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Natural Fiber Reinforced Polymer Composite Material-A Review

Tushar Sonar[1], Shirish Patil[2], Vikram Deshmukh[3], Rishi Acharya[4]
[1] (Department of Mechanical Engineering, Maharashtra Institute of Technology Aurangabad, M.S, India)
[2, 3] (Department of Mechanical Engineering, Rajarshi Shahu College of Engineering Pune, M.S, India)
[4] (Barkatullah University - College of Engineering, Bhopal, Madhya Pradesh)

Abstract : *Natural fiber reinforced polymer composite is the composite material in which natural fibers are used to reinforce the polymer matrix so as to improve its mechanical properties. These are environmental friendly and cost effective to synthetic fiber reinforced composites. The availability of natural fiber, low cost and ease of manufacturing have urged researchers worldwide to try locally available inexpensive fiber and to study their feasibility for reinforcement purposes and to what extent they satisfy the required specifications of good reinforced polymer composite for Industrial and Structural applications.*

Natural fibers need to be treated chemically so as to improve interfacial adhesion between fiber surface and polymer matrix. The chemically treated natural fibers show better improvement in properties than untreated fibers. This can be attributed to the removal waxy layer from the surface of natural fibers and thus making it rougher. Natural fiber reinforcements have resulted in improved impact toughness and fatigue strength. Many efforts have been made by researchers towards improving mechanical properties, directed at improving the interface between fiber and polymer. This review aims at explaining about the research and development in the improvement in properties of natural fibre reinforced polymer composites along with its application.

Keywords *- Chemical modification, Interfacial bonding, Mechanical properties, Natural Fiber, Polymer.*

I. INTRODUCTION

Now-a-days interest in Natural fiber reinforced polymer composites are increasing rapidly due to its many advantages. These composites are more eco friendly and frequently used in many engineering applications worldwide such as in automobile, aerospace, construction (ceiling, partition boards etc.) and household applications etc. In fiber reinforced polymer composites, the fibers can be either synthetic fibers or natural fibers. The fibers derived from natural resources like plants are termed as Natural fibers. A great deal of research work has already been made on the prospective of the natural fibers as reinforcements for composites. Advantages of natural fibers over synthetic fibers comprise low density, low cost, availability, recyclability and biodegradability [1-5]. Due to their numerous advantages they are supposed to be analogous to those of synthetic fibers used as reinforcements.

The synthetic fibers used for reinforcement in SFRPCs are glass, carbon, aramid, Kevlar etc. Synthetic FRPCs have unique advantages over monolithic polymer materials. Besides high strength and high stiffness, these composites have long fatigue life and adaptability to the intended function of the structure. Although the SFRPCs possess exclusive mechanical strength, they have some serious drawbacks such as high cost, high density (as compared to polymers), and poor recycling and non biodegradable properties. For these reasons, over the last few years natural plant fibers reinforced polymer composites are increasingly gaining attention as viable alternative to SFRPCs [2]. The inclination towards using natural fibers as reinforcement of polymer-based composites is mainly due to their availability from renewable natural resources, satisfactorily high specific strength and modulus, light weight, low cost and biodegradability. The biodegradability of the natural plant fibers may present a healthy ecosystem while the low costs and good performance of these fibers are able to fulfill the economic interest of industry. But still the mechanical strength of a natural fibers reinforced polymer composite (NFRPCs) could not match that of SFRPCs and the natural fibers would not replace synthetic fibers in all applications [1-10].

II. NATURAL FIBER REINFORCED POLYMER COMPOSITE

2.1 Constituents of NFRP Composite

2.1.1 Polymer Matrix

Polymers are broadly classified into two categories as follows:-

a. Thermoplastic Polymers

These are linear and branched chain polymers formed by addition polymerization. Thermoplastic can be formed at elevated temperatures, cooled and remelted and reformed into different shapes without changing the properties of polymer. However, the heat used to melt and remelt the thermoplastic must be carefully controlled or material will decompose. Polystyrene, Polypropylene and Polyethylene are mostly used thermoplastic resin for natural fiber reinforced composite [1] [2].

b. Thermosetting Polymers

These are cross-linked polymers, formed by condensation polymerization. These polymers become permanently hard when heat is applied and do not softened or reshaped upon subsequent heating, due to the loss of part of the molecule (the by product of the reaction) during the curing process. Once cured, if further heat is applied to a thermosetting material, it will char, burn or decompose. Thermosetting polymers are generally harder and stronger than thermoplastics and have better dimensional stability. Common thermosetting polymers include phenolics, aminos, polyesters, epoxies and alkyds [1] [2].

