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A Review on Composite Material Reinforced With Natural Fibers

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Abstract: Materials plays vital role for survival of any manufacturing industry. Conventional materials are replaced by composite material because of their high specific strength, strong damping capacity and high specific modulus. In modern era, natural fiber reinforced polymer composites came into light because of promising properties of natural fibers such as light weight, water resistance, high impact strength, environment friendly etc. In this study, different types of natural fibers that can be used as reinforcement in polymer composite are discussed. Various methods of production and steps involved in processing of natural fiber reinforced composite are presented. Then, mechanical and tribological properties of these composites are reviewed and presented. The different applications of natural fiber reinforced polymer composite are also discussed.
Keywords: Natural Fiber, Properties, Mechanical, Composite.

I. INTRODUCTION

Materials are considered as most important pier of any manufacturing industry. There are various materials employed in manufacturing industry ranging from pure metals to alloys to composites. This shifting of materials from pure metals to composites takes place due to shortcoming of pure metals to satisfy the expectations of modern products. In modern era, composite materials are extensively employed in manufacturing industry and replace the traditional materials to a bigger extent because of their promising properties like high specific strength, strong damping capacity and high specific modulus. Composite materials were firstly developed in 19400s by using the fiber as reinforcement [1]. Composite materials are defined as multiphase materials comprising of two or more components possessing special properties [2]. The reinforcement and matrix are two main components of any composite material as shown in Fig. 1 [1]. Reinforcement is the principal component of composite and is the part that takes most of the load applied on the composite material. As reinforcement has to take the load, it must be hard, brittle and have high strength. Matrix is that component of composite that just surrounds the reinforcement. It only protects and supports the reinforcement. There are various factors that influence the properties of the composite materials such as type of reinforcement and matrices, the arrangement and scattering of reinforcement and volume of reinforcement and also the method of production of composites [3]. Composite materials are classified into different categories on the basis of shape of reinforcement and kind of matrix [4,5]. Fiber reinforced composites are most generally employed in the automotive and aircraft industries due to its excellent properties like high strength, light weight, water resistance, chemical resistance, high durability, electrical resistance, fire resistance and corrosion resistance [6]. They are also used in the infrastructure and structural applications [7,8]. Fiber reinforced composites uses different types of fibers as reinforcements such as glass fiber, carbon fiber or natural fiber and polymer as matrices namely plastic, resin, rubber or metal [9].

II. NATURAL FIBER REINFORCED POLYMER COMPOSITE

In the earlier times, only synthetic fiber based reinforced composites were used due to low cost and good mechanical properties [10]. These composites use the glass fiber or carbon fiber as reinforcement for composite materials. In the modern time, sustainability is the major concern of all the research. For sustainable development, there is a great need as well as challenge for every industry to replace the non-sustainable products with the sustainable ones [11]. Also, because of the limited amount of conventional energy resources and rising environmental concerns, we have got to shift towards the renewable raw materials for the development of new components [12]. Owing to the above reasons, it leads to the replacement of synthetic fibers with natural fibers as reinforcement in fiber reinforced composites. Other than this, natural fibers also have many other benefits compared to synthetic fibers such as low relative density, low cost, high impact resistance, and high flexibility, low specific gravity, less abrasiveness to

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equipment, less health hazards, process-friendly, lower greenhouse emissions, recyclability and CO2 neutral [13,11,14,15,12,16,10]. Also, natural fiber composite contain more fiber content which successively decreases the content of harmful base polymer in composite [16]. Hence natural fiber reinforced composite is safe for environment. Natural fiber based composite are extensively used in automotive applications. This is due to their light weight which leads to lesser fuel consumption and reduced emissions of harmful gases [16]. Natural fiber reinforced composite even have extensive application in electronics and sporting goods. There are various other products like bicycles, tennis rackets, laptop cases that may be manufactured using natural fiber composites [17]. Because of the above mentioned properties and applications of natural fiber based polymer composites in present time, research in composites has been shifted from synthetic fiber based composites to natural fiber reinforced composites. Despite these, there are some issues also within the development of these composites. Hydrophilic nature
of natural fibers reduces the application of natural fibers as reinforcement in polymer composites. This is because of the less moisture resistance and poor wettability of natural fibers that decrease the bonding between the matrix and reinforcement [14]. This leads to the development of composite with poor mechanical properties [18,19]. For overcoming this, chemical treatment of composites can be carried out. Natural fibers also possess the tendency to make aggregates during manufacturing of composites that limits the application of natural fibers in manufacturing of composites [12]. Lesser dimensional stability is also a disadvantage of natural fiber reinforced composite [12]. Thermal stability of natural fibers limits their use as reinforcement in composites to some extent [20].

