ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF GRADUATE STUDIES

Abrasive Wear Behavior of Bamboo Reinforced Polymer Composite with PTFE

A Thesis Submitted to the Graduate School of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science

In Mechanical Engineering (Mechanical Design)

By: Sentayehu Worku

Advisor: Prof. Eyasu Woldesenbet

June 2020

Addis Ababa, Ethiopia

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This is to certify that the thesis entitled "**Abrasive Wear Behavior of Bamboo Fiber reinforced Polymer Composite with FTFE**" submitted by **Sentayehu Worku** in partial fulfillment of the requirements of Master of Science (Mechanical Design) in the Department of Mechanical Engineering, Addis Ababa Institute of Technology

Signed by Examining Committee

Internal Examine________________________ Signature ____________Date_____________

External Examine________________________Signature____________Date_____________

Advisor Prof. Eyasu Woldesenbet Signature ____________Date_____________

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School or Center of Chair Person

DECLARATION

I hereby declare that the work which is being presented in this thesis entitle: "Abrasive Wear Behavior of Bamboo fiber reinforced polymer composite with PTFE " is original work of my own, has not been presented for a degree of any other university and all the resources of materials used for the thesis have been duly acknowledged.

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Abstract

The aim of the present work is to study the abrasive wear behavior of composites made by reinforcing bamboo fibers with the addition of PTFE and thermoset resin matrix. The fibers are extracted by hand and manual process and the composite samples were prepared to a maximum of 30% volume of fiber. Wear tests were carried out in dry conditions on a pin-on-disc which is modified by me and the machine at a constant sliding distance of 1000 m with sliding velocities of 2m/s and 4m/s and normal loads of 15N and 30N. The effect of PTFE content on abrasive wear properties of composites were investigated and compared with pure BPC composites made under the similar testing conditions. It is observed that the wear loss of composites increase with increase of normal load whereas the specific wear rate decreases. The optimum weight loss and specific wear rate for bamboo fiber reinforced composites were obtained at 30% volume of pure composite.

Key words: Bamboo, Fiber, Matrix, Composite, Wear

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It gives me a vast pleasure to express my deep sense of gratitude to my supervisor Prof. Eyasu Woldesenbet for his invaluable guidance, motivation, constant inspiration and above all for his ever co-operating attitude that enabled me in bringing up this thesis in the present form.

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Nomenclature

ρ_c	Density of composite
m_c	Mass of composite
m_r	Mass of resin
v_r	Volume fraction of resin
Vf	Volume of fibers,
Vm	Volume of matrix,
V_{PTFE}	Volume of PTFE
Vc	Volume of Composite specimen

List of Abbreviation and Acronyms

ASTM	America Society for Testing and Material
m	Meter
mm	Millimeter
FRP	Fiber Reinforced Polymer
BFRC	Bamboo fiber reinforced polymer composite
PTFE	Polythetraflouroetyline
min	Minute
hr	Hour
cc	Cubic centimeter
Eq.	Equation

CHAPTER ONE

1 INTRODUCTION

1.1 Background

This chapter delivers the required grounding information on the core issues to be reflected in the present research work and to give emphasis on the relevance of the study. Composite material can be defined as the material which is composed of two or more distinct material on macro scale with different properties to form a new material with a property that is entirely different from the individual constituents. The primary phase of a composite material is called a matrix having a continuous character. In other words, matrix is a material which acts as a binder and holds the fibers in the desired position thereby transferring the external load to reinforcement.

These matrixes are considered to be less hard and more ductile. The composite material consists of a matrix along with a fiber with some filler material. The reinforced material can be either synthetic or natural fibers. In the demand of increasing environmental security, several natural fibers reinforced polymer composites (NFPCs) are brought into the competitive market. NFPCs provide a wide range of advantages over synthetic fiber based composites. These advantages include high strength to weight ratio, high strength at elevated temperatures, high creep resistances and high toughness [1].

These advantages can also be in the form of their light weight, high durability and design flexibility. In NFPCs, the used matrices are either thermoset or thermoplastic. Polyester, Epoxy and phenolic resin are the commonly used thermoset matrix whereas polypropylenes, polyethylene and elastomers occupy the large scale position in thermoplastic matrix. Based on the matrix used, composite material can be divided into three types i.e. Metal Matrix Composite (MMC), Polymer Matrix Composite (PMC) and Ceramic Matrix Composite (CMC). The selection of any of the above composite material depends upon the type of application. The most commonly used composites are polymer matrix composite.

