EROSION WEAR BEHAVIOUR OF BAMBOO FIBER BASED HYBRID COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
in
Mechanical Engineering
(Specialization: Production Engineering)

BY

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ROURKELA 769008

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CERTIFICATE

This is to certify that the thesis entitled "**EROSION WEAR BEHAVIOUR OF BAMBOO FIBER BASED HYBRID COMPOSITES**", submitted by **Ms.PRITY ANIVA XESS** bearing **Roll no. 210ME2273** in partial fulfillment of the requirements for the award of ***Master of Technology*** in the Department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

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A C K N O W L E D G E M E N T

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ABSTRACT

In recent years, natural fiber reinforced polymer composites have received much attention because of their many advantages such as lightweight, nonabrasive, nontoxic, low cost and biodegradable properties. Despite their numerous advantages, they suffer from low modulus, lower strength, and poor moisture resistance compared to synthetic fiber reinforced composites. Hybrid composite materials that contains two or more different types of fiber in which one type of fiber could complement with what are lacking in the other. Hybridization of natural fiber with stronger and high corrosion resistance synthetic fibers like glass can improve the various properties such as strength, stiffness etc. In this study, a series of epoxy based composites reinforced with both glass and bamboo fiber are fabricated. The objective of the present work is to study the physical, mechanical, dynamic mechanical and erosion wear behaviour of the composites. It further outlines a methodology based on Taguchi's experimental design approach to make a parametric analysis of erosion characteristics. Finally, the surface morphology of the eroded composites specimen has made using SEM study.

C O N T E N T S

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Introduction

Composite materials consist of two or more chemically distinct constituent on a macro scale having a dispersed interface separating them and having bulk performance which is considerably different from those of any of its individual constituents. Composites are materials that include strong load carrying material known as reinforcement which is surrounded by the weaker material known as matrix. Reinforcement provides strength, rigidity and helping to support mechanical load and the matrix or binder maintains the location and orientation of the reinforcement.

Composites can be classified according to different criteria. Figure 1 shows the classification of composites based on geometry and physical structure of matrix and reinforcement. According to the type of matrix materials, composites materials are classified into three categories, such as metal matrix composites, ceramic matrix composites and polymer matrix composites. Each type of composites is suitable for different applications. When the matrix material is polymer, the composite is called polymer matrix composites (PMC). The reinforcing material can be either fibrous or non-fibrous (particulates) in nature. There are two major classes of polymers used as matrix materials such as thermoplastic and thermoset. Thermoplastic (e.g. nylons, polystyrene, polyethylene etc.) are reversible and can be reshaped by application of heat and pressure. However, thermoset (e.g. epoxides, phenolic, polyesters etc.) are materials that undergo a curing process through part fabrication, after which they are rigid and cannot be transformed. Epoxy resin is the most commonly used polymer matrix with reinforcing fibres for advanced composites applications. Epoxy resin possess very good mechanical properties, chemical resistance and electrical characteristics. In addition to that they have low shrinkage upon curing and good chemical resistance.

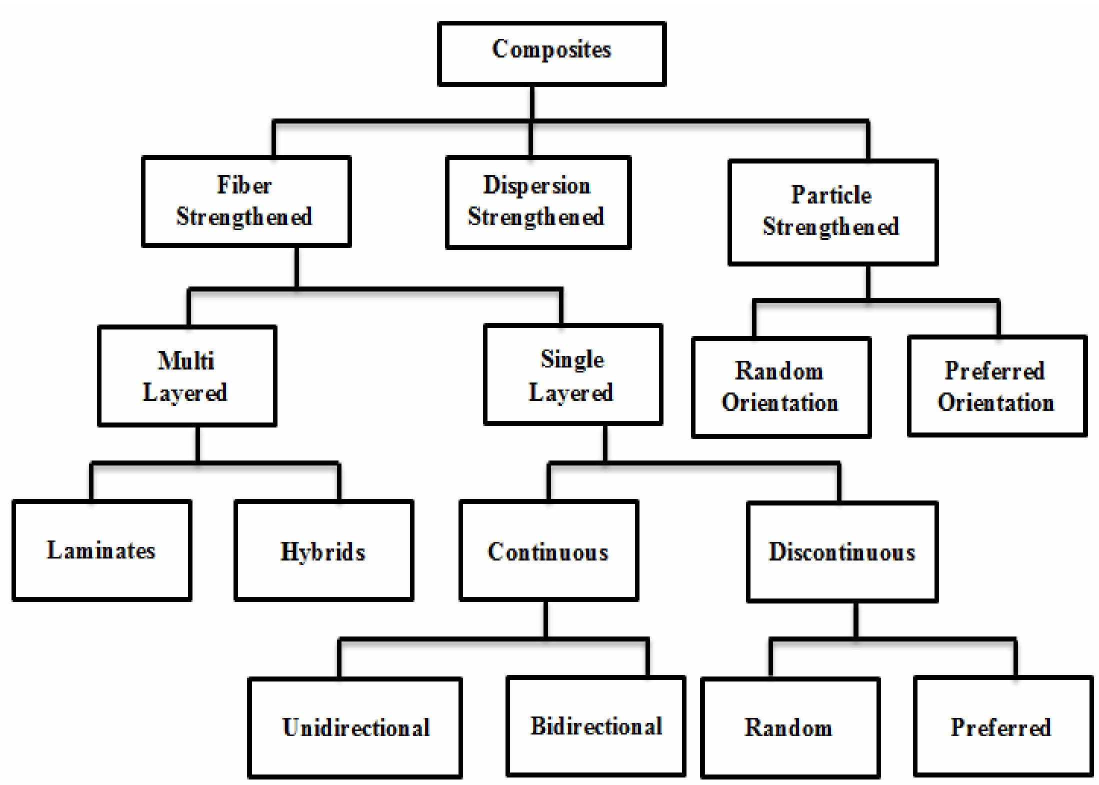

Figure1. Classification of composites based on geometry and physical structure of matrix and reinforcement [1]

Now-a-days, the natural fibers show a great interest as they are a substitute to the ever depleting petroleum sources [2]. Among all reinforcing fibers, natural fibers have gained considerable importance as reinforcements in polymer matrix composites. The benefits associated with the usage of natural fibers as reinforcement in polymers are their availability, biodegradability, low energy consumption, non-abrasive nature and low cost. In addition, natural fibres have low density and high specific properties. The specific mechanical properties of natural fibres are equivalent to those of synthetic reinforcements. A great deal of work has been carried out to measure the potential of natural fibres as reinforcement in polymers. Studies on plastics and cements reinforced with natural fibres such as jute, coir, sisal, bamboo, banana and wood fibers have been reported [3-8]. Among various natural fibers, bamboo finds a wide variety of applications around the world, and is measured as a promising housing material in underdeveloped and developed countries. Wooden products are not used anymore with the wide spread of cheaper artificial materials [9]. So, wood has been replaced by a bamboo as due to high rise in cost of timber products [10]. Bamboo is abundant natural resources in Asian countries and its overall mechanical properties are comparable with those of wood. Bamboo is considered as one of the fastest renewable plant with a maturity cycle of 3-4 years. The use of bamboo fiber can also help to decrease the demand for wood fibers and ecological impacts related with wood fiber harvesting [11]. The structure of bamboo itself is a composite material, containing of long and allied cellulose fibers immersed in a lignin matrix. The basic problem associated with the natural fiber reinforced polymer composites is poor interfacial adhesion of the hydrophobic matrix material with the hydrophilic fiber which results in poor mechanical properties in the final material. So, a hybrid composite material that contains two or more different types of fiber in which one type of fiber could complement with what are lacking in the other. Hybridization of natural fiber with stronger and high corrosion resistance synthetic fibers like carbon, glass, aramid etc. can improve the various properties such as strength, stiffness etc.

Dynamic mechanical analysis (DMA) or dynamic mechanical thermal analysis (DMTA) is a sensitive method that describes the mechanical responses of materials by monitoring property changes with respect to the temperature and/or frequency of the oscillation [12]. DMA is used to study the viscoelastic performance of polymers. It refers to the response of a material subjected to its periodic force. It also enables to investigate the phase structure and morphology. Dynamic mechanical properties of a material depend on the fiber content, existence of the additive like filler, Compatibilizer, fiber orientation and the mode of testing [13]. The technique which separates the dynamic response of materials into two different parts: an elastic part (E') and a viscous or damping component (E"). The elastic process defines the energy stored in the system, while the viscous component describes the energy dissipated during the process. The three important parameters that have been studied during a dynamic mechanical test are: storage modulus, loss modulus and mechanical Damping parameter (tan δ). Storage modulus is defined as the maximum energy stored in a material during one cycle of oscillation. It also gives an idea of stiffness performance and load bearing ability of composite material [14]. Loss modulus is proportional to the amount of energy that has been dissipated as heat per cycle in a viscoelastic material. It is very sensitive to molecular motions and mechanical damping parameter (Tan δ) is the ratio of the loss modulus to the storage modulus. It is the term that can be linked to the impact resistance of a material. Since the damping peak occurs in the region of the glass transition where the material changes from a rigid to elastic state.