1) *Sources of Natural Fiber:* Natural fibers are fibers which are obtained from plants and animals. In this study, we deals with only plants based natural fibers. There are primary and secondary plants that produce the natural fibers on the basis of their usage. Plants which are grown just for their fiber contents are known as Primary plants whereas plants from which fibers are produced as bi-product are called secondary plants. Jute, hemp, kenaf and sisal are primary plants and pineapple and coir are secondary plants.
2) *Types of Natural Fiber:* There are various types of natural fibers available for using as reinforcement in the development of natural fiber reinforced polymer composites. Some natural fibers that yield excellent results as reinforcement in polymer composites are Pineapple leaf fiber, Bamboo, Jowar, Banana, Jute, Hemp, Flax, Sisal etc. Natural fibers are categorised into six types which are as follows: a) Reed Fibers: These fibers includes wheat, corn and rice. b) Leaf Fibers: Abaca, Sisal and Pineapple are leaf fibers. c) Bast Fibers: Jute, Flax, Hemp, Ramie and Kenaf are examples of bast fibers. d) Seed Fibers: These Include Coir, Cotton and kapok. e) Core Fibers: Kenaf, hemp and jute are examples of these fibers. f) All other types: It includes woods and roots. Jowar fiber due to its low density compared to other natural fibers can be extensively used in manufacturing Lightweight materials for housing sector, automobile body building and packaging industry etc. [13]. Table 1 shows the major natural fiber source, their production in world and major applications.
3) *Matrix:* Polymer matrix in composites may be classified into two types i.e. Thermosetting and Thermoplastics as shown in Fig. 2 [17]. Polypropylene, polyurethane, nylon etc. are examples of thermoplastic matrices whereas epoxy and polyester are some of the thermosetting matrices commonly used. Depending on the type of matrices, composite materials are classified as i) Resin matrix composites, ii) Metal matrix composites, iii) Ceramic matrix composites.

The most widely used matrix in polymer composite is epoxy resin because of its promising properties such as low shrinkage, low toxicity, good adhesion properties and high industry applications [22]. Brittleness and low fracture toughness of epoxy are factors that limits its use in industries [23].

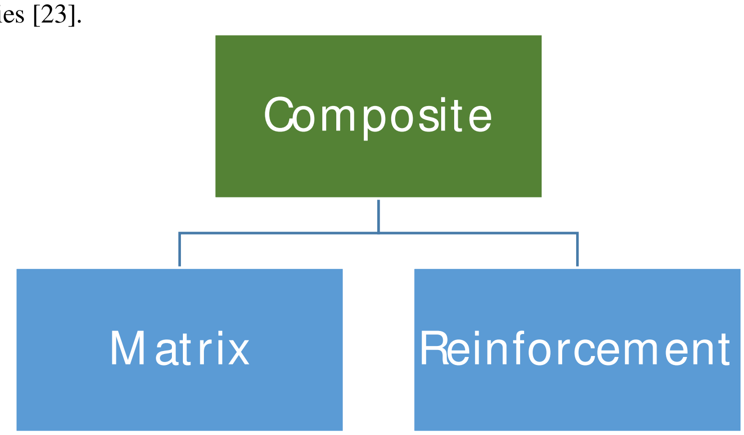

Fig. 1. Components of Composite.

Table 1 - Major Fiber Source, their production and applications [21,10].