This is primarily because of their light weight and specific properties compared to ceramics and metals. Besides, the polymer matrix composites can be processed at low temperature and pressure.

1.1.1 Natural Fiber

Natural fiber is a type of renewable sources and a new generation of reinforcements and supplements for polymer based materials. The development of natural fiber composite materials or environmentally friendly composites has been hot topics recently due to the increasing environmental awareness [1] .Natural fibers are now dominate the automotive, construction and sporting industries by its superior mechanical properties. These natural fibers include bamboo, flax, hemp, jute, sisal, kenaf, coir and many others [2]. Fibers can be categorized into two groups, based on production of fibrous polymers and production of fibers [3].

Based on the source of origin, this natural fiber can be classified into three categories such as animal fiber, vegetable fiber and mineral fibers. The detailed classification of natural fibers is given below in the Figure 1.1

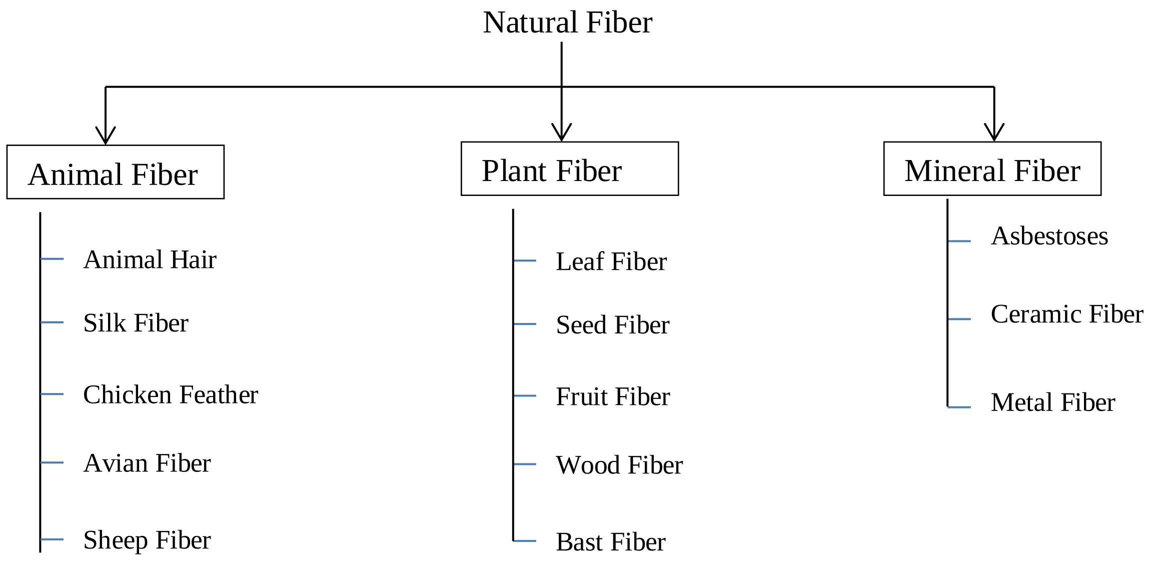


Figure 1: Classification of natural fiber

1.1.2 Plant Fiber

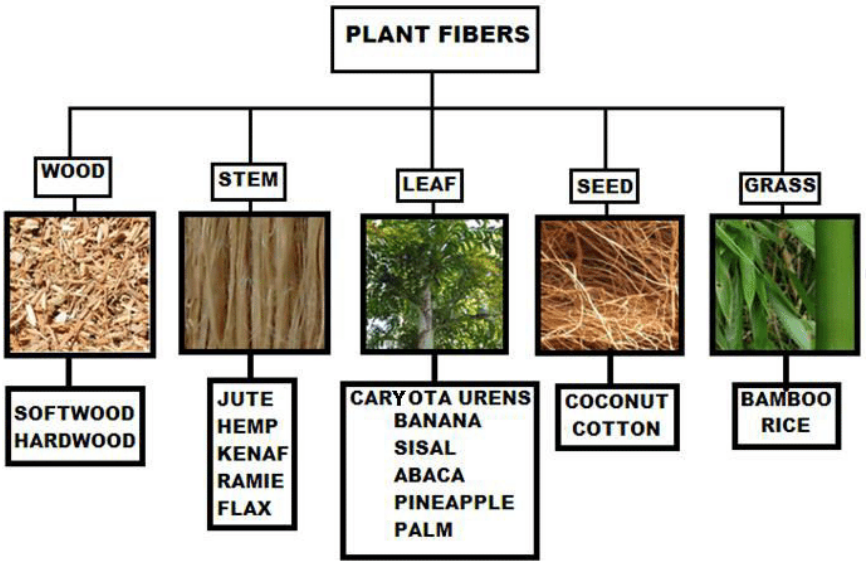


Figure 2: Classification of plant- based natural fibers used as reinforcement in composite (Chandamohan and Marimuthu 2011)