Wear can be defined as progressive loss of substance from the operating surface of a body occurring as a result of relative motion at the surface. There are 4 different types of wear: abrasion, adhesion, erosion and surface fatigue. Abrasive wear can be defined as one in which hard asperities on one body moving across a softer body under some load, enter and remove material from the surface of the softer body leaving a channel. Abrasive wear can occur as two body abrasion or three body abrasions. Adhesion wear is a result of micro connections caused by fusing between the opposing asperities on the rubbing surfaces of the counter bodies. The weight applied to the contacting asperities is so high that they distort and follow to each other forming micro-joints. The motion of the rubbing counter bodies result in rupture of micro-joints. Erosive wear is caused by the impact of particles of solid or liquid against the surfaces of an object. The impacting particles slowly remove material from the surface through recurrent distortions and cutting actions. Surface fatigue is occurs due to the change in the material state due to cyclic load which results in progressive fracture. The process in which tiny wear particles are removed from a surface by fracture on repeated rolling or sliding on the surface is known as surface fatigue. Due to a repeated loading action surface cracks grow from pre-existing defects.

Focussing on the erosion wear of polymer composites, it has not received considerable attention in past two decades. Attention has been drawn in this area due to the increasing application of composites in various applications such as aerospace, transportation and process industries. Solid particle erosion (SPE) is a dynamic process which causes material removal from the target surface due to impingement of fast moving solid particles [15]. SPE is advantageous as in sandblasting and high speed abrasive water jet cutting but there exist some disadvantages in the engineering systems that includes steam and jet turbines, pipelines and valves carrying particulate matter. Solid particle erosion is to be forecast when hard particles enter in a gas or liquid medium striking on a solid at any velocity. In both cases, particles can be accelerated or decelerated and their directions of motion can be changed by the fluid.

The major factors that affect erosion rate are erodent velocity, erodent characteristics (size, shape, etc.), and erodent flux rate. The factors which govern the erosion rate of fiber-reinforced polymers are: the matrix will be either thermosetting or thermoplastic, the fragility of the fibers, and the interfacial bond between the fibers and the matrix.

Currently much attention is towards the study of solid particle erosion behaviour of polymer composites due to the high possible use of these materials in many mechanical and structural applications. Hence, erosion resistance of polymer composites has become a significant material property, particularly in selection of substitute materials and therefore the study of solid particle erosion characteristics of the polymeric composites has become highly relevant.

The present work is undertaken to develop a new class of natural fiber epoxy on the bamboo/glass hybrid epoxy composite materials. Physical and mechanical properties such as tensile, flexural, impact (with varying ratio of bamboo/glass fibers) were studied. Storage modulus, loss modulus and damping characteristics of varying bamboo/glass fiber of epoxy composites have been studied in dynamic mechanical analysis. The erosion wear behaviour of the composites has been studied. The specific objectives of this work are clearly outlined in the next chapter.

1.2 Thesis Outline

The remainder of this thesis is organised as follows:

Chapter 2: Includes a literature survey proposed to provide a summary on the base of information already available concerning the issues of interest.

Chapter 3: The detail description of materials required, fabrication techniques and characterization of the composites under investigation is described in this chapter.

Chapter 4: The physical and mechanical properties of the composites under study are presented in this chapter.

Chapter 5: This chapter presents and discussed the experimental results and parametric studies.

Chapter 6: This chapter presents the conclusions and recommendations for future work.

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CHAPTER 2
LITERATURE REVIEW

This chapter provides the background information on the issues to be considered in the present research work and to focus the relevance of the current study, the work already done so far and also to show the relevance of the current research work.

Now-a-days the interest in natural fiber reinforced polymer composites increasing rapidly due to its many advantages. These composites are more environmentally free and frequently used in many engineering applications worldwide such as transportation (automobile, aerospace and railway coaches), construction (ceiling, partition boards etc.), consumer products, military applications etc. In fibre reinforced polymer composites, the fibres can be either synthetic fibres or natural fibres and if the fibres are derived from natural resources like plants they are termed as natural fibres. A great deal of work has already been made on the prospective of the natural fibres as reinforcements for composites. Advantages of natural fibres over synthetic fibres comprise low density, low cost, availability, recyclability and biodegradability [16-18]. Due to their numerous advantages they are analogous to those of synthetic fibres used as reinforcements. Generally, the natural fibres are consisting of cellulose, hemi-cellulose, lignin, pectin, waxes and water soluble substances. The properties of natural fibres are greatly influenced by their chemical compositions. The properties of some of these fibres are presented in Table 2.1 [19]. It is evident from Table 2.1 that, the tensile strength of glass fibre is substantially higher than that of natural fibres even though the modulus is of the same order. However, when the specific modulus of natural fibres is considered, the natural fibres are better as compared to glass fibres. Therefore, these higher specific properties are the main advantages of natural fibre as reinforcement in polymer composites for weight sensitive applications.

Table 2.1 Physical properties of various natural fibres [19]

Fiber	Tensile strength(MPa)	Young's modulus(GPa)	Elongation at break(%)	Density (g/cm^3)
Abaca	400	12	3-10	1.50
Alfa	350	22	5.80	0.89
Bagasse	290	17	----	1.25
Bamboo	140-230	11-17	-----	0.60-1.10
Banana	500	12	5.90	1.35
Coir	175	4-6	30	1.20
Cotton	287-597	5.50-12.60	7-8	1.50-1.60
Curaua	500-1150	11.80	3.70-4.30	1.40
Date palm	97-196	2.50-5.40	2-4.50	1-1.20
Flax	345-1035	27.60	2.70-3.20	1.50
Hemp	690	70	1.60	1.48
Henequen	500 ± 70	13.20 ± 3.10	4.80 ± 1.10	1.20
Isora	500-600	-----	5-6	1.20-1.30
Jute	393-773	26.50	1.50-1.80	1.30
Kenaf	930	53	1.60	----
Nettle	650	38	1.70	----
Oil palm	248	3.20	25	0.7-1.55
Piassava	134-143	1.07-4.59	21.90-7.80	1.40
Pineapple	1.44	400-627	14.50	0.80-1.60
Ramie	560	24.50	2.50	1.50
Sisal	511-635	9.40-22	2.0-2.50	1.50
E-glass	3400	72	------	2.5

Many investigations have been made on the effect of various factors on mechanical behaviour of natural fiber reinforced polymer composites. Bledzki et al [20] have investigated the effect of flax and jute fibres on the mechanical properties of the composites. Increasing the fibre content results in an increase in the shear modulus and impact strength of the composites. Many similar studies on natural fibers such as bamboo, hemp, flax and kenaf [21-24] 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. Santulli [25] studied on the post-impact behaviour of jute fiber reinforced polyester composites subjected to low velocity impact. Effect of fiber content on tensile and flexural properties of pineapple fiber reinforced poly (hydroxybutyrate-co-valerate) resin composites has studied by Luo and Netravali [26]. The mechanical behviour of jute and kenaf fiber reinforced polypropylene composites has been studied by Schneider and Karmaker [27]. It is concluded from their study that jute fiber based composites provides better mechanical properties than kenaf fiber based composites. A systematic study on the properties of henequen fiber has made by Cazaurang e t al. [28] and reported that fibers have mechanical properties suitable for reinforcement in thermoplastic resins. Various aspects of banana fiber reinforced polymer composites has studied by various investigators [29-33]. It is reported from their study that they have better strengths as comparison to wood based composites.

A great deal of work has already been done on bamboo in various forms. Nugroho et.al [34, 35] studied the structural composite products made from bamboo. They determine the suitability of bamboo zephyr strand as raw material for the manufacture of bamboo zephyr. Silva et.al [36] studied on the finite element method and homogenization to investigate the structural behaviour of bamboo. It was observe that bamboo behaviour under applied loads, simulations are conducted under multiple considerations such as a spatially varying Young's modulus, an averaged young's modulus and orthotropic constitutive properties obtained from homogenization theory. Obataya et.al [37] studied on the flexural ductility of split bamboo culm which is related to its characteristic fiber–foam composite structure. It was observed that there is no difference between the remaining strains of the bamboo and wood. This indicated that the bamboo has excellent ductility. Yu et.al [38] studied on the variation in tensile properties and the relationship between tensile properties and air-dried density for moso bamboo. Mingjie et.al [39] studied on the hygrothermal effect of bamboo by dynamic mechanical analysis.