S. No.	Fiber Source	World Production	Applications
1	Bamboo Fiber	30000	Commonly used in construction and carpentry industries
2	Jute Fiber	2300	Packing, geotextiles, door frames and shutters, building panels, chip board
3	Kenaf Fiber	970	Mobile cases, insulations, bags, packing materials, animal bedding
4	Flax Fiber	830	Tennis racket, snowboarding, window frame, decking, fencing, bicycle frame
5	Sisal Fiber	378	Construction industries such as door, panels, roofing sheets, etc.
6	Hemp Fiber	214	Furniture, electrical, paper industry, textile industry, cordage
7	Coir Fiber	100	Flush door shutters, mirror casing, filling material for upholstery, brushes and brooms, ropes and yarns for nets, seat cushions, roofing sheets
8	Ramie Fiber	100	Packing material, industrial sewing thread, fishing net, household furnishings and clothing, paper manufacture

III. METHODS OF PROCESSING

Natural fiber reinforced polymer composites are manufactured by various methods viz. hand lay-up technique, injection molding, compression molding and resin transfer molding. The methods of processing include three steps i.e. removal of moisture from natural fiber, mixing of fiber and matrix and part fabrication. From different studies, it has been found out that 80_ C is the optimal temperature for the removal of moisture from natural fibers [19,24,25,26]. Extrusion and mixing using internal mixing machine are the two methods most commonly used for mixing of fiber and matrix [17]. The compression molding technique and injection molding technique are standard techniques used for manufacture of natural fiber reinforced polymer composite [27]. Injection molding possess various advantages in comparison to other methods such as mass production, smaller production cycle and closer tolerances in complex parts [28,29]. Compression molding also possess advantages such as lesser waste and low cost along with high reproducibility and low cycle time [29,30,15,21].

There are various factors that affect the processing such as moisture content of natural fibers, type and content of fiber and length of fiber [21]. Table 2 shows the different mixing and manufacturing processes of composite depending upon the type of fiber and length of fiber. From table, it is clear that Manual mixing process and Hand lay-up technique are suitable for manufacturing composite have long natural fibers whereas short length natural fiber reinforced composite can be easily manufactured using automatic mixing process and compression molding technique.

Titania reinforced epoxy composites are prepared by simple mechanical stirring and functionally graded composites are developed by vertical centrifugal casting technique [31]. Multi component hybrid composite can be prepared by simple Hand Lay-up technique [32]. Injection molding technique is also used for fabricating composite and it is considered as more precise methods than other methods [14]. During the development of polymer composites, distortions and wrinkling of fibers are the frequent problems that rises [33]. If composites are produced by conventional extrusion method, it may leads to damaging of fibers and shortening of length of fiber [34]. There is a new method for developing the natural fiber reinforced composites that is the combination of molded fiber production method and resin transfer molding processes. This new technique enables us to produce composite successfully at 5 mm thickness [11].

IV. MECHANICAL PROPERTIES

Mechanical properties of composites are very important factors that promote the usage of composites in different industries such automobile industry, housing sector etc. Following are the various researches regarding mechanical properties of natural fiber reinforced composites. Chemical composition of natural fiber effects the properties of natural fiber reinforced composites. Cellulose content in natural fiber determines the mechanical properties of that fiber which in turn effects the properties of natural fiber reinforced composite [39,40,41]. Amount of hemicellulose and lignin also effects the properties of natural fibers [42].

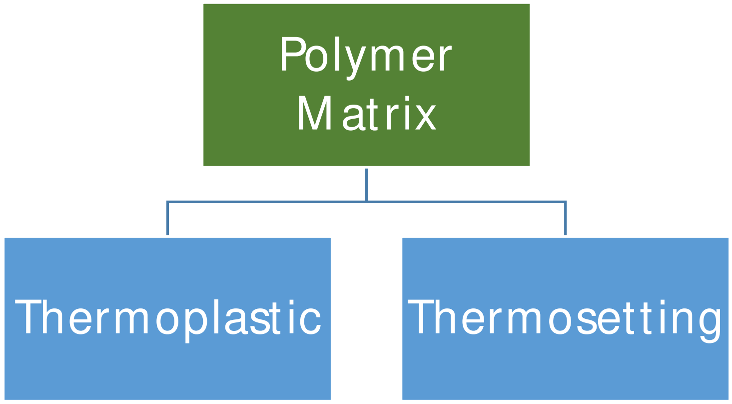

Fig. 2. Classification of Polymer Matrix.

