Natural Fiber Reinforced Polymer Composites: A Review

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Abstract— Now-a-days, natural fiber reinforced polymer composites are increasingly being used for varieties of engineering applications due to their many advantages. Among natural fibers, bamboo has been widely used for many such applications due to its availability. Since these composites are finding wide applications in highly dusty environment which are subjected to solid particle erosion, a study of their erosion characteristics are of vital importance. Generally solid particle erosion, a typical wear mode leads to Material loss due to repeated impact of solid particles. For a composite material, its mechanical behavior and surface damage by solid particle erosion depends on many factors. Attempts have been made in this paper to explore the potential utilization of bamboo fiber in polymer matrix composites and review on before work, done by different researchers related to natural fiber reinforced polymer composites.

Key words: Bamboo, Filler Material, Polymer Matrix Composite

I. Introduction

When two or more materials with different properties are combined together, they form a composite material. In general, the properties of composite materials are superior in many respects, to those of the individual constituents. This has provided the main motivation for the research and development of composite materials. There are two categories of constituent materials one is matrix and another is reinforcement. The primary functions of the matrix are to transfer stresses between the reinforcing fibers/particles and to protect them from mechanical and/or environmental damage whereas the presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness etc. The objective is to take advantage of the superior properties of both materials without compromising on the weakness of either. The matrix material can be metallic, polymeric or can even be ceramic. When the matrix is a polymer, the composite is called polymer matrix composite. The properties of polymeric composite materials are mainly determined by three constitutive elements such as the resin, the reinforcement, such as particles and fibers, and the interface between them.

Fiber reinforced polymer (FRP) composites can be simply described as multi-constituent materials that consist of reinforcing fibers embedded in a rigid polymer matrix. Many FRPs offer a combination of both strength and modulus that are either comparable to or better than many traditional metallic materials. A diverse range of polymers can be used as the matrix to FRP composites, and these are generally classified as thermoplastic (e.g. polyether-ether-ketone, polyamide) resins or thermoset (e.g. epoxy, polyester). Thermoplastics start as fully reacted high-viscosity materials that do not cross-link on heating. On heating to a high enough temperature, they either soften or melt, so they can be reprocessed a number of times. On the other hand, thermoset resins the most widely used matrices for advanced composites usually consist of a resin and a comparable curing agent. When they two are initially mixed they form a low viscosity liquid that cures as a result of either internally generated or externally applied heat. The curing reaction forms a series of cross links between molecular chains so that one large molecular network is formed, resulting in an intractable solid that cannot be reprocessed on reheating.

As far as the reinforcement is concerned, extensive use has been made of inorganic man-made fibers such as glass and organic fibers such as carbon and aramid. Recently, the rapidly increasing environmental awareness, geometrically increasing crude oil prices, growing global waste problem and high processing cost trigger the development concepts of sustainability and reconsideration of renewable resources.

Use of natural fibers, derived from annually renewable resources, as reinforcing fibers in both thermoplastic and thermoset matrix composites provides positive environmental benefits with respect to ultimate disposability and raw material utilization . The advantages associated with the use of natural fibers as reinforcement in polymers are their availability, non-abrasive nature, low energy consumption, biodegradability and low cost. In addition, natural fibers have low density and high specific properties. The specific mechanical properties of these fibers are comparable to those of traditional reinforcements. Among the various natural fibers, bamboo finds widespread use in housing construction around the world, and is considered as a promising housing material in underdeveloped and developed countries. Being a conventional construction material since ancient times, bamboo fiber is a good candidate for use as natural fibers in composite materials. Many studies focus on bamboo is due to the fact that it is an abundant natural resource in Asia and its overall mechanical properties are comparable to those of wood. Furthermore, bamboo can be renewed much more rapidly compared with wood. Bamboo is an extremely light weight, functionally graded and high strength natural composite. The structure of bamboo is a composite material, consisting of long and aligned cellulose fibers immersed in a ligneous matrix. Besides, bamboo is one of the fastest renewable plants with a maturity cycle of 3 to 4 years. Although the utilization potential of this material for a number of applications has been explored, such superior mechanical properties have not been adequately well drawn for polymer-based composites.