The hygrothermal effect on dynamic mechanical properties shows negative value. The storage modulus decreases with increasing temperature and moisture content, and glass transition temperature decreases with increasing moisture content. Amada et.al [40] studied on the fracture properties of bamboo. It was concluded that fracture toughness of the bamboo culm has the high value in the outer surface layer and decreases towards the inner surface. Chand et.al [41] studied on the anisotropic abrasive wear behaviour of bamboo. In bamboo the anisotropic wear behaviour exists due to the vascular fibre's orientation parallel to the sliding direction or the central axis of the bamboo. Zou et.al [42] studied on the Nano scale structure of the cell wall of bamboo fibers was characterized using an atomic force microscope. Ismail et.al [43] studied on the effects of a silane coupling agent on curing characteristics and mechanical properties of bamboo fiber filled natural fiber composites. It was concluded that the silane coupling agent improved the adhesion between the fiber and the rubber matrix and enhanced the mechanical properties of the composites. Bamboo fibre filled natural rubber composites were studied by Ismail et.al [44]. He studied on the effects of filler loading on the curing characteristics and mechanical properties of bamboo fibre reinforced natural rubber composites. Tensile modulus and hardness of composites increases with increasing filler loading and the presence of bonding agents. Sumardi et.al [45] studied on the influence of strand length and layer structure on the mechanical properties of bamboo strand-board. Tong et.al [46] studied on the effects of vascular fiber content on abrasive wear of bamboo.

The effect of various factors on the properties of hybrid composites is studied by many investigators. Mechanical properties of bamboo/glass 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. [47]. Thwe et.al [48] studied the effect of environmental aging on the mechanical properties short bamboo-glass fiber reinforced polypropylene hybrid composites and reported replacement of bamboo fiber by glass fiber results an improved tensile strength and tensile modulus in bamboo glass reinforced plastics. Biswas et.al [49] studied on erosion characteristics of red mud filled bamboo and glass epoxy composites. Mi et al. [50] studied on the bamboo-glass fiber based hybrid composites and concluded that the tensile and flexural strength and stiffness of bamboo fiber reinforced plastics and bamboo glass reinforced plastics both decreased after aging in water at 25°C and 27°C for prolonged period. Bamboo fiber degrades by decomposition into thin fibrils and detached layers while polypropylene matrix degrades by dissolution. Tensile and flexural strength and stiffness are enhanced by inclusion of a Compatibilizer. The dynamic mechanical properties of a composite material depend on the fiber content, presence of the additive like filler, Compatibilizer, fiber orientation and the mode of testing [51,52]. Samal et.al [53] studied on bamboo/glass fiber hybrid composites. In this study mechanical properties of polypropylene reinforced with glass as well as a lignocellulosic bamboo fiber had been examined. Nayak et.al [54] studied on influence of short bamboo/glass fiber on the thermal, dynamic mechanical and rheological properties of polypropylene hybrid composites. Rao et.al [55] studied on the hybrid composites and their effect of fibers on mechanical properties. It was found that the hybrid composites with alkali treated bamboo fibers were found to possess higher impact properties. Prasad et.al [56] studied on the chemical resistance and tensile properties of bamboo and glass fibers reinforced epoxy hybrid composites. It was found that the hybrid composites exhibit good tensile and chemical resistance properties.

Many researchers have investigated the solid particle erosion behaviour of various polymers and their composites. Polymers that have been studied include polypropylene [57], polyaryletherketone [58], polyester [59], epoxy [60-63], and polyethermide [64].

2.1 The Knowledge Gap

The literature survey presented above reveals the following knowledge gap in the research reported so far:

- ❖ Though much work has been made on a wide variety of natural fibers for polymer composites, very less has been reported on the reinforcing potential of short bamboo fiber in addition to glass fiber in polymer composites in spite of several advantages of hybrid composites over others.
- ❖ Studies carried out worldwide on erosion wear behaviour 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.

2.2 Objectives of the Work

The knowledge gap in the existing literature review has helped to set the objectives of this research work which are outlined as follows:

1. Fabrication of a new class of epoxy based hybrid composites reinforced with short glass fibers and bamboo fibers.
2. To study the mechanical behaviour (such as tensile strength, flexural strength, impact strength, and micro-hardness etc.) of the composites.
3. Evaluation of dynamic mechanical behaviour of the composites.
4. To study the effects of fiber content on wear behaviour of the composites.
5. To study the surface morphology of the composites using SEM study.

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CHAPTER 3
MATERIALS AND METHODS

This chapter describes the materials required, fabrication method and the experimental procedures followed for their characterization. It presents the details of the characterization and tests which the composite specimens are subjected to. Raw materials used in the present research work are:

1. Bamboo fiber
2. Glass fiber
3. Epoxy
4. Hardener

3.1 Materials

3.1.1 Matrix Material

Matrix materials are of different types like metals, ceramics and polymers. Polymer matrices are most commonly used matrix materials due its advantages like cost efficiency, easy availability, low density, light weight, high strength to weight ratio and environmental friendly. Polymer matrices can be either thermoplastic or thermoset. Thermoset 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, better creep resistance and excellent thermal stability.

The most commonly used thermoset resins are epoxy, vinyl ester, polyester and phenolic etc. Among them, the epoxy resins are being extensively used for many advanced composites due to their outstanding adhesion to wide variety of fibers, good performance at elevated temperatures, superior mechanical and electrical properties etc. In addition they have low shrinkage upon curing and good chemical resistance. Epoxy (LY 556) is chosen as a matrix material for the present research work. It chemically belongs to the ‘epoxide’ family and its common name of epoxy is Bisphenol-A-Diglycidyl-Ether.

3.1.2 Fiber Material

Fiber is a reinforcing phase of composite materials. In the present research work bamboo and glass fiber is taken as the reinforcement in the epoxy matrix to fabricate composites. Bamboo fibre is found from bamboo pulp, which is taken out from the bamboo stem and leaves by wet spinning, including a procedure of hydrolysis alkalisation and multi-phase bleaching [65]. A mixture of chemical and mechanical methods is generally used for the removal of bamboo fibers. In chemical method, the process undergoing for the removal of bamboo fibers are done by delignification, fiber separation and isolation of fibers [66]. The chemical constituents of bamboo fibers can be classified into cellulose and lignin. Lignin plays the role of binding the fibers of cellulose.

The chemical composition of bamboo varies with age, height, season, species and layer, aging of a bamboo culm influences physical, chemical, and mechanical properties, and consequently its processing and utilization. Such variation can lead to physical and mechanical properties changes during the growth and maturation of bamboo [67,68]. In general bamboo is available everywhere and is an abundant in the natural resources. The structure of bamboo itself is a composite material, consisting of long and allied cellulose fibers engrossed in a ligneous matrix.

Bamboo is the fastest growing plant. Depending upon the species, the culms can grow to 3-30 m long within 3-4 months [69]. Bamboo species grow to their full height and diameter around one year. The culm ripens in two to four years. The time it takes for maturing limits the commercial harvest age [70]. It is generally said that up to certain age height and diameter of the annual flush of culms increases. The scientific name of the type of bamboo used for this work is Dendrocalamus strictus [71]. This is one of the predominant species of bamboo in Orissa, Uttar Pradesh, Madhya Pradesh and Western Ghats in India. This species occupies approximately 53% of total bamboo area in India.

Glass is the most common fiber used in polymer matrix composites. Its advantages include its high strength, high chemical resistance, low cost and good insulating properties. There are two types of glass fiber. The main types are E-glass and S-glass fiber. The “E” in E-glass stands for electrical because it is usually designed for electrical applications. Glass fiber is mainly used as an insulating material. It is also used as a reinforcing agent for many polymer products to form a very strong and light fiber-reinforced polymer(FRP) composites material called glass-reinforced plastic (GRP). The letter “S” in S-glass stands for structural applications. S-glass got different chemical formulation and it has higher strength to weight ratio and higher elongation strain percentage but it is quite expensive. C-glass fibers are advantageous in resisting chemical corrosion. Glass fibers are available in different forms like continuous, chopped and woven fabrics. The type of glass fiber used as reinforcement in this study is E-glass fiber.

3.2 Composite Fabrication

The bamboo fiber is collected from local sources. The epoxy resin and the hardener are provided by Ciba Geigy India Ltd. A stainless steel mould having dimension of 180 ×180× 40 mm^3 is used for composite fabrication. The short bamboo fiber and E-glass fiber 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 (EBGF-1 to EBGF-4) with different weight percentage of fibers are prepared. A releasing agent is used for facilitate easy removal of the composite from the mould after curing. If any entrapped air bubbles are there, then they are removed by a sliding roller and the mould is closed for curing at a temperature of 30°C for 24 h at a constant pressure of 50kg. After curing the specimens of suitable dimensions are cut for mechanical test. The composition and designation of the composites prepared for this study are listed in Table 3.1.

Table 3.1 Designation of Composites

Sl. No.	Composites	Composition
1	EBGF-1	Epoxy + bamboo fiber (0 wt.%) + glass fiber (0 wt.%)
2	EBGF-2	Epoxy + bamboo fiber (7.5 wt.%) + glass fiber (7.5 wt.%)
3	EBGF-3	Epoxy + bamboo fiber (15 wt.%) + glass fiber (15 wt.%)
4	EBGF-4	Epoxy + bamboo fiber (22.5 wt.%) + glass fiber (22.5wt.%)

Figure 3.1: Short bamboo fiber and glass fiber reinforced epoxy based composite

3.3 Mechanical tests

3.3.1 Density

The theoretical density of composite materials can be obtained as per the equations given by Agarwal and Broutman [72].

$$\rho_{ct} = \frac{1}{\frac{w_f}{\rho_f}+\frac{w_m}{\rho_m}} \qquad (3.1)$$

where w and ρ represent the weight fraction and density respectively. The suffix f, m and ct stand for the fiber, matrix and the composite materials respectively. However, the actual density (ρ_{ce}) of the composite can be obtained experimentally by simple water immersion technique. The volume fraction of voids (V_v) in the composites is calculated by the following equation:

$$V_V = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \tag{3.2}$$

3.3.2 Tensile strength

Tensile testing of the composite samples is done as per ASTM D3039-76 test standards. A uniaxial load was applied through the ends. The ASTM standard test recommends that the length of the test section should be 100 mm specimens with fibres parallel to the loading direction should be 11.5 mm wide. The test is repeated three times on each composite type and the mean value is considered.