Table 2- Different Mixing and Manufacturing Processes Based on Different natural fiber and their Length [17,35,36,37,38].

S. No.	Natural Fiber	Matrix	Mixing Process	Manufacturing Processes	Critical Length (mm)
1	Hemp Fibre	Polyester	Manual Mixing	Vacuum Bagging Method Hand lay-up technique	3.4
2	Kenaf	Unsaturated Polyester	Kenaf fibre was put into the mold into which resin was injected with a pressure of 1.3 bar	Resin Transfer Molding	6
3	Pineapple Leave Fiber (PALF)	High Impact Polystyrene (HIPS)	Internal Mixing Compression	Molding	0.5
4	Banana	Epoxy	Epoxy resin was put into the mold into which fiber was manually laid.	Hand lay-up technique	15
5	Kenaf	Soy based resin	Extrusion	Compression molding	6
6	Bamboo	Starch	Manual Mixing	Dried in an oven	15
7	Kenaf-PALF	High Density Polyethylene (HDPE)	Internal Mixing	Compression Molding	1.0
8	Basalt	Polyester	Manual Mixing	Compression Molding	10
9	Agave	Epoxy	Stirring Process	Compression Molding	3

Large amount of hemicellulose and lignin in natural fiber is not desirable as it leads to high moisture absorption and biodegradation of fiber. For developing the composite with good mechanical properties, we have to use the natural fiber having high cellulose content and low hemicellulose and lignin content. Physical properties such as length and diameter of natural fiber also influence the mechanical properties of composite. Natural fibers having small diameter have more positive impact on mechanical properties than large diameter fibers. If length of fiber is less than the critical length, it leads to the decrease in the stress transfer efficiency between fiber and matrix that results in poor mechanical properties. Percentage of fibers is also an important factor for mechanical properties of composites. Increase of high strength fiber content results in enhancement of mechanical properties. But if content of high strength fiber increases beyond optimum value, it may leads to deterioration of mechanical properties. This is because of the reason that with increasing fiber content, matrices composition is reduced which leads to weaker interfacial bonding between matrix and composite. Manufacturing technique also has an impact on mechanical properties of composite.

Removal of moisture from raw material, process of mixing between fiber and matrix and fabrication of part are three steps involved in manufacturing process of composite. There are various tests available for determining various mechanical properties. Flexural Properties may be obtained by using three point bend tests. From literature, it is observed that density of reinforced polymer composites increases with the volume fraction of particulates. Porosity content in the composites also increases with volume fraction. Large porosity content in the composites decreases the fatigue resistance of composites [32]. For epoxy-TiO2 particulate filled graded composite, with the increase in weight fraction of TiO2, there is a decrease in tensile strength of composites [31]. Also, the tensile strength of composites changes with the change of filler material in composite [32]. The tensile strength of natural fiber reinforced composites also depend on many other factors namely hydrophilicity of fiber, length of fiber and chemical nature of fiber [14]. For glass–epoxy composites, the impact strength improves with the addition of particulate fillers such as SiC and Al2O3 [9]. By adding pine bark dust as filler into polymer composite, surface hardness of composite can be increased to a larger extent [32]. Tensile strain decreases with the increase in content natural fibers in composite [15]. By adding the plasticizers obtained from vegetable oils that are environment friendly such as Epoxidised linseed oil and maleinized linseed oil to the polymer composite, the mechanical properties of composites such as tensile strength, impact strength and flexural strength can be improved to a large extent. The configuration of fibers in natural fiber reinforced composites also determines various properties of these composites. The configuration of fibers are unidirectional, bidirectional or multidirectional [13]. Interfacial bonding between fiber and matrix and strength of fiber and matrix are the parameters that effect the overall strength of composites [15]. Uniform stress distribution in composite leads to good tensile strength of composite. By adding fibers in polymer composite, there is a weight loss of composites which makes them suitable for lightweight applications. As far as long term properties of natural fiber reinforced composites are concerned, the tensile properties of composites reduce with the increasing heat and exposure time. Elastic modulus of composites increase with the age of composites. Banana fiber in reinforced composites results in increased hardness of composites. Tensile strength of composite increases with increase in loading of fiber. Hardness of composite also increases with the increase in concentration of hemp fiber.