2.1.2 Natural fibers for reinforcement

Natural fibers have many important advantages over the use of synthetic fibers. Currently, many types of natural fibers have been investigated as reinforcement in polymer matrix including flax, hemp, jute straw, wood, rice husk, wheat, barley, oats, rye, cane (sugar and bamboo), grass, reeds, kenaf, ramie, oil palm empty fruit bunch, sisal, coir, hyacinth, pennywort, kapok, paper mulberry, raphia, banana fiber, pineapple leaf fiber and papyrus. The chemical composition of fiber is cellulose, hemicelluloses, lignin, pectin and waxy substances. The natural fibers are hydrophobic in nature and thus are treated with suitable chemicals to decrease the hydroxyl group in the fibers. Chemical treatment reacts with hydroxyl group of the natural fiber and improves hydrophobic characteristic and improves interfacial adhesion with polymer matrix [1-5].

2.2 Mechanical properties of Natural fibers

The mechanical properties and physical properties of natural fibers depends on the chemical and structural composition, fiber type and growth conditions. Table 1 shows the mechanical properties of various types of natural fibers. The properties of natural fibers are comparable to the glass fibers due to their low density, the specific properties (property-to-density ratio), strength, and stiffness [1].

2.3 The interface between the natural fiber and polymer resin

The bonding interfacial adhesion between the natural fiber and the polymer matrix is affected by mechanical interlocking, attractive forces and chemical bonds between the natural fiber and the rein. Natural fibers have hydroxyl groups and hydrogen bonds can therefore be formed to the surface of the natural fiber. The bond strength in natural fiber reinforced composite is decreased by the absorption of moisture. The hydrophilic fibers absorb the moisture from the environment and hydrogen bonds are formed between hydroxyl group of the cellulose molecule and the absorbed water. Moisture absorption also affects the dimensional stability of natural fiber. This results to poor adhesion between resin and matrix which causes debonding. Drying fiber before processing is very important because it increase the mechanical properties of the composites [2].

Table 1 Mechanical properties of Natural fibers [2]

Natural Fiber	Tensile Strength MPA	Young's Modulus	Elongation at break (%)	Density ($g/cm^{3)}$)
Hemp	690	70	1.60	1.48
Kenaf	930	53	1.60	-
Flax	345-1035	27.60	2.70-3.20	1.50
Ramie	560	24.50	2.50	1.50
Bamboo	140-230	11-17	-	0.60-1.10
Jute	393-773	26.50	1.50-1.80	1.30
Coir	175	4-6	30	1.20
Banana	500	12	5.9	1.35
Cotton	287-597	5.50-12.60	7-8	1.50-1.60
Sisal	511-635	9.40-22	2.0-2.50	1.50
Oil palm	248	3.20	25	0.7-1.55
Pineapple	1.44	400-627	14.50	0.80-1.60
Bagasse	290	-	-	1.25

Date palm	97-196	2.50-5.40	2-4.50	1-1.20

III. CHEMICAL MODIFICATION OF NATURAL FIBERS

Chemical modification of natural fiber is necessary in the development of NFRPCs, since natural fibers tend to be highly hydrophilic in nature and in order to improve the compatibility with the hydrophobic polymer matrix this level of processing is required. The surface modification techniques provide fiber dispersion within polymer matrix as well as improve the fiber-matrix interaction [1-3].