1.1.3 Chemical Composition of natural fibers

Reinforcing efficiency of natural fiber depends upon the nature of cellulose and its crystalline. Components which are present in natural fibers are cellulose (α-cellulose) hemicelluloses, lignin, pectin and waxes [4].

Table 1: Natural fibers chemical composition

Types of Fiber	Cellulose (%)	Lignin (%)	Others (%)
Bamboo	60.8	32.2	7
Coir	36 to 43	41 to 45	13 to 24
Banana	63 to 68	5	19
Sisal	67 to 78	8 to 11	22 to 26
Jute	61 to 72	12 to 13	14 to 21
Hemp	70 to 74	4 to 6	19 to 24
Kenaf	31 to 39	15 to 19	21.5
Flax	71	2.2	22 to 25
Ramie	69 to 76	0.6 to 0.7	15 to 19

Note: Data from Okubo *et al*. 2004 and Malkapuram *et al*. 2009

1.1.4 Fibers reinforced composites

The fiber reinforced polymers (FRP) consist of fibers of high strength and modulus embedded in or bonded to a matrix with distinct interface between them. In this form, both fibers and matrix retain their physical and chemical identities

Natural fiber polymer composites (NFPC) are a composite material consisting of a polymer matrix embedded with high-strength natural fibers, like jute, oil palm, sisal, kenaf, and flax. According to previous studies, the properties of natural fiber composite are different to each other because of different kinds of fibers, sources, and moisture conditions. The performance of NFPCs relies on some factors, like mechanical composition, structure, defects, cell dimensions, physical properties, chemical properties, and also the interaction of a fiber with the matrix [5].

Table 2: Properties of natural fibers (6)

Fiber	Tensile Strength (MPa)	Young's Modulus (Gpa)	Elongation at break (%)	Density gm/cc
Abacca	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	500-1150	11.8	3.7-4.3	1.4
Date palm	97-196	2.5-5.4	2-4.5	1-1.2
Flax	345-1035	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

1.1.5 Wear properties of natural fiber

Wear, fatigue and corrosion are the three most commonly encountered industrial problems leading to the replacement of components and assemblies in engineering. Wear is rarely catastrophic, but it reduces operating efficiency by increasing the power losses, oil consumption and the rate of component replacement

The tribological performance of natural fiber reinforced polymer matrix composites. Fiber treatments, fiber orientations and fiber volume fractions are the important parameters affect the tribological performance where treated fibers and normal orientation against the sliding direction provide better wear and frictional properties Content [7]. For tribological behavior, wear and friction are the two important phenomena during relative motion of solid surfaces. The wear behavior of composite material was analyzed based on the different working parameters like speed, load, and sliding distance [8].

1.1.5.1 Wear Mechanisms

Wear can be classified based on the ways that the frictional junctions are broken, that is, elastic displacement, plastic displacement, and cutting, destruction of surface films and destruction of bulk material. There are many types of wear mechanisms but the most common wear mechanisms are presented in the following figure:

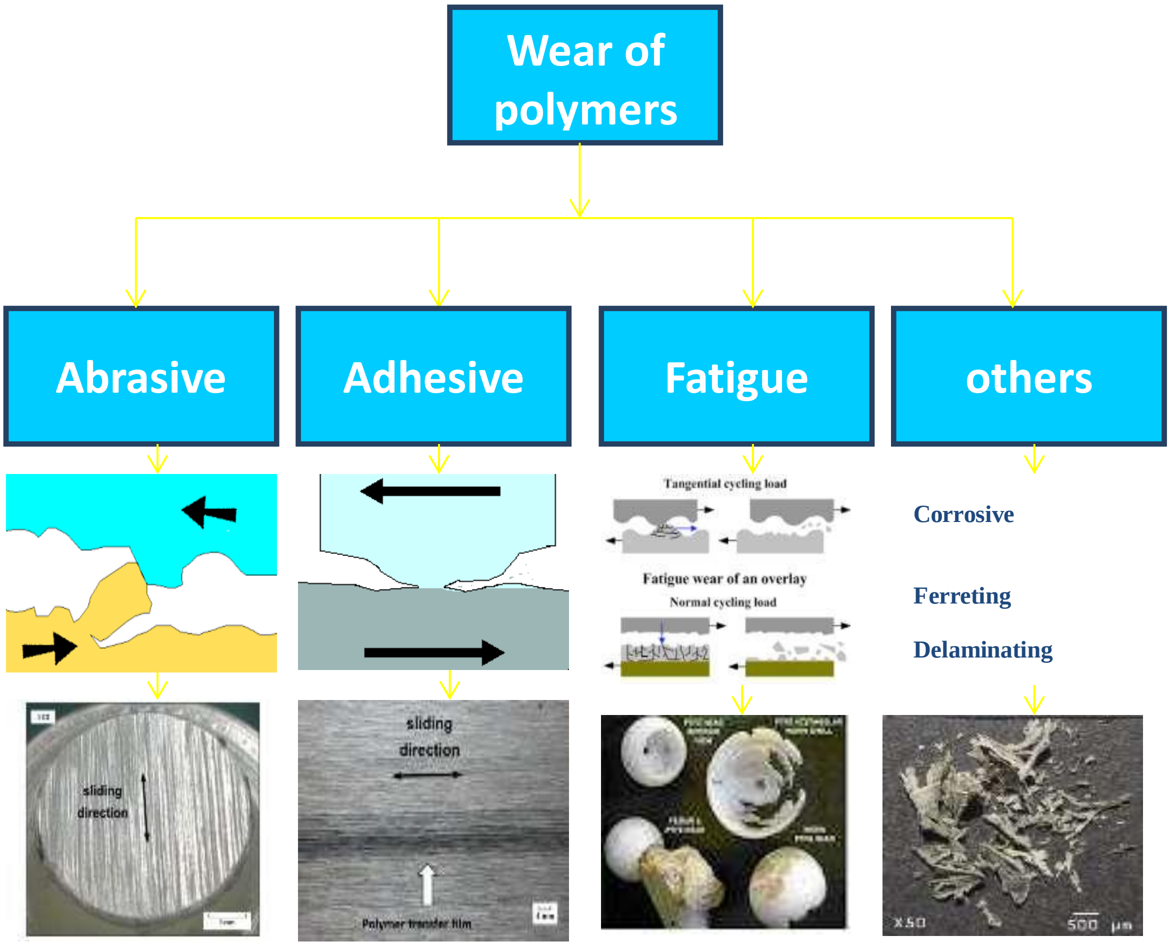


Figure 3: Wear type

Adhesive wear

Adhesive wear occurs when two metallic surfaces with inadequate lubrication are in contact and experience relative motion, especially under a cyclical load. As the surfaces contact each other, the local pressure causes them to fuse together so that small particles of one material adhere to the other. Repeated action of this metal transfer leads to deterioration of the surface, and formation of wear debris

Fatigue wear

Fatigue wear is the result of cracks and flaking that have been triggered by repeated alternating stress cycles like rolling. For example, rail or wheel systems may exhibit this type of wear. Micro-cracks develop, which may be either on the surface or sub-surface. Eventually parts may fail due to repeated tensile and shear stresses

Abrasive wear

Abrasive wear which appears in sliding, results from scratching by hard particles trapped by or protuberances projecting from the mating surface and is characterized by the presence of parallel scratches in the sliding direction. Interestingly, only a very small fraction of the contacting particles or protuberances may contribute to pure mechanical chip cutting while the rest is only capable of deforming the surface.

Two-body and three-body abrasion wear

Abrasion wear can be classified as two-body or three body abrasion and are shown in the figure below. The two-body abrasive wear involves the removal of material by abrasive particles which are held fixed (as in abrasive paper) while being moved across a surface. This form of abrasive wear results in grooving form of wear. In three-body abrasion wear phenomenon the abrasive particles are trapped between two surfaces which may rotate as well as slide as they contact the wearing surface

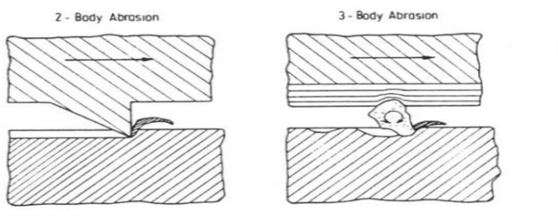


Figure 4: Two body and three body abrasion

Abrasion wear measurement

Abrasion wear measurement tests have been standardized and been divided into different categories

