

Mechanical Characterization of Hybrid Bamboo/E-Glass Fibre Reinforced Polymer Epoxy Composites

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ABSTRACT: Conventional fiber reinforced plastics (FRP's) have long been important if not indispensable in many crucial applications such as transportation, renewable energy, defense applications, as well as many others. Composite materials are of interest to these industries due to their attractive properties including high strength to weight ratio and high modulus to weight ratio. Comprehensive research has been conducted on conventional composite materials to optimize their processing parameters as well as optimize their mechanical behavior and reliability. Although composites provide excellent mechanical properties, certain applications demand improved mechanical behavior as well as the presence of additional properties. Recent developments in polymers have developed nanocomposites, which are composites reinforced by nanopowders. In these materials, the nanopowders have shown great enhancements in mechanical properties, thermal properties, and electrical properties. Nevertheless, these composites lack the strength for applications where FRP's are currently used. The addition of nanopowders as reinforcement to conventional composites shows great promise to not only enhance the existing properties of these composites, but also add many other properties that would maximize their applications. The objective of this project work is to investigate the fiber orientation reinforced hybrid polymer nanocomposites that combine with hybrid composites i.e BAMBOO/E-GLASS and epoxy polymer in the ratio of 0.1wt %, 0.2 wt% and 0.3 wt% percent of volume are to be considered. The mechanical properties are to be calculated by carrying out tests on specimens in tension, compression and flexure in accordance with the test procedure laid down in ASTM standards. Finally after obtaining the tested results, those values are checked

KEYWORDS: FRP's, Hybrid composite, BAMBOO, E-Glass, ASTM standards.

I. INTRODUCTION

The In recent years, the concept of 'eco-materials' has gained key importance due to the need to preserve our environment. The meaning of eco-material includes 'safe' material systems for human and other life forms at all times. Past experiences have shown that it is necessary to characterize materials and determine those which are safe for both short and long-term utilization. Selection of a material system that satisfies not only industrial requirements but also this wider definition of eco-materials, as described above, is an urgent necessity. Here, the most appropriate concept for material selection is composite materials with natural fiber reinforcement. The interest in natural fiber reinforced composites is growing rapidly both in terms of their industrial applications and fundamental research. Their availability, renewability, low density and price as well as satisfactory mechanical properties make them an attractive ecological alternative to glass, carbon and other man-made fibers used for the manufacturing of composites. Basically, composites are materials consisting of two or more chemically distinct constituents, on a macro-scale, having a distinct interface separating them. One or more discontinuous phases are, therefore, embedded in a continuous phase to form a composite. The discontinuous phase is usually harder and stronger than the continuous phase and is called the *reinforcement*, whereas, the continuous phase is termed as the *matrix*. The matrix material can

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Vol. 6, Issue 11, November 2017

be metallic, polymeric or can even be ceramic. When the matrix is a polymer, the composite is called polymer matrix composite (PMC). Over the past few decades, it is found that polymers have replaced many of the conventional metals/materials in various applications. This is possible because of the advantages such as ease of processing, productivity, cost reduction etc. offered by polymers over conventional materials. In most of these applications, the properties of polymers are modified by using fibers to suit the high strength/high modulus requirements. Fiber reinforced composite materials consist of fibers embedded in or bonded to a matrix with distinct interfaces (boundaries) between them. In this form, both fibers and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone. In general, fibers are the principal load-carrying members, while the surrounding matrix keeps them in the desired location and orientation. The matrix also acts as a load transfer medium between them and protects the fibers from environmental damages due to elevated temperatures, humidity etc.[1]. Thus, even though the fibers provide reinforcement for the matrix, the latter also serves a number of useful functions in a composite material. Many fiber reinforced polymers (FRPs) offer a combination of strength and modulus that are either comparable to or better than many traditional metallic materials. In addition, fatigue strength as well as fatigue damage tolerance of many composite laminates are excellent. For these reasons, FRPs have emerged as a major class of structural materials and find applications in almost all material domains such as house furnishing, packaging, sports, leisure and in many other weight-critical components in aerospace, automotive and other industries.