The term 'filler' is very broad and encompasses a very wide range of materials plays an important role for the improvement in performance of polymers and their composites. Filler materials are used to reduce the material costs, to improve mechanical properties to some extent and in some cases to improve processability. Besides, it also increases properties like abrasion resistance, hardness and reduces shrinkage. So, although in FRP, a judicious selection of matrix and the reinforcing phase can lead to a composite with a combination of strength and modulus comparable to or even better than those of conventional metallic materials, their physical and mechanical properties can further be modified by addition of a solid filler phase to the matrix body during the composite preparation.

Polymer composites containing different fillers and/or reinforcements are frequently used for many applications in which friction and wear are critical issues. Also these composites are finding further applications that subjected to solid particle erosion, which is the loss of material that results from repeated impact of small, solid particles. Examples of such applications are in petroleum refining pipe line carrying sand slurries, pump impeller blades, high speed vehicles and aircraft operating in desert environments, helicopter rotor blades, aircraft engine blades, water turbines etc. Hence, erosion resistance of polymer composites has become an important material property, particularly in selection of alternative materials and therefore the study of solid particle erosion characteristics of the polymeric composites has become highly relevant. Also a full understanding of the effects of all system variables on the wear rate is necessary in order to undertake appropriate steps in the design of machine or structural component and in the choice of materials to reduce/control wear.

II. Literature Review

In fiber reinforced polymer composites, the fibers can be either synthetic fibers or natural fibers. Advantages of natural fibers over synthetic fibers include low density, availability, low cost, recyclability and biodegradability studied by Saheb et al. [1-3]. The mechanical properties of natural fibers are greatly influenced by their chemical compositions. Mechanical properties of natural fiber based polymer composites are influenced by many factors such as fibers volume fraction, fiber length, fiber aspect ratio, fiber-matrix adhesion, fiber orientation, etc. A great deal of work has already been done on the effect of various factors on mechanical behavior of natural fiber reinforced polymer composites. The post-impact behavior of jute fiber reinforced polyester composites subjected to low velocity impact has studied by Santulli [4]. Effect of fiber content on tensile and flexural properties of pineapple fiber reinforced poly (hydroxybutyrate-co-valerate) resin composites has studied by Luo et al. [5]. Thwe and Liao [6]. Studied the effects of fiber content, fiber length, bamboo to glass fiber ratio, and MAPP content on mechanical properties of bamboo fiber reinforced plastics and bamboo-glass fiber reinforced plastics. Jiang et al. [7] studied the mechanical behavior of poly (3-hydroxybutyrate-co-3-Hydroxyvalerate)/bamboo pulp fiber composites. Okubo et al. [8] studied the tensile strength and modulus of bamboo fiber reinforced polypropylene based composites. The mechanical properties of bamboo fiber reinforced polypropylene composites was studied and compared with those of commercial wood pulp by Chen et al. [9].

Fiber	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm3)
Abaca	400	12	3-10	1.5
Alfa	350	22	5.8	0.89
Bagasse	290	17	-	1.25
Bamboo	140-230	11-17	-	0.6-1.1
Banana	500	12	5.9	1.35
Coir	175	4-6	30	1.2
Cotton	287-597	5.5-12.6	7-8	1.5-1.6
Curaua	500-1,150	11.8	3.7-4.3	1.4
Date palm	97-196	2.5-5.4	2-4.5	1-1.2
Flax	345-1,035	27.6	2.7-3.2	1.5
Hemp	690	70	1.6	1.48
Henequen	500 ± 70	13.2 ± 3.1	4.8 ± 1.1	1.2
Isora	500-600	-	5-6	1.2-1.3
Jute	393-773	26.5	1.5-1.8	1.3
Kenaf	930	53	1.6	-
Nettle	650	38	1.7	-
Oil palm	248	3.2	25	0.7-1.55
Piassava	134-143	1.07-4.59	21.9-7.8	1.4
Pineapple	400-627	1.44	14.5	0.8-1.6
Ramie	560	24.5	2.5	1.5
Sisal	511-635	9.4-22	2.0-2.5	1.5
E-Glass	3400	72	-	2.5