3.3.3 Flexural strength

Flexural strength of the composite is done on a three point bend test using Instron 1195. The cross head speed was taken as 10mm/min and a span of 30 mm was maintained. The strength of the material in bending is expressed in terms of MPa is equal to

$$Flexural\ strength = \frac{3PL}{2bd^2} \tag{3.3}$$

Where, P= applied central load (N)

L= test span of the sample (m)

b= width of the specimen (m)

d= thickness of specimen under test (m)

3.3.4 Micro-hardness

Micro-hardness of composite specimens is made using Leitz micro-hardness tester. A diamond indenter in the form of a right pyramid of a square base of an angle 136° between opposite faces under a load F is forced into the specimen. After removal of the load, the two diagonals of the indentation (X and Y) left on the surface of the specimen are measured and their arithmetic mean L is calculated. The load considered in the present study is 24.54N and Vickers hardness is calculated using the following equation:

$$H_V = 0.1889 \frac{F}{L^2} \quad \text{and} \quad L = \frac{X+Y}{2} \tag{3.4}$$

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).

3.3.5 Impact test

As per ASTM D 256 using an impact tester the impact tests are done on the composite samples. The pendulum impact testing machine determines the notch impact strength of the material by devastating the V-notched sample with a pendulum hammer, calculating the spent energy. The standard sample size for ASTM D 256 is 64 × 12.7 × 3.2 mm and the depth of the notch is 10.2 mm.

3.4 Dynamic mechanical properties of the composites

The thermo-mechanical responses of the composites were measured using TA instruments-Q800 model dynamic mechanical analysis (DMA) instrument in bending mode and conducted in a nitrogen atmosphere at a fixed frequency of 1 Hz, heating rate of 5^0C/min, temperature range of 0°C to 180°C and at a strain of 1% on rectangular samples with approximate dimensions of 38×12.5×3.5 mm.

3.5 Scanning electron microscopy (SEM)

The morphological characterization of the composite surface is done in scanning electron microscope of Model JEOL JSM-6480LV (Figure 3.2). The samples are cleaned carefully, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. A thin film of platinum is vacuum evaporated onto the composite specimens in order to improve the conductivity before the micrographs are taken. The eroded surface morphology of the composite specimens after erosion test is observed by means of SEM.

Figure 3.2 SEM Set up

3.6 Erosion test

The erosion test of the composite specimens is performed as per ASTM G76 standard on erosion test rig (Figure 3.3). The test rig consists of an air compressor, an air drying unit, a conveyor belt-type particle feeder, an air particle mixing and an accelerating chamber.

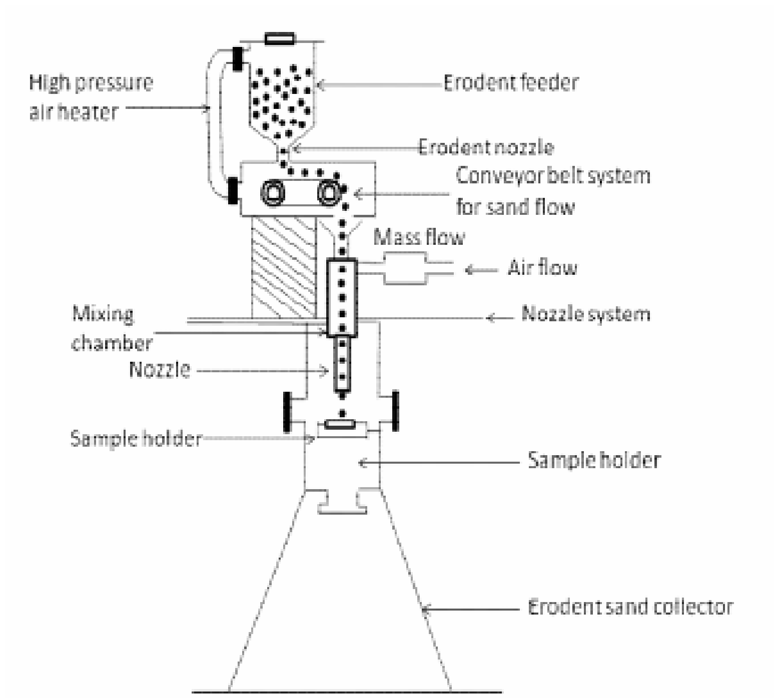

Figure 3.3 A schematic diagram of the erosion test rig

The compressed and dried air is mixed with the erodent and is constantly fed into the mixing chamber by means of a conveyor belt feeder and accelerated by passing the mixture through a convergent brass nozzle. The set-up is capable of making an erosive environment for measuring solid particle erosion wear resistance of the composite samples. Dry silica sand particles of 450µm are used as erodent particle in the present study. The silica sand particles impact the composite samples which can be held at different impingement angles with respect to the direction of erodent flow. The equipment is equipped with a heater which can maintain and regulate the erodent temperature at any predetermined fixed value during the test. After each erosion test, the weight loss is recorded for calculation of erosion rate. Erosion rate is the ratio of the weight loss to the weight of the eroding particles causing the material loss. The process is repetitive till the steady state erosion rate.

3.7 Taguchi method

Taguchi experimental design is an important tool for robust design. It offers a simple and systematic approach to optimize the design parameters because it can significantly minimize the overall testing time and the experimental costs. In this robust design, two major tools are used: signal to noise ratio (S/N), which measures quality with emphasis on variation and orthogonal array, which accommodates many design factors at the same time. The most important stage in design of experiment lies in the selection of the control factors. Through exhaustive literature review, it has been observed that factors viz., impact velocity, fiber loading, impingement angle, stand-off distance and erodent temperature etc. mostly influence the erosion rate of polymer composites. For elaboration of experiments plan the method of Taguchi for five factors at four levels is used, being understood by levels taken by the factors. The orthogonal array chosen is the L_{16} (4^5) which have 16 rows corresponding to the number of tests with 5 columns at four levels. The selected parameters are impact velocity, fiber loading, erodent temperature, stand-off distance and impingement angle. The control factors and their levels are given in Table 3.2.

Table 3.3 presents the orthogonal array for L_{16} (4^5) Taguchi design. The experimental observations are transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of characteristics such as:

'Smaller the better' characteristics: $\frac{S}{N} = -10\log\frac{1}{n}(\sum y^2)$ (3.5)

'Nominal the better' characteristics: $\frac{S}{N} = 10\log\left(\sum\frac{\bar{Y}}{S^2}\right)$ (3.6)

'Larger the better' characteristics: $\frac{S}{N} = -10\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right)$ (3.7)

where n the number of observations, y the observed data, Y the mean and S the variance. The S/N ratio for minimum erosion rate comes under 'smaller is better' characteristic, which can be calculated as logarithmic transformation of the loss function by using Eq. (3.5).

Table 3.2 Levels for various control factors

Control factor	Level				Units
	I	II	III	IV	
A: Impact velocity	35	45	55	65	m/sec
B: Fiber loading	0	15	30	45	wt %
C:Impingement angle	45	60	75	90	°C
D: Stand-off- distance	55	65	75	85	mm
F:Erodent Temperature	35	70	105	140	Deg.

Table 3.3 Orthogonal array for L_{16} (4^5) Taguchi Design

Sl. No.	Impact velocity (m/sec)	Fiber content (wt %)	Impingement Angle (Degree)	Stand-off-distance (mm)	Erodent Temperature (°C)
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	2	1	2	3	4
6	2	2	1	4	3
7	2	3	4	1	2
8	2	4	3	2	1
9	3	1	3	4	2
10	3	2	4	3	1
11	3	3	1	2	4
12	3	4	2	1	3
13	4	1	4	2	3
14	4	2	3	1	4
15	4	3	2	4	1
16	4	4	1	3	2

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CHAPTER 4

MECHANICAL CHARACTERISTICS OF COMPOSITES: RESULTS & DISCUSSION

This chapter represents the physical and mechanical behaviour of short bamboo/glass fiber based hybrid composites.

4.1 Physical and mechanical characteristics of composites

4.1.1 Effect of fiber content density of composites

The presence of void content in the composites significantly reduces the mechanical and physical properties of the composites. Table 4.1 presents the theoretical density, experimental density and the corresponding void content. It can be seen that the void fraction in the composites increases with the fiber content.