V. TRIBOLOGICAL PROPERTIES

Tribological properties of composites play an important role in selection of material for different purposes. As composite materials which are using in the industries are exposed to different types of wears such as adhesive, abrasive during their service life, so tribological performance of composites are very important to consider. Along with this by considering tribology of composites, we can save a lot of energy which is required for overcoming friction between two moving surfaces. Following are the various work carried out by researchers on the tribological properties of natural fiber reinforced composites. Natural fiber reinforced composites can be used in some applications where they may be subjected to solid particle erosion. So, for using composites successfully in these applications, we have to work on improving wear resistance of these composites. With the increase in fiber loading of bamboo, the hardness of bambooepoxy composites improves which in turn improves the erosion resistance of composites [14]. Graded composites possess excellent wear resistance than homogeneous composites [31]. Reinforced glass fiber composites filled with SiC filler possess least wear resistance in comparison with the Al2O3 and pine dust filler [32]. Wear in composites having Al2O3 filler are mainly caused by micro-cutting and plastic deformation [32]. By reinforcing the composites with short fiber, abrasion resistance of composites is reduced. Chemically treated fibers shows excellent strength properties than mechanically treated fibers in natural reinforced fiber composites [11]. Suresh et al have reported that hybrid composite containing 20% banana-hemp fiber possess low coefficient of friction an low wear loss at all sliding conditions. At low loads, fibers are not much beneficial in improving wear resistance of composite as wear resistance at low load is mostly provided by matrix. Natural fibers like hemp fiber are effected in providing wear resistance to composite at higher load conditions because of no-brittle behaviour of natural fiber that wear resistance of composites is reduced by increasing the fiber length. Nirmal et al. investigated wear performance of bamboo fiber reinforced epoxy (BMBFRE) composite at different orientations which are anti-parallel orientations (AP-O), parallel orientations (P-O) and random orientations (R-O). They found that composites with anti-parallel orientations exhibit best wear resistance than other orientations. This is due to the excellent shear resistance offered by bamboo fiber in AP-O. Gopakumar and Rajesh had reported that sisal fiber reinforced composite shows a great decrease in material removal and hence enhanced wear resistance. Ibrahim et al. found that by adding wood flour as reinforcement to polypropylene composites, tribological properties of composite such as wear resistance, coefficient of friction etc. has been improved to a large extent. This is due to the development of polymeric chains on the surface of composite that prevents the direct contact. The coefficient of friction for ramie fiber in polymer composite increases with the increase of fiber loading.

VI. CONCLUSION

From above discussion, it can be concluded that natural fibers are potential candidates for replacing the synthetic fibers as reinforcement in polymer composite because of their excellent properties such as low density, low cost, high impact resistance, and high flexibility, low specific gravity, less abrasiveness to equipment, less health hazards, process-friendly, lower greenhouse gas emissions, recyclability and CO2 neutral. Less moisture resistance and poor wettability of natural fibers hinders their application in composites to some extent, but this can be overcome by chemical treatment. Hand Lay-up technique, injection molding technique and compression molding process are some methods of processing of natural fiber reinforced polymer composite. Amount of cellulose and hemicellulose have great impact on mechanical properties of these composites. Various other factors that affect the mechanical properties of composites are diameter, length of fiber, fiber content and manufacturing technique. Different orientations of fiber in composite effects the tribological properties of composite. Wear resistance of composites are increased by increasing the fiber loading. Coefficient of friction of these composites increases as well as decreases with the increase of fiber loading. These both have their applications in different areas. Reduction in coefficient of friction has application in moving parts of automobiles whereas increase in friction has application in brake pads. There is lot of natural fibers available in the world which can be used as reinforcement for development of new natural fiber reinforced polymer composite. Thermal properties of natural fiber reinforced polymer composite are less explored and provide a good future scope in this area.

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