3.1. Alkaline treatment

In this process the natural fibers are soaked in 2-30% NaOH solution for a period of 1 to 8 hours at a temperature of 40^{o}C. The fibers are then dried at a room temperature for about 48 hours. After that oven drying takes 6 hours at 100^{o}C. The efficiency of alkali treatment depends on the type concentration of alkali solution, time of treatment, temperature and fiber tension. The immersion of alkaline leads to formation of high amounts of voids and makes the surface rougher. The effective surface area is increased which improves the adhesion between the fiber and the matrix. [2][3].

$$\text{Fiber-OH} + \text{NaOH} \rightarrow \text{Fiber-O-Na+} + H_2O \quad (1)$$

3.2 Silane treatment (SiH_4)

Treatment of fibers with silane coupling agents significantly improves the interfacial adhesion and mechanical properties of the composites. The bifunctional silane molecule acts as a link between matrix and the cellulose. They form a chemical bond with the surface of cellulose trough a siloxane bridge while its organo functional group bond with matrix. The chemical formula of silane is multifunctional which consists of reactive R- and X- group. One end of it reacts with the cellulose fiber surface and other reacts with polymer phase [2].

$$CH_2CHSi\ (OC_2H_5)_3 \rightarrow CH_2CHSi\ (OH)_3 + 3C_2H_5OH$$
$$CH_2CHSi\ (OH)_3 + \text{Fiber} – OH = CH_2CHSi\ (OH)_2O\text{-Fiber} + H_2O \quad (2)$$

3.3 Acetylation of Natural Fibers

The Acetylation includes the estrification of hydroxyl groups on the fiber surface. The fibers become hydrophobic when treated with acetic anhydride substitutes. The polymer hydroxyl group reacts with acetyl groups. Acetylation is based on reaction between the cell wall hydroxyl groups acetic or prop ionic anhydride at elevated temperature. Lignin and Hemicellulose have also hydroxyl groups that react with reagent from the treatment. The hydroxyl group of the cellulose is being packed with hydrogen bonds. The reaction of acetic anhydride with fiber is shown as [3].

$$\text{Fiber -OH} + CH_3 –C\ (= O) - O – C\ (=O) - CH_3 \rightarrow \text{Fiber -}OCOCH_3 + CH_3COOH \quad (3)$$

IV. RESEARCH AND DEVEOPMENT IN NFRPCS

Many investigations have been made on the effect of various factors on mechanical behavior of Natural fiber reinforced polymer composites. Reddy S. S. and Husain S. P. [4] studied development and testing of Natural Fiber Reinforced Composites with Polyester Resin and reported that the mechanical properties of sisal and Hemp reinforced polymer composites are found to increase with increasing fiber weight fraction. In important properties Hemp and Sisal combination composites showed best results. The Tensile properties of Natural Fiber Reinforced composite (both Thermoplastic and Thermosetting) are mainly influenced by the interfacial adhesion between matrix and fibers. Further Mechanical properties can be improved with chemical modifications of composites. Many similar studies on natural fibers such as bamboo, hemp, flax and kenaf reveal that the mechanical properties of fiber reinforced composites depend on several fiber parameters such as fiber loading, fiber length, fiber aspect ratio, fiber orientation and fiber matrix adhesion. Sakthive M. and Ramesh S. [5] studied Mechanical Properties of Natural Fiber (Banana, Coir and Sisal) Polymer Composites. They fabricated Banana reinforced, Coir Reinforced and Sisal reinforced polymer composites by simple Hand lay technique and observed that Banana reinforced natural composites is the best natural composites among the various combination. It can be used for manufacturing of automotive seat shells among the other natural fibre combinations.