All synthetic polymers (thermoplastics, thermo sets and elastomers) can be used as matrices in PMCs. 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. As all these reinforcing fibers are expensive, various fibers like cellulose, wool, silk etc. abundantly available in nature are also used in composites. Cellulosic fibers like henequen, sisal, coconut fiber (coir), jute, palm, bamboo and wood, in their natural conditions and several waste cellulosic products such as shell flour, wood flour and pulp have also been used as reinforcing agents of different thermosetting and thermoplastic resins. It is well known that natural fibers impart high specific stiffness, strength and Biodegradability to polymer matrix composites. Also, cellulosic fibers are readily available from natural sources and most importantly, they have low cost per unit volume. Historically, the origin of the concept of composite material is based on natural resources such as bamboo and wood. These are good examples of natural composites where cellulosic fibers are in close association with hemi-celluloses to reinforce the lignin matrix. Our ancestors have also used this concept in building houses that consisted of bamboo, straw and clay in building walls. Being a conventional construction material since ancient times, bamboo fiber is a good candidate for use as natural fibers in composite materials. As the development of modern material science progresses, a large amount of masonry, concrete and steel are used in the building structure, but bamboo and some other non-conventional natural materials still exist and are being used due to their natural characteristics and good mechanical properties. Bamboo is available everywhere around the world and is an abundant natural resource. It is a giant grass-like plant and not a tree as commonly believed, belonging to the family of the *Bambusoideae*. Besides, bamboo is one of the fastest renewable plants with a maturity cycle of 3 to 4 years. It has excellent mechanical properties in comparison with its weight due to its longitudinally aligned fibers. 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 use of bamboo fiber can also help to reduce the demand for wood fibers and environmental impacts associated with wood fiber harvesting. In view of this, the present research work is undertaken to study the reinforcement potential of bamboo fibers in polymer composites. Major constituents in a natural fiber reinforced composite are the reinforcing fibers and a matrix, which acts as a binder for the fibers. In addition, particulate fillers can also be used with some polymeric matrices primarily to reduce cost. and improve their dimensional stability. So, although 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, the physical and mechanical characteristics can further be modified by adding a solid filler phase to the matrix body during the composite preparation. The fillers play a major role in determining the properties and behaviour of particulate reinforced composites. The term 'filler' is very broad and encompasses a very wide range of materials. It is arbitrarily defined as a variety of natural or synthetic solid particulates (inorganic, organic) that may be irregular, acicular, fibrous or flakey. The improved performance of

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Vol. 6, Issue 11, November 2017

polymers and their composites in industrial and structural applications by the addition of particulate fillers has shown a great promise and so has lately been a subject of considerable interest. Hard particulate fillers consisting of ceramic or metal particles and fiber-fillers made of glass are being used these days to dramatically improve the mechanical and wear properties of many composites. But in this context, the potential of ceramic-rich industrial wastes for such use in polymeric matrices has rarely been explored. Rapid industrial development over the last decades has led to the generation of large amounts of solid wastes in the form of ash, mud or slag, which has now come to a stage of environmental threat and needs disposal and/or utilization. Most of these wastes are buried in landfills, which is costly and environmentally unsatisfactory. Therefore, it is essential to seek new options to recycle or reuse these inorganic residues. It is evident from the characteristics of some of these wastes, generated from different processes, that they have good potential for recycling and for utilization in developing various value-added products. To this end, an attempt has been made in this research work to effectively utilize a couple of industrial wastes as particulate fillers for making composites.

Another possibility that the incorporation of both particulates and fibers in polymer could provide a synergism in terms of improved properties and wear performance has not been adequately explored so far. However, some recent reports suggest that by incorporating filler particles into the matrix of fibre reinforced composites, synergistic effects may be achieved in the form of higher modulus and reduced material cost, yet accompanied with decreased strength and impact toughness. Such multi-component composites consisting of a matrix phase reinforced with a fiber and filled with particulates are termed as *hybrid* composites.