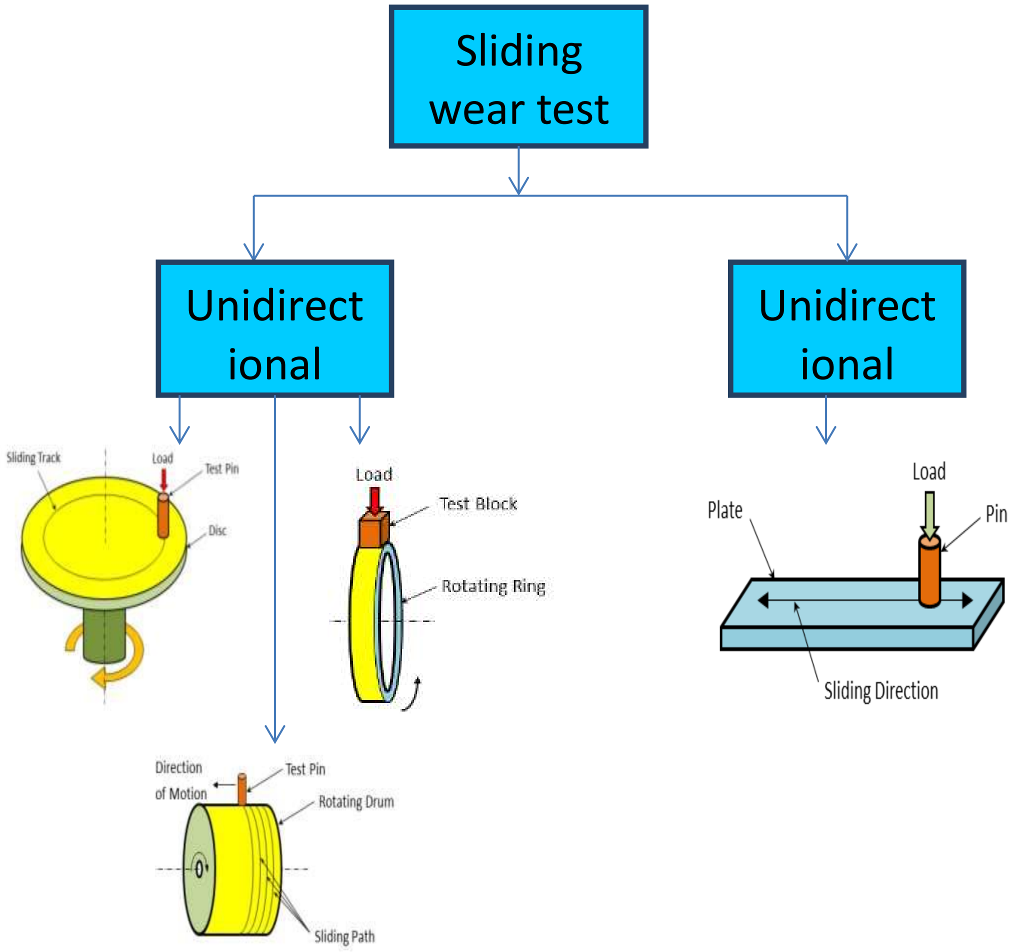


Figure 5: Measurement of abrasive wear

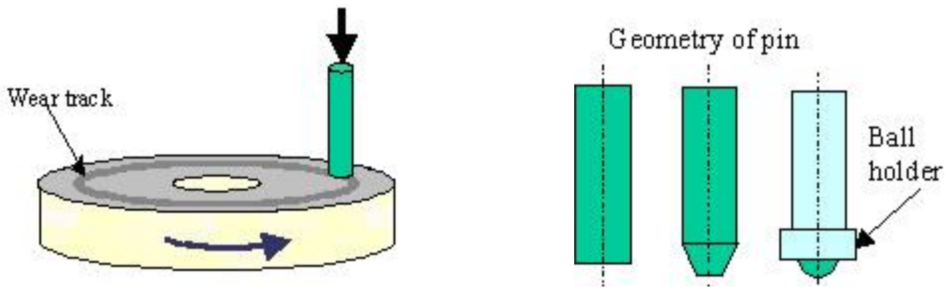


Figure 6: a pin-on-disc wear test and the arrangement of samples

1.1.6 Bamboo Fiber

The growing interest in bamboo fibers is due to their anatomical properties, ultra structure and plant fracture mechanism, allowing bamboo fibers to provide higher specific strength and stiffness in plastic materials compared to other known natural fibers like jute, coir, sisal, straw and banana. Ethiopia has an estimated one million hectares of natural bamboo forest, the largest in the African continent. Despite the versatile resource base and advanced bamboo utilization at a global scale, its great potential to enhance socio-economic and ecological development remains unrealized in Ethiopia [9]