Table 1: Properties of natural fibers [9]

In polymers, fillers are used for a variety of reasons such as cost reduction, density control, improved processing, control of thermal expansion, optical effects, magnetic properties, thermal conductivity, electrical properties, and improved hardness and wear resistance, flame retardancy etc. A great deal of work has been made on the effect of fillers on polymer composites. When silica particles are incorporated into polymer matrix, they play an important role in improving various properties of the composites [10, 11]. Polymers and polymer matrix composites reinforced with metal particles have a wide range of industrial applications [12, 13]. The effect of filler size and shape on the mechanical properties of composites was studied by Nakamura et al. [14, 15].

Many researchers have investigated the erosion behavior of various polymers and their composites [16-20]. Similarly, the effect of various parameters on the erosion behavior of bamboo fiber reinforced epoxy composites was studied by Biswas et al. [21].

III. Materials Used for Composite

A. *Matrix Material:*

Among different types of matrix materials, polymer matrices are the most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties. Polymer matrices can be either thermoplastic or thermoset. Epoxy resin is commonly used thermoset having advantages like good adhesive with any fiber, good performance at elevated temperature and good mechanical and electrical properties. Due to several advantages over other thermoset polymers as mentioned above, epoxy (LY 556) is chosen as the matrix material for the present research work. Epoxy resin is chosen as the matrix material for the present research work. It chemically belongs to the 'epoxide' family.

B. Fiber Material:

Fiber is the reinforcing phase of a composite material. The present research work, bamboo fiber is taken as the reinforcement in the epoxy matrix to fabricate composites. In general, bamboo is available everywhere around the world and is an abundant natural resource. It has been a conventional construction material since ancient times. Bamboo is an orthotropic material with high strength along and low strength transversal to its fibers. The structure of bamboo itself is a composite material, consisting of long and aligned cellulose fibers immersed in a ligneous matrix. In this work, short bamboo fiber is used as the reinforcement in the composites.

Fig. 1: Short bamboo fiber and bamboo based composite

C. Particulate Filler Materials:

Particulate fillers are plays an important role for the improvement of performance of polymers and their composites. Various types of fillers of natural or synthetic, both organic and inorganic is already being used as reinforcement in polymeric composites. Among them, alumina (Al_2O_3), silicon carbide (SiC), silica (SiO_2), titania (TiO_2) etc. are most widely used as conventional fillers. Due to the many advantages, different weight percentages of alumina (Al_2O_3) particulate is used as filler material for fabrication of bamboo fiber reinforced epoxy composites in the present work.

Generally, Al_2O_3 is an inorganic material that has the potential to be used as particulate filler material in various polymer matrices. Al_2O_3 commonly referred to as alumina, can exist in several crystalline phases which all revert to the most stable hexagonal alpha phase at elevated temperatures. This is the phase of particular interest for structural applications. It is the most cost effective and widely used material in the family of engineering ceramics. It is hard, wear resistant, has excellent dielectric properties, high strength and stiffness, resistance to strong acid and alkali attack at elevated temperatures. Due to its many advantages and with a reasonable price, the fine grain technical grade Al_2O_3 has a very wide range of engineering applications.

Features Of Using Natural Fiber Reinforced Polymer Composites:

1) Properties of composite materials are superior in many respects, to those of the individual constituents.
2) Recently, the rapidly increasing environmental awareness and harmful nature of synthetic fiber, natural fiber is good source for composite material.
3) Synthetic fiber required high processing cost and increase global waste problems which is reduced by natural fiber reinforced composites.
4) From different natural fibers Bamboo is one of the fastest renewable plants with a maturity cycle of 3 to 4 years.
5) The advantages associated with the use of natural fibers as reinforcement in polymers are their availability, non-abrasive nature, low energy consumption, biodegradability and low cost.
6) In addition, natural fibers have low density and high specific properties.