Singh A. S. and Thakur V. [6] studied Mechanical Properties of Natural Fiber Reinforced Polymer Composites. The Mechanical properties such as tensile strength, compressive strength and wear resistance etc. of the urea–formaldehyde resin increases to considerable extent when reinforced with the fibre. In case of mechanical behaviour particle reinforcement of the UF resin has been found to be more effective as compared to short fibre reinforcement. These results suggest that Flax fibre has immense scope in the fabrication of Natural fibre reinforced polymer composites having vast number of industrial applications. Girisha et. al. [7] investigated Tensile properties of Natural Fiber Reinforced Epoxy Hybrid Composite by reinforcing Sisal, Coconut coir and Ridge guard as the Natural fibers into epoxy resin matrix. The Natural fibers extracted by retting and manual process were subjected to alkali treatment. It was observed that the tensile properties were increased with increase in weight fraction of Fibers to certain extent and then decreased. Maleque et. al [8] developed coconut fiber reinforced Aluminum composite for Automotive brake pad application and observed that better mechanical properties in terms of higher density, lower porosity and higher compressive strength were obtained from 5 and 10% coconut fibers. Alaneme K. [9] studied Mechanical Properties and Corrosion behavior of Aluminium Hybrid Composite Reinforced with Silicon Carbide and Bamboo Leaf Ash. The results showed that the hardness, ultimate tensile strength, and % elongation of the Hybrid Composite decreases with increase in Bamboo Leaf Ash Content. They have high corrosion resistance as compared to that of Single Reinforced Composite.

Sen T. [10] studied various industrial applications of Hemp, Kinaf, Flax and Ramie Natural fibers. Among the various natural fibers, Sisal fibers, Bamboo fibers, Coconut coir and Jute fibers are of particular interest as these fiber reinforced composites have high impact strength besides having moderate tensile and flextural properties compared to other lignocellulosic fibers. Shinji Ochi [11] studied Tensile Properties of Bamboo Fiber Reinforced Biodegradable Plastic and observed that the tensile strength of the composites increases with increase in Fiber content up to 70% and posses extremely high tensile strength of 265 N/mm^2.

The tensile strength of Bamboo Fiber and Bamboo Fiber Reinforced Composite decreases at 160^o C. Bhandari N. [12] studied Analysis of Morphological and Mechanical Behaviors of Bamboo Flour Reinforced Polypropylene Composites. The composites of Polypropylene with neat Bamboo Flour (BF) and treated Bamboo Flour (TBF) in different proportions were prepared by melt mixing followed by compression molding. The Alkali treated Bamboo Flour is compatible with Polypropylene matrix than the neat BF.

Okubo K. and Yamamato Y. [13] studied the Development of Bamboo based polymer composites and their mechanical properties and concluded that the Bamboo fibers have a specific strength which is equivalent to that of Glass Fibers. The Tensile Strength and the modulus of PP based composites using steam exploded fibers increased about 15 to 30% respectively due to well impregnation and the reduction of the number of voids compared to the composites using Fibers that were mechanically extracted. The steam explosion technique is an effective method to extract bamboo fibers for reinforcing thermoplastic. Cholachagudda V. and Udaykumar P. [14] studied Mechanical Characterization of Coir and Rice Husk Reinforced Hybrid Polymer Composite and concluded that there is increase in flextural strength of the composite where as it losses its tensile strength at 20% Wt of Coir fiber loading. Flextural strength of the composite decreases at 5% Wt of Rice husk fiber loading. Maleque M. A. and Jahurin H. [15] developed new Natural fiber reinforced Aluminium composite for Automotive Brake Pad application. The better properties in terms of higher density, lower porosity and high compressive strength were obtained from 5 to 10% coconut fiber composite. The microstructure reveals uniform distribution of resin and coconut fiber in the matrix.

V. CURRENT INDUSTRIAL APPLICATIONS OF NFRPCS

Figure 1, shows the current applications of NFRPCs in automotive industries. Most of the car manufacturing industries in Germany (i.e. Daimler-Chrysler, Mercedes, Volkswagen Audi Group, BMW, Ford and Opel) are now using natural fiber composites for interiors, door linings and paneling. Wood fibers are also used to enclose the rear side of seat backrests and cotton fibers are utilized as a sound proofing material. Coconut fibers are used in cars for interior trim and seat cushioning [16] [17].