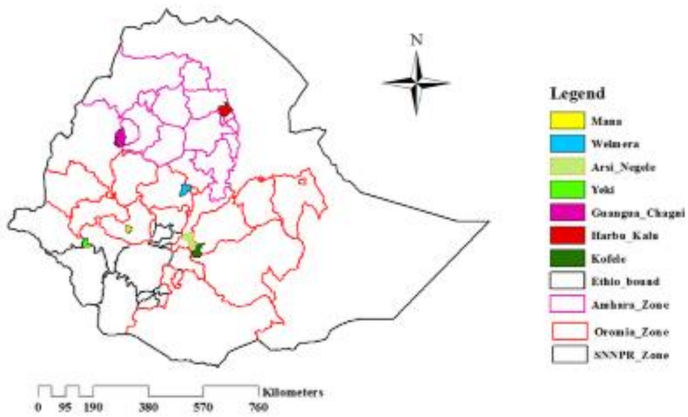


Figure 7: Testing sites of introduced bamboo species in Ethiopia during the last eight years (map developed by Zebene Tadesse)

Bamboo shows the mechanical properties which are analogous to that of wood. Bamboo shows better mechanical properties as compared to fibers such as sisal, banana, coir etc. Bamboo can be used in a different form to synthesize a composite product. These can be either in a form of a long strip, whole bamboo, sections, and short bamboo fibers.

1.1.7 Chemical composition and structure of bamboo fibers

The chemical composition of bamboo fiber constitutes mainly cellulose, hemicelluloses and lignin. These components are actually same high glycans, and make about 90% of total weight of bamboo fiber. The other constituents are protein, fat, pectin, tannins, pigments and ash. These constituents play important role in physiological activity of bamboo and they are found in cell cavity or special organelles. The chemical composition of the bamboo fiber is given in figure

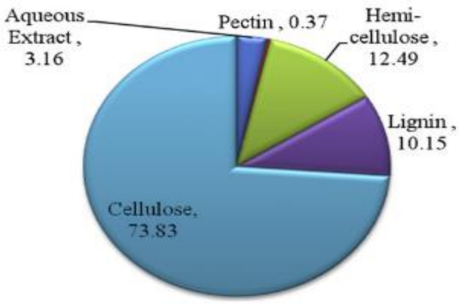


Figure 8: Chemical composition of bamboo fiber [11]

Usually the chemical content of bamboo changes with age of the bamboo, particularly cellulose content keeps on decreasing as the age of bamboo increases; time directly affects the chemical composition of bamboo fiber. The lignin is considered to provide stiffness and yellow color to bamboo fibers. Different treatments cannot remove all the lignin content of the bamboo fibers, as lignin has been found quite resistant to various alkalis. Non cellulosic components have enough contribution to fiber properties such as strength, flexibility, moisture, and even density [12]

1.1.8 Polytetrafluoroethylene (PTFE)

Polymer and its composites are finding ever increasing usage for numerous industrial applications in sliding/rolling components such as bearings, rollers, seals, gears, cams, wheels, piston rings, transmission belts, grinding mills and clutches where their self-lubricating properties are exploited to avoid the need for oil or grease lubrication with its attendant problems of contamination [13]

1.2 Statement of the problem

These days, a significant amount of research is being carried out to analyze the possibility of using bamboo fiber as reinforcement in polymer matrices, often shortened to "composites". The industrial acceptance of natural resources for reinforcing composites is an active subject of major projects across the world. In fact, while one of the main concerns for huge industrial application of bamboo fiber is their variability in mechanical properties, in spite of the wide spread availability of the plant in Ethiopia its use is limited in the sphere of the primary economy.

The literature I have surveyed presented the gap that large amount of works that have been made on a variety of natural fibers for polymer composites and very less has been reported on the reinforcing of potential and wear behavior of short bamboo fibers. Besides, many researchers have investigated the solid particle Abrasive wear behavior of various polymers and their composites but the researchers are not considering PTFE as a modifier material for bamboo reinforced polymer composite This research attempts to fill the gap observed in the course of our literature review.