Table 4.1 Void fraction of hybrid composites

S.No.	Composites	Theoretical Density (gm/cc)	Experimental density (gm/cc)	Volume fraction of voids (%)
1	EBGF-1	1.17	1.15	1.71
2	EBGF-2	1.38	1.25	9.42
3	EBGF-3	1.41	1.27	9.92
4	EBGF-4	1.44	1.29	10.41

The mechanical properties of the short bamboo and glass fiber reinforced epoxy composites with different fiber loading under this investigation are presented in Table 4.2. It is evident from the Table 4.2 that at 30wt% of fiber i.e. EBGF-4 loading show better mechanical properties as compared to others.

Table 4.2 Mechanical properties of the hybrid composites

Composites	Hardness (Hv)	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J)
EBGF-1	57	31.47	105.6	3.971
EBGF-2	61	33.13	63.8	4.167
EBGF-3	64	43.96	67.3	4.216
EBGF-4	55	51.26	39.95	4.579
EBGF-5	51	35.04	38.96	4.815

4.1.2 Effect of fiber content on hardness of composites

In fig.4.1 shows the hardness of various composites at different fiber loading of bamboo/glass hybrid epoxy composites. Surface hardness increased by the increase of fiber loading up to 30wt%. For instance, hardness of bamboo/glass-epoxy composite is increased from $32H_v$ to $65H_v$ i.e. up to 30wt% and then decreased from $65H_v$ to $55H_v$ i.e. up to 45wt% respectively. It is also observed that a linearly increasing trend up to a certain value of fiber loading (30wt %) and suddenly drops due to breakage and pull out of individual fibers from the resin matrix.

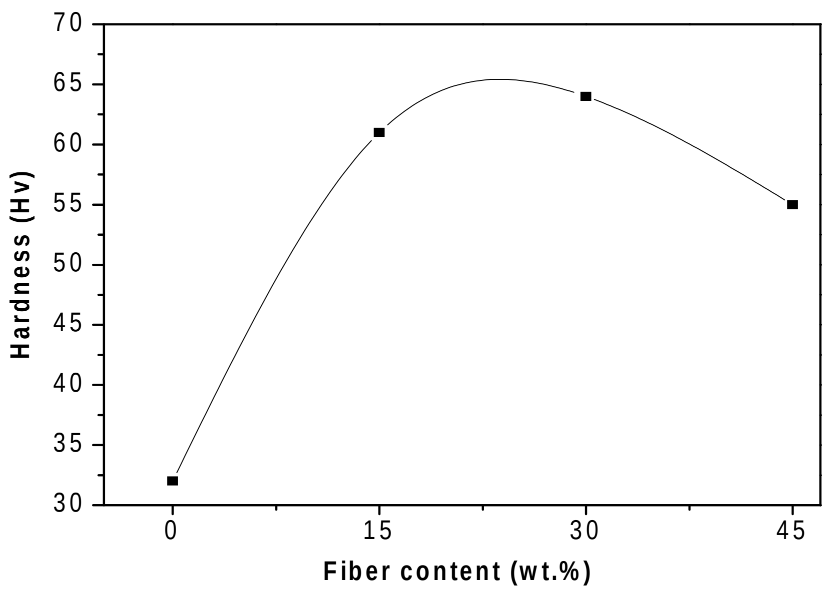

Figure 4.1 Hardness of the short bamboo/glass epoxy composites

4.1.3 Effect of fiber content on tensile strength of composites

Figure 4.2 shows the variation of the tensile strength of bamboo-glass hybrid composites with fiber content. An increase in tensile strength can be observed with an increase in the content of the bamboo/glass fiber. This is due to the proper adhesion between the both types of fiber and the matrix. An increase of 45% in the tensile strength is seen at 30% (by weight) bamboo-glass fiber content compared in the case of 0% of SBGE. The improvement in the tensile strength of the composites is because at these particular compositions the bamboo fiber can effectively transfer the load from the glass fiber.

4.1.4 Effect of fiber content on flexural strength of composites

Flexural strength of bamboo/glass hybrid epoxy composites is shown in Figure 4.3. The flexural strength of composite is increased from 5MPa to 70MPa i.e. up to 30wt% and then decreased from 70MPa to 40MPa i.e. up to 45wt% respectively. It is also observed that a linearly increasing trend up to a certain value of fiber content (30wt%) and suddenly drops due to breakage and pull out of individual fibers from the resin matrix.

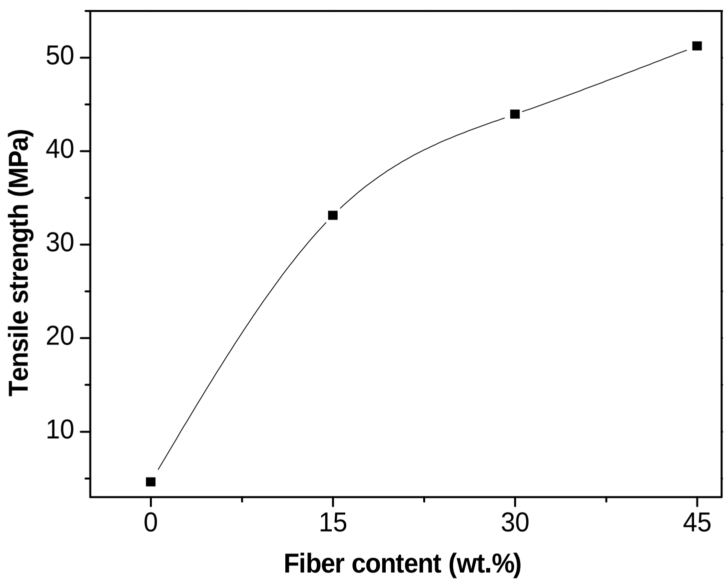

Figure 4.2 Tensile strength of the short bamboo/glass fiber epoxy composites

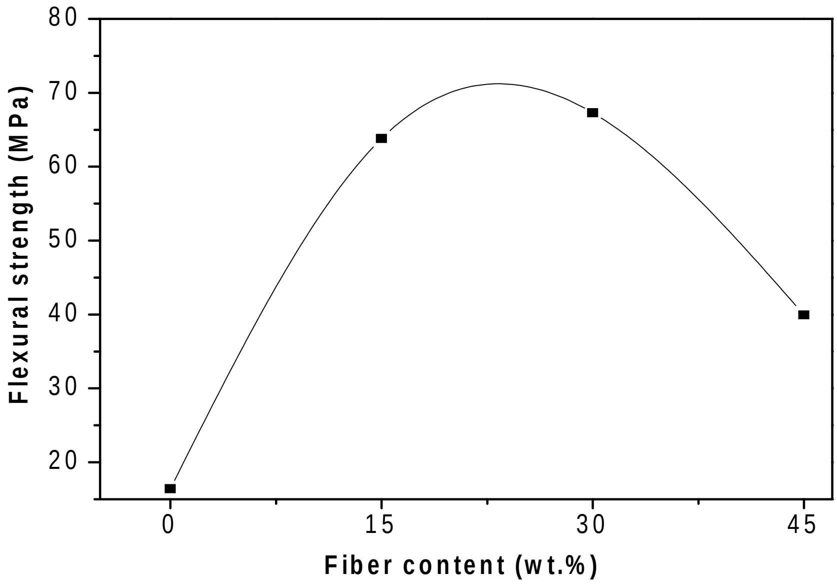

Figure 4.3 Flexural strength of the short bamboo /glass fiber epoxy composites

4.1.5 Effect of fiber content on impact strength of composites

Figure 4.4 shows the variation of the impact strength of bamboo/glass hybrid epoxy composites with fiber content. It is found that the impact strength of bamboo/glass composites linearly increased as the content of the glass fiber is increased. This is due to excellent dispersion of fiber and effective stress transfer between the fiber and the matrix.

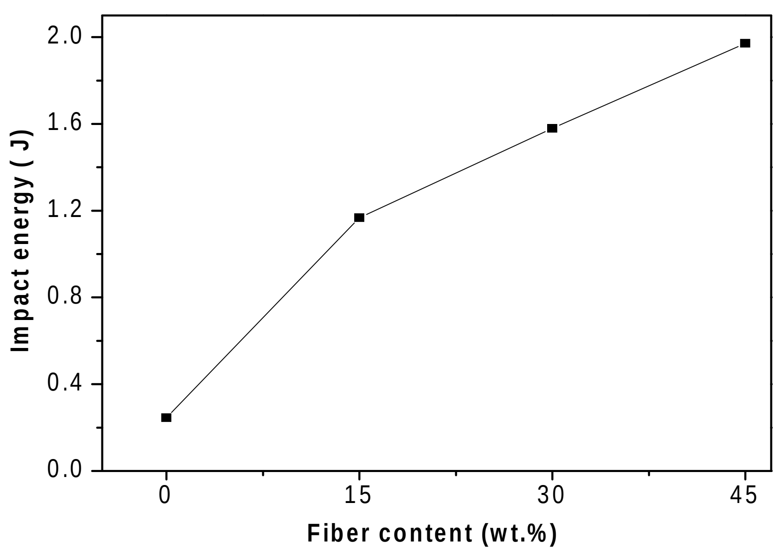

Figure 4.4 Impact strength of short bamboo/glass epoxy composites

4.2 Thermo-Mechanical characterization composites

4.2.1 Dynamic Mechanical Analysis

Dynamic Mechanical Analysis (DMA) has been carried out to investigate the thermo-mechanical performance of the fabricated composites. Figures (4.5-4.7) shows the temperature dependence of storage modulus (E'), loss modulus (E'') and damping factor (tan δ) to characterize the thermo-mechanical response in the entire range of fibre loadings. In polymer, storage and loss modulus change with temperature as the molecular mobility is affected. The storage modulus of a polymer decreases rapidly whereas the loss modulus reaches a maximum when the polymer is heated up through the glass transition (T_g) region. Mobility of the amorphous regions causes reduction in the storage modulus, but the material exhibits useful solid-state properties before approaching melting temperature.