Polymer composites are often used as engineering as well as structural components functioning in hostile workplaces where they are subjected to different wear situations. *Wear* is defined as the damage to a solid surface usually involving progressive loss of materials, owing to relative motion between the surface and a contacting substance or substances. It is a material response to the external stimulus and can be mechanical or chemical in nature. The effect of wear on the reliability of industrial components is recognized widely and the cost of wear has also been recognized to be very high. Systematic efforts in wear research were started in 1960s in industrialized countries. The direct costs of wear failures (i.e. wear part replacements), increased work and time, loss of productivity as well as indirect losses of energy and the increased environmental burden are real problems in everyday work and business. In catastrophic failures, there is also the possibility of human losses. Although wear has been extensively studied scientifically, still wear problems persist in industrial applications. This actually reveals the complexity of the wear phenomenon. There are quite a few terms to describe various wear modes which can be clubbed into four principal categories viz. abrasion, adhesion, erosion and surface fatigue [8]. Generally, abrasive wear occurs when two surfaces in contact move against each other and the harder particle in one cut through the other. This form of wear comes into play when a tangential motion causes the material removal by the simultaneous micro-ploughing and micro-cutting [6]. However, wear due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or the loss from either surface is termed as adhesive wear. Similarly, surface fatigue is another wear process that takes place when tiny wear particles are dislodged from a surface by fracture on repeated rolling or sliding on the surface. Owing to a repeated loading action subsurface cracks grow from pre-existing defects, join hands with other vicinal cracks and finally come to the surface removing a small chunk of material [8]. Finally in the erosion wear mode, a progressive loss of material occurs from a solid surface due to mechanical interaction between that surface and a fluid, a multi-component fluid, or impinging liquid or solid particles [9]. Solid particle erosion (SPE), a typical erosion wear mode, is the loss of material that results from repeated impact of small, solid particles. In some cases SPE is a useful phenomenon, as in sandblasting and high-speed abrasive water jet cutting but it is a serious problem in many engineering systems including steam and jet turbines, pipelines and valves carrying particulate matter and fluidized bed combustion systems. Solid particle erosion is to be expected whenever hard particles are entrained in a gas or liquid medium impinging on a solid at any significant velocity. In both cases, particles can be accelerated or decelerated and their directions of motion can be changed by the fluid. Polymers and their composites form a very important class of tribo-engineering materials and are invariably used in mechanical components, where wear performance in non-lubricated condition is a key parameter for the material selection. Nowadays much attention is devoted towards the study of solid particle erosion behaviour of polymer composites due to the high potential use of these materials in many mechanical and structural applications. Hence, erosion resistance

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Vol. 6, Issue 11, November 2017

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. Differences in the erosion behaviour of various types of composite materials are caused by the amount, type, orientation and properties of the reinforcement on one hand and by the type and properties of the matrix and its adhesion to the fibers/fillers on the other hand. 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 [10]. Statistical methods have commonly been used for analysis, prediction and/or optimization of a number of engineering processes. Such methods enable the user to define and study the effect of every single condition possible in an experiment where numerous factors are involved. Solid particle erosion is a complex wear phenomenon in which a number of control factors collectively determine the performance output (i.e. the erosion rate) and there is enormous scope in it for implementation of appropriate statistical techniques for process optimization. But unfortunately, such studies have not been adequately reported so far.

II.LITERATURE REVIEW

On Natural Fibers and Natural Fiber Reinforced Composites-In polymer composites, the reinforcing phase can either be fibrous or non-fibrous (particulates) in nature and if the fibers are derived from natural resources like plants or some other living species, they are called natural-fibers. Natural fibers as reinforcement in composite materials have recently attracted the attention of researchers because of their several advantages. These fibers can be divided into three groups based on their origin, i.e. vegetable/plant fibers (flax, hemp, sisal, etc.), animal/protein fibers (hair, wool, silk, chitin, etc.) and mineral fibres (asbestos, wollastonite etc.). Plant fibers are renewable with good mechanical properties, which justify their use as reinforcement for polymers.

Table 2.1 Properties of Natural Fibers 11

| Fiber | Tensile strength (MPa) | Young's modulus (GPa) | Elongation at break (%) | Density (g/cm ³) |
|-----------|---------------------------|--------------------------|----------------------------|---------------------------------|
| 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 |

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Vol. 6, Issue 11, November 2017

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|-----------|----------|------------|-----------|----------|
| 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 |

On Mechanical Properties of Natural Fiber Composites : Most of the studies made on natural fiber composites reveal that their mechanical properties are strongly influenced by many factors such as volume fraction of the fibers, fiber aspect ratio, fiber-matrix adhesion, fiber orientation, stress transfer at the interface etc. A number of investigations have been made on various natural fibers such as kenaf, hemp, flax and jute to study the effect of these fibers on the mechanical properties of composite materials. Gowda evaluated the mechanical properties of jute fabric-reinforced polyester composites and found that they have better strengths than those of wood based composites. Similarly, an investigation on pulp fiber reinforced thermoplastic composite exhibited that while the stiffness is increased by a factor of 5.2, the strength of the composite is increased by a factor of 2.3 relative to the virgin polymer. **On bamboo and Bamboo Fiber Reinforced Composites -** Bamboo is widely recognized as one of the most important non-timber forest resources because of the high socio-economic benefits from bamboo based products. It is a natural composite, which consists of lignin matrix and cellulose fibers. Cellulose fibers provide high tensile, flexural strengths and rigidity in its longitudinal direction. Because the strength and modulus of bamboo fiber are at least one order of magnitude greater than those of lignin matrix, the bulk mechanical properties of the outer surface region in the reformed bamboo should be much higher than those of the inner surface. Bamboo has many advantages, such as ample availability, fast growth rate, lightweight, low cost and low energy consumption in the processing and biodegradability [52].