1.3 Objective

1.3.1 The General objective

- ❖ The general objective of this research is the fabrication and abrasive wear analysis of bamboo reinforced polymer composites with PTFE based

1.3.2 The specific objective

- ✓ To study the effects of PTFE content on wear behavior of the composites
- ✓ Fabrication of a new class of PTFE based composites reinforced with short bamboo fibers
- ✓ To study the effect of load and sliding velocity on wear behavior of the composite
- ✓ To identify the fiber and matrix content
- ✓ To make chemical treatment for bamboo fiber to improve its properties

1.4 Expected Result

The present thesis "wear resistance of bamboo fibers reinforced polymer composite " presents the development of an environmentally friendly material as an alternative among other natural and synthetic fiber reinforced composites .The outcome of the study will be used to improve and conform the possible use of these composites in components for automobile parts such as steering wheel, Transmission stick ,brake pad, break clippies and suitable for coating purpose such as table ,chair and also we can use for pen external cover

1.5 Beneficiary

The industrial adoption of natural resources for reinforcing composites is an active subject of the thesis and from the output the following sectors will benefit

- ✓ Automotive industries
- ✓ Aerospace industries
- ✓ Medical Equipment factories
- ✓ Industrial machinery Manufacturers
- ✓ Small and Medium enterprises

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Overview

This section provides the background information on the issues to be considered in the present research work; it will also be used to center the significance of the present study. The aim is also to present a detailed understanding of some additives and composition ratio on mechanical behavior of wear properties of bamboo fiber reinforced composites. In fiber reinforced polymer composites, the reinforcing phase can either be fibrous or non-fibrous in nature. Many investigations have been made on the potential of the natural fibers as reinforcements for composites. Various treatments and resins are used to improve the mechanical properties in bamboo fiber reinforced composites. Bamboo plants are giant, fast-growing grasses that have woody stems.

Composite materials have two components: the matrix and the reinforcement. The matrix material surrounds and supports the reinforcement materials and maintains their relative spots. The reinforcements impart their distinct mechanical and physical properties to improve the matrix properties. Polymer composites comprising different fillers and/or reinforcements are commonly used for numerous applications in which friction and wear are critical issues. In addition, these composites are discovering further applications that can be subjected to solid particle erosion.

2.2 Natural fiber polymer composite

Due to the consideration of developing interest in environmentally friendly materials, natural fiber reinforced polymer composites have raised a great attention and interest among scientists and engineers in recent years. They are high specific strength and modulus materials, low priced, recyclable and are easily available. Researchers such as Taj et al reported that natural fibers are generally lignocelluloses in nature, consisting of helically wound cellulose micro fibrils in a matrix of lignin and hemicellulose. The use of natural fibers composites matrices is highly beneficial because the strength and toughness of the resulting composites are greater than those of the un-reinforced matrix. Moreover, cellulose-based natural fibers are strong, light in weight, very cheap, abundant and renewable. These fibers with high specific strength improve the mechanical properties of the polymer matrix

Seema Jain and Rakesh Kumar [15] studied that natural fibers have high specific strength and modulus materials, low priced, recyclable and are easily available. It is recognized that natural fibers are non-uniform with asymmetrical cross sections which make their structures quite unique and much different with man-made fibers such as glass fibers, carbon fibers etc . Among the various natural fibers, bamboo fiber is an excellent candidate for use as natural fibers in composite materials. Jindal has observed that tensile strength of bamboo-fiber reinforced plastic (BFRP) composite is comparatively equivalent to that of the mild steel, whereas their density is only 12% of that of the mild steel. Hence, the BFRP composites can be extremely useful in structural applications.

According to Bledzki et al. and McKendry, hemicelluose, cellulose and lignin are the three main components of biomass. In general, they cover respectively 20-40, 40-60 and 10-25 wt % for all natural fibers. Ray AK, Das SK, and Mondal S [19] explained, moreover environmental friendliness, natural abundance and renewability make natural fibers a possible alternative to synthetic reinforcing fiber materials, while offering good specific properties such as strength and stiffness .