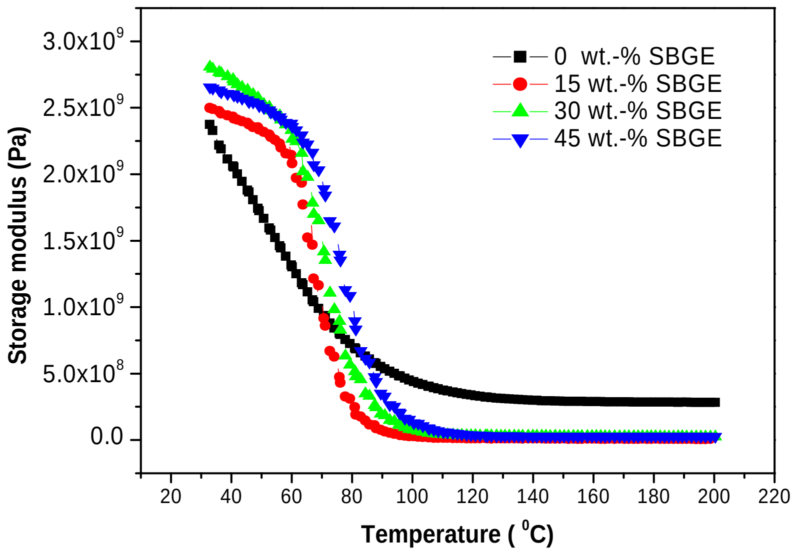

Figure 4.5 Variation of the storage modulus (E') as a function of temperature

Figure 4.5 shows that the slope corresponding to the temperature dependent decay of the storage modulus (E') for composite with 30 wt.% of glass fibre and bamboo fiber loading is much higher as compared to other composites in the temperature range of 38-65°C. However, above a temperature of 65°C till ~100°C the trend of temperature dependent decay of the storage modulus for the composites remained identical irrespective of the composition. Whereas the neat epoxy composite shows the minimum value of storage modulus and there is decay in the storage value after 29°C temperature. Interestingly above 100°C the storage modulus remained inappreciably affected by temperature for all the composites.

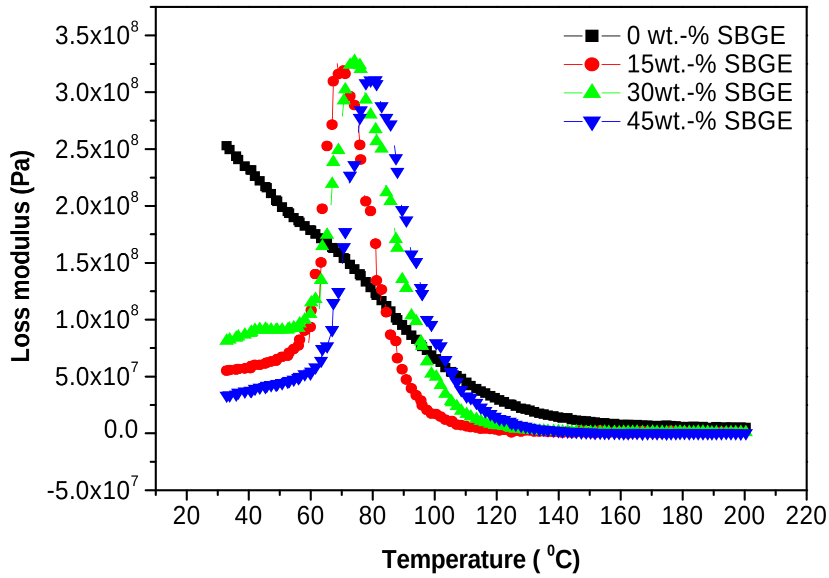

Figure 4.6 Variation of the loss modulus (E") as a function of temperature

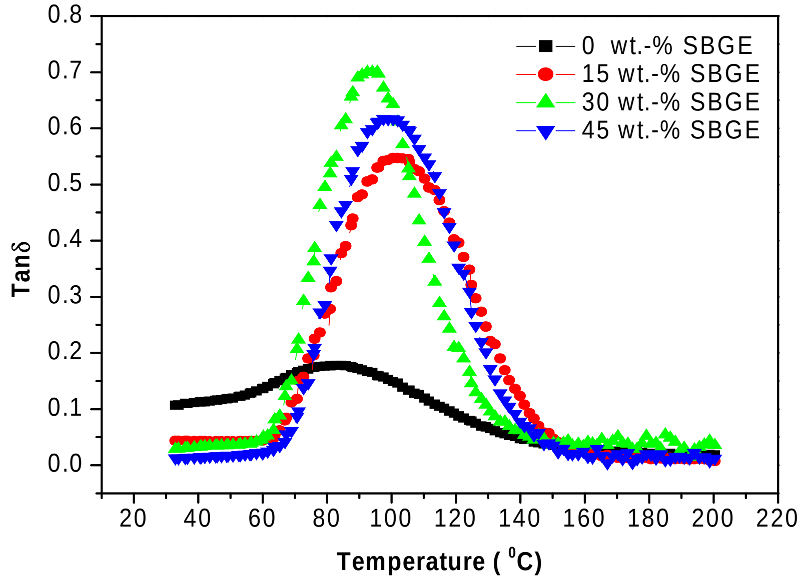

Figure 4.7 Variation of the damping parameter (tan δ) as a function of temperature

The loss modulus (E") represents the energy dissipation ability of the material that has theoretical correspondence to the toughness of the composites. The variation of E" as a function of temperature is shown in Figure 4.6. It is seen that the composite with 30 wt.-% fiber content shows the maximum value of the loss modulus followed by the 15 wt.-% fiber, 0 wt.-% fiber and 45 wt.-% fiber reinforced composites. Figure 4.6 shows the loss modulus of the all the fiber reinforced composites increases with increase in the temperature from 30°C to 80°C after that there is sharp decay in the loss modulus take place with increase in the temperature. The maximum loss modulus (E") followed the trend $E''_{30wt.\%} > E''_{15wt.\%} > E''_{45wt.\%} > E''_{0wt.\%}$. Apparently $E''_{30wt.-\%}$ of fiber loading indicates higher viscous energy dissipation ability than the other composites. The damping factor (tan δ) indicates the recoverable energy in terms of mechanical damping or internal friction in a viscoelastic system. The variation of the tan δ of the composites as a function of temperature is shown in Figure 4.7. A maximum in the tan δ (highest glass transition temperature T_g) has been observed for 30 wt.% fiber reinforced composite at temperature 98°C indicating enhanced damping performance. Usually, the interaction between polymer matrix and fibre is affected by the temperature. At the lower temperature, molecular chains are fixed in a small space, holding both the fibres. But at the higher temperature, molecular chains can move freely in a large space, and the interaction between matrix and both the fibres becomes weak. With 30 wt-% of fiber loading tan δ reached the maximum value of 0.790 at 98°C and the minimum tan δ value i.e. 0.0182 was observed with 0 wt-% fibre loading at 84^oC. Damping is the rate at which something dissipates energy and the higher the damping, the higher the rate of energy dissipation. It is reasonable to anticipate that the increased damping in the investigated composites was caused by the energy dissipation of the matrix. However, there was no change in damping properties after 150°C temperature for all the composites (Figure 4.7).

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CHAPTER 5

SOLID PARTICLE EROSION CHARACTERISTICS OF COMPOSITES:

RESULTS & DISCUSSION

This chapter presents the effect of fiber loading on erosion behaviour of composites through steady state erosion test results and their experimental analysis through Taguchi experimental design. This part deals with erosion wear behaviour of unfilled bamboo/glass-epoxy hybrid composites.

5.1 Steady state erosion test results

5.1.1 Effect of impingement angle on erosion rate of composites

Impingement angle is one of the important parameters for the erosion behaviour of composite materials. Dependence of erosion rate on the impingement angle is largely determined by the nature of the target material and other operating conditions.