III. MATERIALS AND METHODS

Matrix Material-Matrix materials are of different types like metals, ceramics and polymers. Polymer matrices are most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared to metal and ceramic matrices. Polymer matrices can be either thermoplastic or thermoset. Thermo set matrices are formed due to an irreversible chemical transformation of the resin into an amorphous cross-linked polymer matrix. Due to huge molecular structures, thermoset resins provide good electrical and thermal insulation. They have low viscosity, which allow proper fiber wet out, excellent thermal stability and better creep resistance. Normally, these resins can be formulated to give a wide range of properties upon the requirement. The most commonly used thermoset resins are epoxy, polyester, vinyl ester and phenolics. Among them, the epoxy resins are being widely used for many advanced composites due to their excellent adhesion to wide variety of fibers, superior mechanical and electrical properties and good performance at elevated temperatures. **Fiber Material -** Generally, fiber is the reinforcing phase of a composite material. The present investigation employs bamboo as the

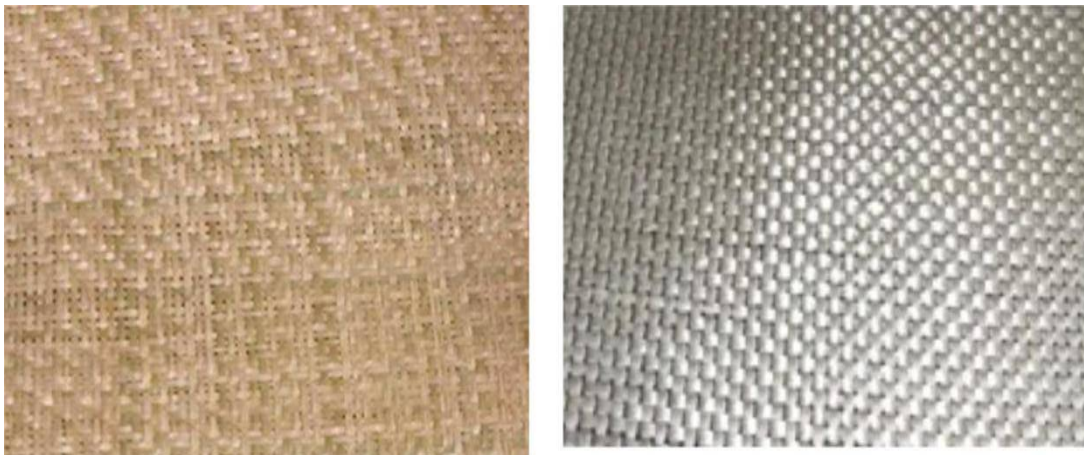
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Vol. 6, Issue 11, November 2017

natural fiber in the epoxy matrix to fabricate a series of hybrid composites. The scientific name of the type of bamboo used for this work is *Dendrocalamus strictus*. This species occupies about 53 per cent of total bamboo area in India. **Particulate Filler Materials**-A variety of natural or synthetic solid particulates, both organic and inorganic is already being commercially used as reinforcing fillers in polymeric composites. While ceramic powders such as alumina (Al_2O_3), silicon carbide (SiC), silica (SiO_2), titania (TiO_2) etc. are widely used as conventional fillers, the use of industrial wastes for such purpose is hardly found. **Composite Fabrication**-Cross plied bamboo and E-glass fibers are reinforced separately in epoxy resin to prepare the fiber reinforced composites B_1 and Z_1 in which no particulate filler is used. The other composite samples $B_2 - B_9$ and $Z_2 - Z_9$ with four different particulate fillers of varied amount but with fixed fiber loading (50 wt %) are fabricated.