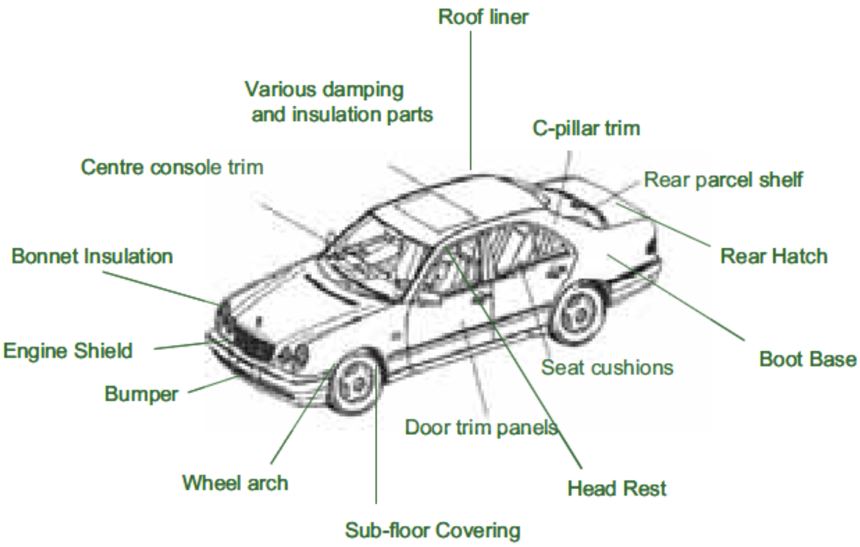

Fig. **1** Components on a generic vehicle, made from natural fiber composite material [20]

To provide the weight reduction afforded by the all aluminium body, door trim panels were made of polyurethane reinforced with a mixed flax/sisal mat. Soya based foam fillings are used in car seats along with natural fibers. A cellulose based cargo floor tray is produced replacing the traditional flax and polyester combination used previously which resulted in improved noise reduction [16].

Kenaf fibers used are used for manufacturing board along with Polypropylene. The Mercedes-Benz Travego travel coach is equipped with flax reinforced engine and transmission covers. A truck with flax-based, rather than glass-based, exterior skirting panels is now in production [17].

The hemp fiber has also been used in the manufacture of the lightweight lotus designed seats. The hemp material is used with a polyester resin to form a hybrid composite; however, the intention is to use a fully recyclable resin in the future. Sisal, a renewable crop, has been used for the carpets in the Eco Elise, as it is a tough, abrasion resistant material [16-18].

VI. ADVANTAGES AND LIMITATIONS OF NFRPCS

6.1 Advantages NFRPCs

They are eco friendly, fully biodegradable, available in large amount, renewable, cheap and have low density as compared to synthetic fibers such as glass, aramid, carbon and steel fibers

1. Low cost and high performance of NFRPCs contented the economic aspect of the industry.
2. The disposal of NFRPCs is simple as compared to SFRPCs.
3. The abrasive nature of fiber is much lower which leads to advantages in regard to technical process and recycling process of the composite materials.
4. Natural fiber composites are used in place of glass mostly in non-structural applications. Automotive components such as doors, bonnets etc. made from Glass fiber reinforced composites are now being replace by NFRPCs.

6.2 Limitations of NFRPCs

1. High moisture absorbing property is the major drawback of the natural fibers. This phenomenon reduces the interfacial bonding between the polymer matrix and fiber and causes detrimental effects on the mechanical properties.
2. These have: poor wettability, incompatibility with some polymeric matrices.
3. Plant fibers can not be used directly in its natural form. It requires chemical modification to remove the waxy layer to improve the interfacial adhesion between fibers and polymer matrix.

VII. CONCLUSION

The on going research in Natural fiber reinforced polymer composites has resulted in replacement of Synthetic fiber reinforced polymer composites in many automotive, constructional and household applications. Natural fibers are cheap, lighter in weight, biodegradable and are easily available as compared to Synthetic fibers. Chemical modification of natural fibers is necessary for increased adhesion between the hydrophilic fibers and hydrophobic matrix. Mechanical properties of natural fibers are much lower than those of glass fibers but their specific properties, especially stiffness, is comparable to the glass fibers.

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