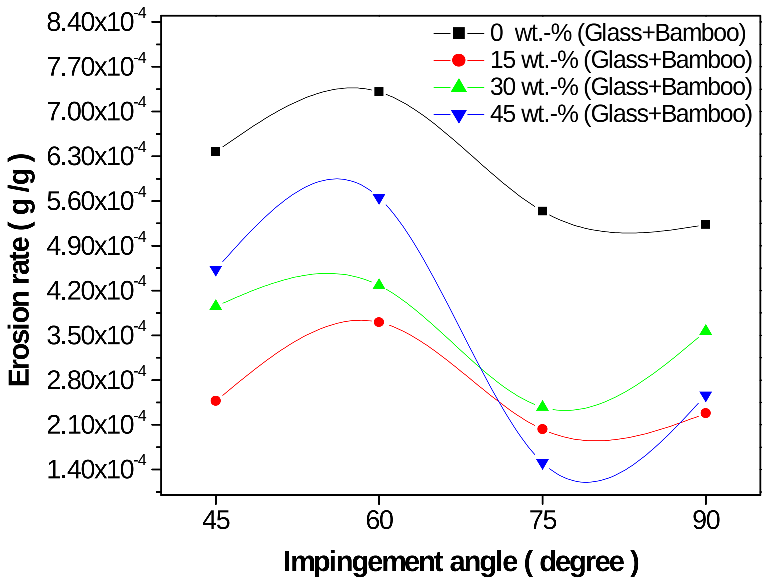


Figure 5.1 Effect of impingent angle on erosion rate of hybrid composites

In the literature, materials are broadly classified as ductile or brittle, based on the dependence of their erosion rate with impingement angle [73]. The ductile behaviour is characterized by maximum erosion rate at low impingement angle i.e. typically in the range of 15° < α<30°. On the other hand, if the maximum erosion rate occurs at normal impact (E_{max} at α=90°), the behaviour of material is purely brittle mode. The effect of impingement angle on erosion rate of untreated bamboo epoxy composite is studied and results are shown in Figure 5.1. The erosion rate increases with increase in fiber content. Sundararajan et al. [74] concluded that this behaviour is attributed to the fact that the harder the material, larger is the fraction of the crater volume that is removed. In this investigation higher hardness values have been noted for composites with higher fiber loading and this is therefore the reason why the composites exhibit declining erosion resistance with the increase in fiber content. It is evident from the Figure 5.1 that impingement angle has significant influence on erosion rate and the maximum erosion is occurring at an impingement angle of 60° for all composite samples irrespective of fiber loading. So the mode of wear is neither a ductile erosion mode nor brittle erosion wear mode, it is behaving like semi-brittle mode of erosion wear.

5.1.2 Effect of impact velocity on erosion rate of composites

The speed of erosive particle has a very strong effect on the wear process. If the speed is very low then the stresses at impact are insufficient for plastic deformation to occur and wear proceeds by surface fatigue. When the speed increases it is possible that subsurface cracking occurs as untreated composites are brittle in nature. Effect of impact velocity of particle on erosion rate is studied and the results are represented in Figure 5.2. It is evident from the Figure 5.2 that at low impact velocity from 35m/sec to 45m/sec, there is not much variation in erosion rate. However, with the further increase in impact velocity, the erosion rate is significantly increasing i.e. up to 55m/sec. This may be due to the at higher impact velocity, the erosion rate is occurring due to plastic deformation and more amount of material is removed. On further increase in impact velocity all the composites show gradually increase in erosion rate except 0wt% bamboo/glass fiber reinforced epoxy composites shows quite reverse in trend as shown in Figure 5.2. This is due to the neat epoxy losses its properties and then starts melting. From Figure 5.2 it is also clear that neat epoxy shows maximum erosion rate and 15wt.% bamboo/glass fiber shows least erosion rate whereas 30 and 45wt.% hybrid composite lies in between the other two composites.

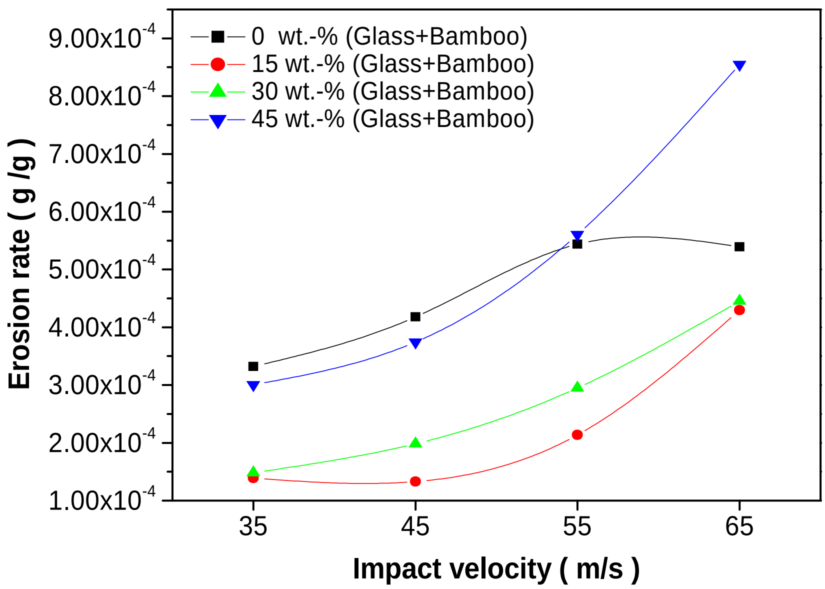


Figure 5.2 Effect of impact velocity on erosion rate of hybrid composites

5.2 Taguchi experimental results

Taguchi design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. Tables 5.1 show the erosion rates of different composites for all 16 test runs and their corresponding S/N ratios. Each of the values in these columns is in fact the average of two replications. The overall mean for the S/N ratio of the erosion rate is found to be 70.66db for the bamboo/glass hybrid composites. The analysis is made using the popular software specifically used for design of experiment (MINITAB 15). Before any attempt is made to use this simple model as a predictor for the measure of performance, the possible significant control factors are presented in Figure 5.3.

Table 5.1 Experimental design using L_{16} orthogonal array (for unfilled bamboo epoxy composites

Sl no.	Impact velocity (m/sec)	Fiber loading (wt.%)	Impingement angle (°)	S.O.D (mm)	Erodent Temp. (°C)	Erosion rate (gm/gm)	S/N Ratio
1	35	0	45	55	35	3.940E-05	88.0901
2	35	15	60	65	70	1.167E-04	78.6611
3	35	30	75	75	105	5.685E-05	84.9051
4	35	45	90	85	140	2.363E-04	72.5309
5	45	0	60	75	140	3.550E-04	68.9954
6	45	15	45	85	105	3.670E-04	68.7077
7	45	30	90	55	70	1.154E-04	78.7533
8	45	45	75	65	35	7.239E-03	42.8063
9	55	0	75	85	70	3.790E-04	68.4272
10	55	15	90	75	35	2.256E-04	72.9337
11	55	30	45	65	140	3.703E-04	68.6291
12	55	45	60	55	105	2.856E-04	70.8852
13	65	0	90	65	105	2.200E-04	73.1515
14	65	15	75	55	140	5.392E-04	65.3650
15	65	30	60	85	35	4.096E-04	67.7528
16	65	45	45	75	70	1.001E-03	59.9896