Density-The theoretical density (ρ_{ct}) of composite materials in terms of weight fractions of different constituents can easily be obtained as for the following equation. where, W and ρ represent the weight fraction and density respectively. The suffixes f and m stand for the fiber and matrix respectively. Since the composites under this investigation consist of three components namely matrix, fiber and particulate filler, the expression for the density has been modified as where, the suffix p stands for the particulate fillers. The actual density (ρ_{ce}) of the composite, however, can be determined experimentally by simple water immersion technique. The volume fraction of voids (V_v) in the composites is calculated using the following equation:

Micro-hardness-Micro-hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136° between opposite faces, is forced into the material under a load F . The two diagonals X and Y of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. In the present study, the load considered $F = 24.54N$ and Vickers hardness number is calculated using the following equation.

$$H_v = 0.1889 \frac{F}{L^2} \quad (3.4)$$

and $L = \frac{X + Y}{2}$

where, F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm).

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Vol. 6, Issue 11, November 2017

Tensile Strength - The tensile test is generally performed on flat specimens. The dimension of the specimen is 150 mm × 10 mm × 4 mm and a uniaxial load is applied through both the ends. The ASTM standard test method for tensile properties of fiber-resin composites has the designation D 3039-76. In the present work, this test is performed in the universal testing machine Instron 1195 (Figure 3.2a) at a crosshead speed of 10 mm/min and the results are used to calculate the tensile strength of composite samples. The loading arrangement is shown in Figure 3.2b. Here, the test is repeated three times on each composite type and the mean value is reported as the tensile strength of that composite.

Flexural and Inter-Laminar Shear Strength (ILSS)-The flexural strength of a composite is the maximum tensile stress that it can withstand during bending before reaching the breaking point. The three point bend test is conducted on all the composite samples in the universal testing machine Instron 1195. The dimension of each specimen is 60 mm × 10 mm × 4 mm. Span length of 40 mm and the cross head speed of 10 mm/min are maintained. The loading arrangement is shown in Figure 3.2c. For both flexural strength and ILSS, the test is repeated three times for each composite type and the mean value is reported. The flexural strength of the composite specimen is determined using the following equation.

$$\text{Flexural Strength} = \frac{3PL}{2bt^2} \quad (3.5)$$

where, L is the span length of the sample (mm)

P is maximum load (N)

b the width of specimen (mm)

t the thickness of specimen (mm)

The data recorded during the 3-point bend test is used to evaluate the ILSS also.

The ILSS values are calculated as follows:

$$\text{ILSS} = 3P/4bt$$

Impact Strength - Low velocity instrumented impact tests are carried out on the composite specimens. The tests are done as per ASTM D 256 using an impact tester (Figure 3.3). The pendulum impact testing machine ascertains the notch impact strength of the material by shattering the V-notched specimen with a pendulum hammer, measuring the spent energy and relating it to the cross section of the specimen. The standard specimen size as per ASTM D 256 is 64 mm × 12.7 mm × 3.2 mm and the depth under the notch is 10 mm. The respective values of impact energy of different specimens are recorded directly from the dial indicator.

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Vol. 6, Issue 11, November 2017