IV. METHOD OF OPERATION:

To minimize cost of material, reduce global waste problems and available material easily during heavy requirement of material. Here we use three materials to manufacturing composite material. From that bamboo fiber is available in huge quantity in nature, second material is polymer like epoxy resin which is having good mechanical and electrical properties and excellent adhesiveness with many reinforced fibers and third material is filler material, here we use alumina (Al_2O_3) as filler material to improve the different properties of composite.

These three materials are used in different percentage to check the properties of composite to manufacture a superior quality of composite. We check all properties of composite like tensile strength on UTM machine, flexural strength and hardness test by using diamond indenter on hardness testing machine, Scanning electron microscope was used for the morphological characterization of the composite surface. The erosion testing of composite specimens is performed on a standard erosion test rig.

V. COMPOSITE FABRICATION

The short bamboo fiber and Al_2O_3 particulates are mixed with epoxy resin by the simple mechanical stirring and the mixture is poured into various moulds conforming to the requirements of various testing conditions and characterization standards. The composite samples of four different compositions (EB-1 to EB-4), in which no particulate filler is used. The other composite samples EBA-1 to EBA-4 are prepared in four different percentages of alumina particulates (0wt%, 5wt%, 10wt% and 15wt% of alumina) is used keeping bamboo fiber at a fixed percentages (i.e. 45wt%). A releasing agent is used to facilitate easy removal of the composite from the mould after curing. The entrapped air bubbles (if any) are removed carefully with a sliding roller and the mould is closed for curing at a temperature of 30°C for 24 h at a constant pressure of 10 kg/cm2. After curing, the specimens of suitable dimension are cut for mechanical and erosion tests. The composition and designation of the composites prepared for this study are listed in Table 2

Composites	Compositions
EB-1	Epoxy + Bamboo Fiber (0 wt. %)

EB-2	Epoxy + Bamboo Fiber (15 wt. %)
EB-3	Epoxy+ Bamboo Fiber (30 wt. %)
EB-4	Epoxy + Bamboo Fiber (45 wt. %)
EBA-1	Epoxy + Bamboo Fiber (45 wt. %) + Alumina (0 wt. %)
EBA-2	Epoxy + Bamboo Fiber (45 wt. %) + Alumina (5 wt. %)
EBA-3	Epoxy + Bamboo Fiber (45 wt. %) + Alumina (10 wt. %)
EBA-4	Epoxy + Bamboo Fiber (45 wt. %) + Alumina (15 wt. %)

Table 2: Designation of Composites

VI. FUTURE SCOPE OF WORK

Though much work has been done on a wide variety of natural fibers for polymer composites, very less has been reported on the reinforcing potential of short bamboo fiber in spite of its several advantages over others.

A number of research efforts have been devoted to the mechanical and wear characteristics of either fiber reinforced composites or particulate filled composites. However, a possibility that the incorporation of both particulates and fibers in polymer could provide a synergism in terms of improved performance has not been adequately addressed so far.

Studies carried out worldwide on erosion wear behavior of composites have largely been experimental and the use of statistical techniques in analyzing wear characteristics has been rare. Taguchi method, being a simple, efficient and systematic approach to optimize designs for performance, quality and cost, is used in many engineering applications. However, its implementation in parametric appraisal of wear processes has hardly been reported.

VII. CONCLUSIONS

A critical review of natural fiber reinforced composite: bamboo is presented in this literature. Much research work has been reported. The natural fiber reinforced composites have high potential of replacing conventional material used in many appliances. Research works regarding the use of natural fiber composite in many appliances is reported. Only very few research work is on checking mechanical properties of natural fiber composites with different percent of contents has been reported.

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