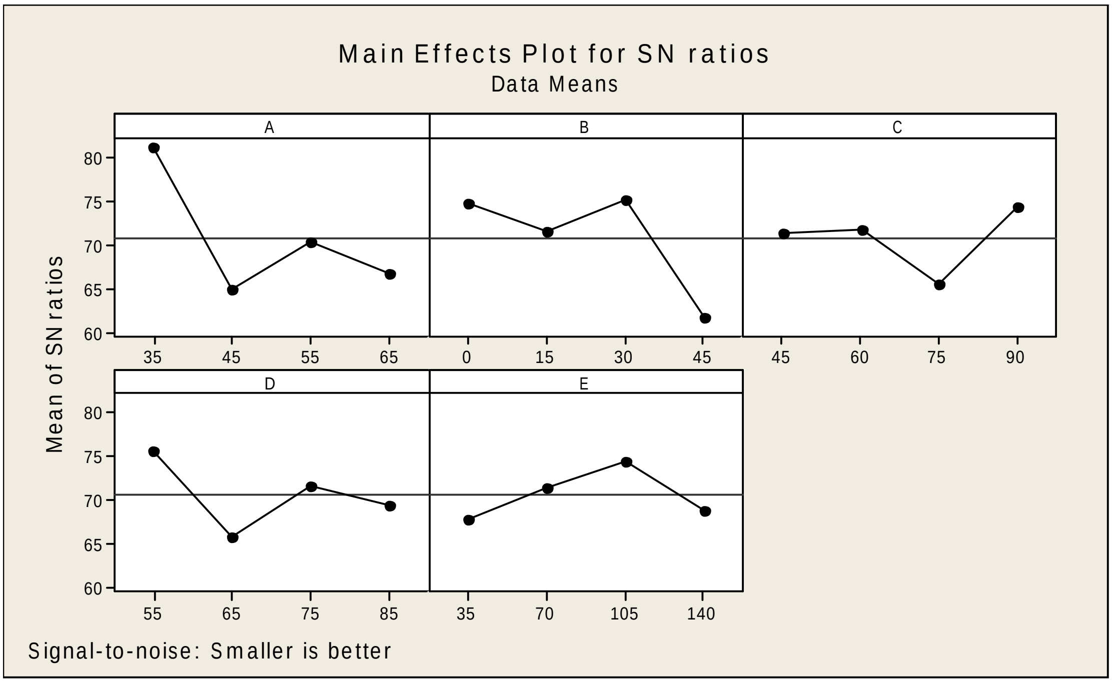


Figure 5.3 Effect of control factors on erosion rate for hybrid composites

5.3 ANOVA and the effects of factors

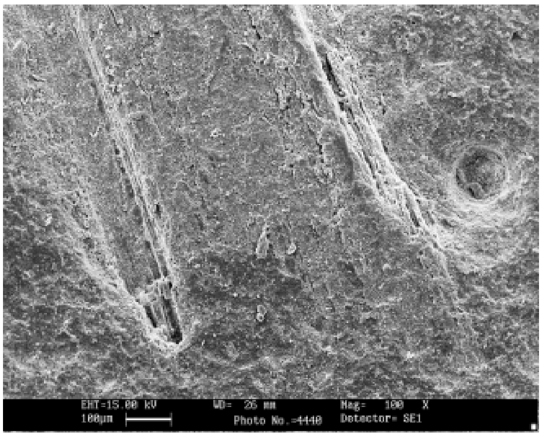
Analysis of Variance (ANOVA) has been carried out from the experimental data for bamboo/glass fiber reinforced epoxy composites on erosion rate. Table 5.2 shows the ANOVA result for the erosion rate of hybrid composites under solid particle erosion. This analysis is undertaken for a level of confidence of significance of 5 %. The last column of the table indicates that the main effects are highly significant (all have very small p-values). From Table 5.2, it can be observed for the hybrid composites that impact velocity (p=0.120), fiber loading (p= 0. 142), stand-off distance (p= 0.564) and erodent temperature (p=0.797) have great influence on erosion wear rate, whereas impingement angle shows least significant control factor in the present study.

Table 5.2 ANOVA table for erosion rate

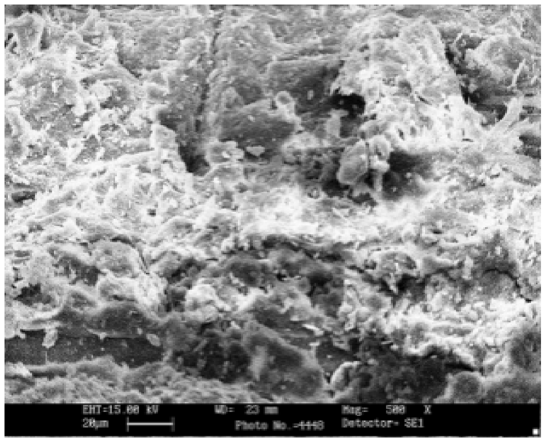
Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	289.5	289.5	289.5	2.88	0.120
B	3	255.6	255.6	255.6	2.55	0.142
C	3	1.5	1.5	1.5	0.02	0.904
D	3	35.7	35.7	35.7	0.36	0.564
E	3	7.0	7.0	7.0	0.07	0.797
Error	0	1003.8	1003.8	100.4		
Total	15	1593.0				

5.4 Surface morphology

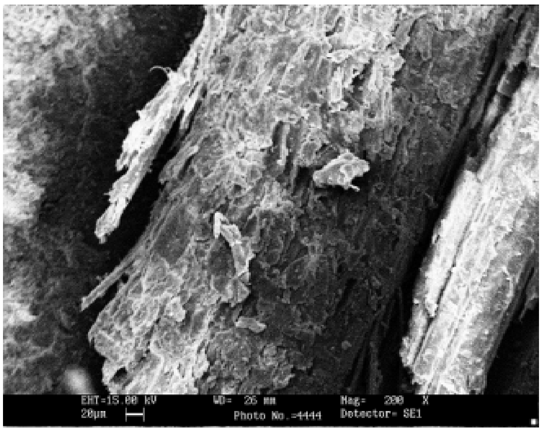
The SEM observations explain the results presented in the Figure 5.4 for bamboo/glass fiber reinforced epoxy composites under steady state erosion rate studied at constant impact velocity 45m/sec, erodent size 125μm and stand-off distance of 65mm at controlled conditions with variations of impingement angle (30 to 90°). Figure 5.4 shows the SEM of surfaces of the hybrid composite eroded under various test conditions. In Figures 5.4(a) and 5.4(b) show the 15wt% fiber loading at lower impingement angle, it appears that composites under consideration exhibit several stages of erosion and material removal process. Very small craters and short cracks are seen on the eroded surface of the composite at 30° impingement angle. On increase in impingement angle to 45° under similar operating conditions shows slightly increased in erosion rate as evident from Figure 5.4 (b) for 30wt% fiber loading. This indicated that the initiation of matrix material loss from the surface and the matrix is chipped off and the fibers are slightly visible beneath the matrix layer after the impact of dry silica sand particles. But as the erosion tests are carried out with further higher impingement angle (60°) at constant impact velocity 45m/sec, erodent size 250μm and stand-off distance 65mm the morphology of the eroded surface becomes different as in Figure 5.4(c). Such cracks are clearly noticed in Figure 5.4(c) and distinctly illustrate a crater formed due to material loss and the arrays of broken/semi-broken fibers. Due to repeated impact of hard silica sand and higher impingement angle the sand particles tries to initiation of cracks on the matrix body and as erosion progresses gradually, these cracks subsequently propagate on the fiber bodies both in transverse as well as in longitudinal manner. But on further increase in impingement angle from 60° to 75° almost all the composites showed maximum erosion rate (Figure 5.2) as shown in Figure 5.4(d) for 45wt% fiber loading. As discussed earlier for ductile materials, repeated impacts lead to plastic deformation processes and heavily strained regions on the composite surface. In the case of brittle materials on other hand, the propagation of cracks grows towards the surface and their intersection to form a wear particle separated from the surface leads to additional mass loss of the composite.



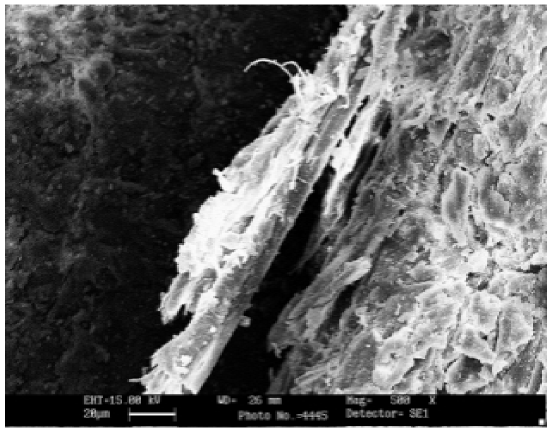
(a)



(b)



(c)



(d)

Figure 5.4 Surface morphology of eroded composites

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CHAPTER 6
CONCLUSIONS

The experimental investigation on the effect of fiber loading content on mechanical, thermo-mechanical behavior and erosion behavior of short bamboo/glass reinforced epoxy composites were conducted. The experiments lead us to the following conclusions obtained from this study:

1. Successful fabrication of hybrid bamboo/glass fiber reinforced epoxy composites is possible by simple hand lay- up technique.
2. The present investigation revealed that 30wt.% fiber content shows superior hardness, tensile strength, flexural strength and impact strength, whereas, for flexural strength, hardness decreases beyond 30wt% of fiber content. Through dynamic mechanical analysis, it has been observed that the storage modulus, loss modulus shows a better result up to 30wt% fiber content then it steadily decreases with respect to temperature.
3. In steady state erosion rate is concerned with respect to impact velocity all the composites show gradually increase in erosion rate except 0wt% bamboo/glass fiber reinforced epoxy composites shows quite reverse in trend at higher impact velocity. This is due to the neat epoxy losses its properties and then starts melting. It is also clear that neat epoxy shows maximum erosion rate and 15wt.% bamboo/glass fiber shows least erosion rate whereas 30wt.% and 45wt.% hybrid composite lies in between the other two composites.
4. Similarly, as far as impingement angle is concerned all the hybrid composites show maximum erosion rate at 60° impingement angle irrespective of fiber loading. So the mode of wear is neither a ductile erosion mode nor brittle erosion wear mode, it is behaving like semi-brittle mode of erosion wear.
5. However, analysis of variance is concerned for hybrid bamboo/glass fiber composites impact velocity (p=0.120), fiber loading (p=0.142), stand-off

distance (p= 0.564) and erodent temperature (p=0.797) have great influence on erosion wear rate, whereas impingement angle shows least significant control factor in the present study.

6.1 Scope for future work

There is a very wide scope for future scholars to explore this area of research. This work can be further extended to study other aspects of such composites like use of other potential fillers for development of hybrid composites and evaluation of their mechanical and erosion behavior and the resulting experimental findings can be similarly analyzed.

Acknowledgement

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