IV. RESULTS

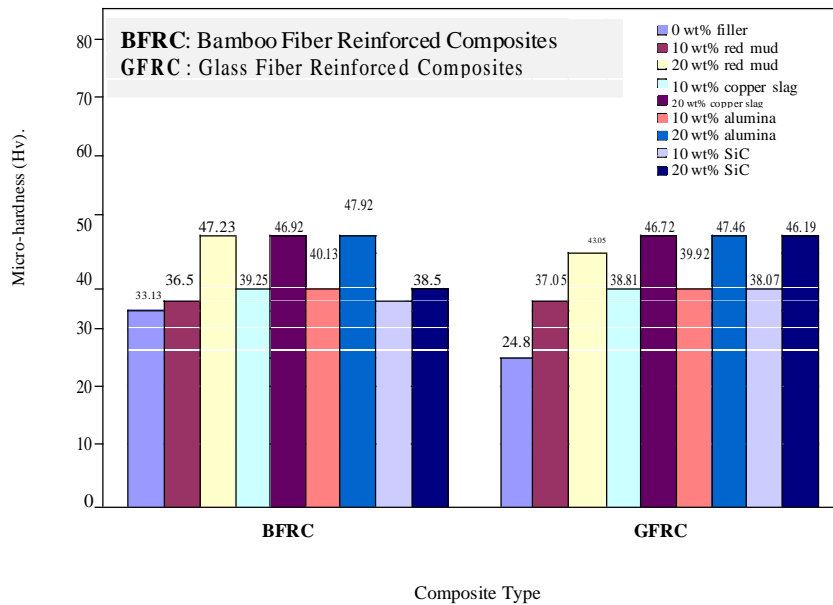


Figure 4.1 Micro-hardness of composites with different particulate

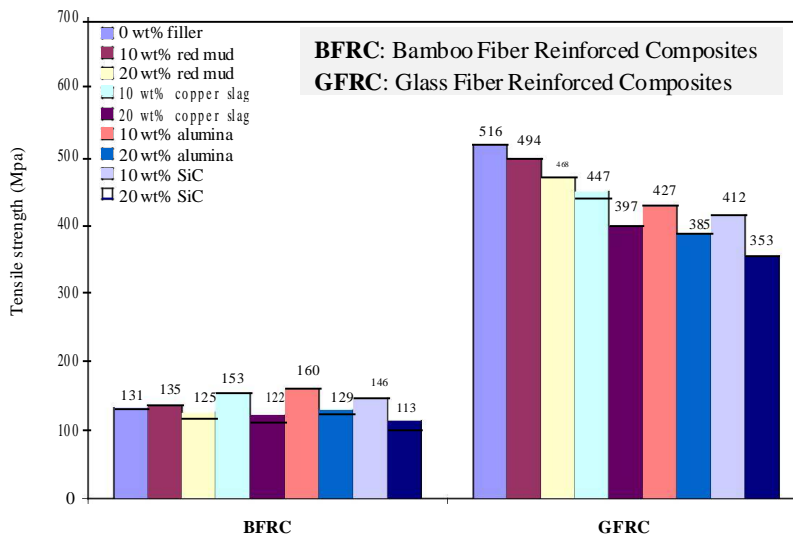


Figure 4.2 Tensile strength of composites with different particulate fillers

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Vol. 6, Issue 11, November 2017

