer composites reinforced with natural fibers. Part B of Composites, 2011; 42: 856–873.

9. Negi YS, Kumar V, and Malkapuram R. Recent advancements in polypropylene composites bonded with natural fibers. 2008; 28(10): 1169–1189. J Reinf Plast Compos.

10. Mohanty AK, Drzal LT, Joshi SV, and others. Are glass fiber-reinforced composites less environmentally friendly than natural fiber composites? Part A of Compos: Application

11. Quazi Shubhra TH, Alam AKMM, Gafur MA, et al. Characterization of natural fiber reinforced polypropylene composites based on plants and animals and a comparative analysis of them. 2010; 11(5): 725–731. Fiber Polym.

12. Verpoest I, Ivens J, and Wambua P. Can glass be substituted with natural fibers in fiber-reinforced plastics? 2003; 63(9): 1259–1264, Compos Sci Technol.

13. Tung NH, Ogihara S, Nam TH, and others. Impact of alkali treatment on the mechanical and interfacial characteristics of biodegradable composites reinforced with coir fiber and poly(butylene succinate). Part B of Composites 412.12: 1648–1656, 2011.

14. Lau K-T, Ho M-P, Cheung H-Y, and others. Composites reinforced with natural fibers for use in environmental and bioengineering fields. Part B of Composites: 2009; 40(7): 655–663.

15. Houston D. and Holbery J. Composites made of polymers bonded with natural fibers for automotive use. Mineral and Materials Society Journal 2006; 58(11): 80–86.

16. Hinrichsen G, Misra M, and Mohanty K. Biofibres, biodegradable polymers and biocomposites: an overview. Macromol Mater Eng 2000; 276–277(1): 1–24.

17. Monteiro SN, Lopes FPD, Ferreira AS, et al. Naturalfiber polymer–matrix composites: cheaper, tougher, and environmentally friendly. J Mineral Metal Mater Soc 2009; 61(1): 17–22

18. Kestur Satyanarayana G, Wypych F, and Gregorio Arizaga GC. An overview of biodegradable composites based on lignocellulosic fibers. Journal of Polymer Science 2009; 34(9): 1022–1027.

19. Zhang MQ, Lu X, and Rong MZ. All plant fiber composites are completely biodegradable natural fiber composites made from renewable resources. 2005; 65(15–16): 2514–2525 in Compos Sci Technol.

20.Munikenche Gowda T, Naidu ACB, and Chhaya R ranked 20th. A few mechanical characteristics of untreated polyester composites bonded with jute fiber. Part A of the composition: Appl Sci Manuf 1999; 30(3): 277–284.

21. Santulli C. Impact properties of hybrid laminates made of plant fiber and glass. 2007; 42: 3699–3707 in J Mater Sci.

[22] Hayashi, T. 'On the improvement of mechanical properties of composites by hybrid composition', Proceedings of the Eighth International Reinforced Plastics Conference (October 1972) paper 22.

[23] Hofer,.K.E., Rao, N. and Stander, M. 'Fatigue behaviour of graphiteglass-epoxy composites', Proceedings of the Second International Carbon Fibers Conference (February 1974)

[24] Tetlow, R. - Carbon Fibres in Engineering, Chap. 4, Ed. M. Langley McGraw Hill Sept, 1973.

[25] Tetlow, R. - Design and Testing of Some Reinforced Plastic Components "Fibre Reinforced Materials" Inst. Of Civil Eng. 1977.