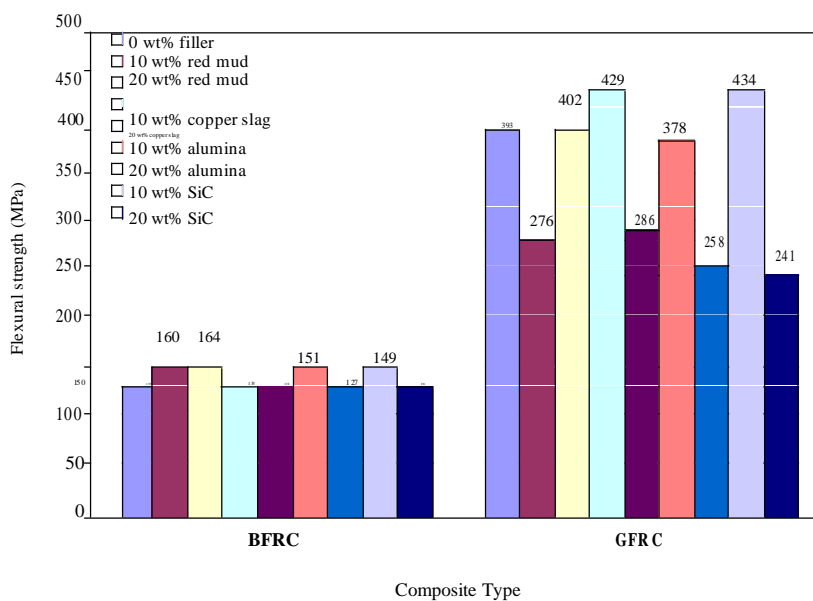


Figure 4.3 Flexural strength of composites with different particulate fillers

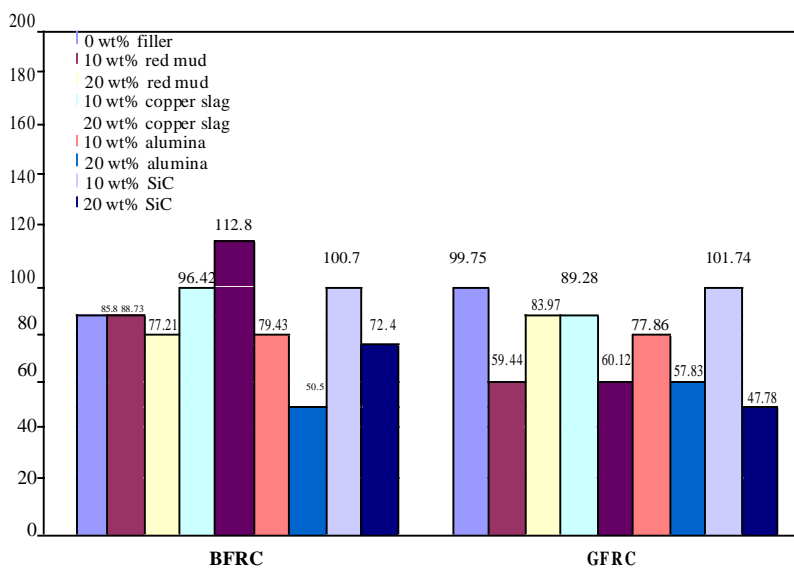


Figure 4.4 Inter-laminar shear strength of composites with different fillers

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Vol. 6, Issue 11, November 2017

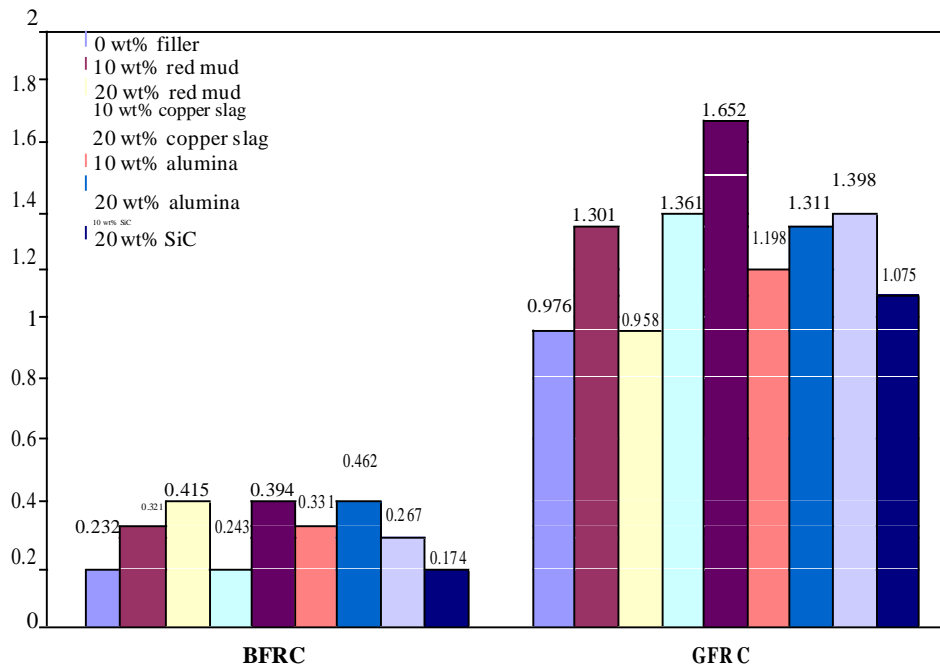


Figure 4.5 Impact strength of composites with different particulate fillers

V. CONCLUSION

This analytical and experimental investigation on particulate filled bamboo/glass-epoxy composites has led to the following specific conclusions:

1. Successful fabrication of multi-component hybrid bamboo/glass-epoxy composites with reinforcement of conventional ceramic fillers such as Al₂O₃ and SiC is possible. Industrial wastes like red mud and copper slag can also be gainfully utilized as fillers in composite making.

2. Incorporation of these fillers modifies the tensile, flexural, impact and inter-laminar shear strengths of the composites both for bamboo as well as for glass fiber reinforcement. The tensile modulus, micro-hardness and density of the composites are also greatly influenced by the type and content of fillers. The particulate filled bamboo-epoxy composites possess higher hardness values compared to the glass-epoxy composites irrespective of the filler type. However, their strength properties are not found as good as those of the glass fiber reinforced composites. This suggests that bamboo fiber has the potential to replace glass fiber in some applications that do not require very high load bearing capabilities. However, while fabricating a composite of specific requirements, there is a need for the choice of appropriate fiber and filler material for optimizing the composite system.

3. A theoretical model based on conservation of particle kinetic energy and thermal energy during multiple impact erosion process has been developed. To overcome the shortcomings of the existing theoretical models an

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