Wambua, P., Ivens, J., & Verpoest, I [20] reported about cellulose based fibers are used in fabricating natural fiber composites. To develop NFC's, it is vital to understand the chemical composition and the surface adhesive bonding properties of natural fiber. The main constituents of natural fiber include cellulose, hemicellulose, lignin, pectin, ash, waxes and water-soluble substances. Among all the natural fiber reinforcing materials, bamboo appears to be a promising material because it is relatively inexpensive, anti-bacterial and commercially available in the required form. [21] Additionally, unlike the traditional engineering fibers (e.g. glass and carbon fibers), lingo cellulosic fibers cause no health hazards due to fiber cutting and low machine wear during post-processing and composite finishing. In composite use, the thermal conductivity of the natural fiber composite is low; therefore they make a good thermal barrier.

2.2.1 Bamboo reinforced polymer composite

Bamboo fiber used as reinforcement and it is characterized and modified using different physical and chemical treatments. The high strength to weight ratio of bamboo has attracted researchers' attention to maximize its potential in composites. BFRP is an eco-composite that is lightweight, environmental friendly, and has comparable strength to conventional materials (Abdul Khalil et al. [22]. In bamboo composite fabrication, numerous factors affect the properties of the products, and the three main factors that need to be evidently addressed to distinguish bamboo composites are types of fibers, types of matrices, and method of fabrication. These three factors are inter-related to each other in producing good properties of bamboo composites. Bamboo strip is a robust type of fiber because many fiber bundles are tied together in the natural matrix of lignin.

2.2.1.1 Mechanical properties of Bamboo Fiber

Numerous investigations were made so far on the effect of various factors on mechanical behavior of natural fiber reinforced polymer composites.

Bamboo fibers are often called “natural glass fibers” because of their properties [23]. Among the well-known natural fibers, bamboo has a favorable combination of Low density and high mechanical properties giving good specific properties (Stiffness and strength).

Thwea and Liao [24]-[25] have fabricated the bamboo reinforced polypropylene (BFRP) and bamboo-glass reinforced Polypropylene (BGRP) composites. They have studied the effect of fiber content, fiber length, bamboo to glass ratio, coupling agent (Malted polypropylene) on tensile and flexural properties of these composites. It was observed that flexural strength, flexural modulus and tensile modulus increases with increase in bamboo fiber length. They have reported that poor adhesion between the matrix/fiber decreased tensile strength at higher bamboo fiber content in BFRP. Fiber content increased the void formation during processing, which further leads to micro crack information under loading, hence reducing the tensile strength. Bamboo finds its application in composite materials in several forms. These forms range from short bamboo fiber to long strips including the whole bamboo. Researchers have expanded their interest in the product development by using the usage of raw materials like bamboo fiber which is stronger as well as can be utilized in generating high end quality sustainable industrial products [26].

Wong K.J and Zahi S [27] reported the impact strength of a composite and optimum property when reinforced with a short bamboo fiber has been studied by several investigators for different fiber length and fiber content and optimum property

Vikram S. Yendhe, et.al.[28] investigated the mechanical behavior of short bamboo fiber reinforced epoxy based composites. Bamboo fibers with different length and fiber contents were reinforced in epoxy resin to fabricate composite materials. The effect of fiber length and content on the mechanical properties such as tensile strength, flexural strength, impact strength, and micro-hardness of short bamboo fiber reinforced epoxy based composites were studied

Takagi et al. [29] have studied the effect of fiber content and fiber length on mechanical properties of bamboo fiber reinforced green composites (BFGC). Fiber length up to 15mm has given positive effect on tensile strength and flexural strength. It was observed that tensile strength and flexural strength increase with increase in fiber content.

Kumar [30] studied the effect of fiber loading on mechanical behavior of short bamboo fiber reinforced epoxy composites and observed the tensile strength of bamboo-epoxy composite increases to the certain level of fiber loading and then starts decreasing on further fiber loading. The maximum value of tensile strength is obtained at 25wt% of fiber loading.

Ismail et.al [31]. The author studied on the influence of filler loading on the curing characteristics and mechanical properties of bamboo fiber reinforced natural rubber composites. Tensile modulus and hardness of composites rises with increasing filler loading and the attendance of bonding agents.

2.2.2 Wear properties of bamboo polymer composite

Wear is one of the most commonly encountered industrial problems, leading to frequent replacement of components, particularly abrasion. Abrasive wear occurs when hard particles penetrate a softer surface and displace material in the form of elongated chips.

Ku H, Wang H [32] studied composite materials which are replacing conventional materials in various engineering applications due to their high strength, resistance to corrosion, and its reasonable cost. Application includes aerospace and automobile bodies, sports kits, structures, marine equipment, etc.

Hussein AB, Hashim FA and Kadhim TR [33] are reported polymer composites are extensively affected by erosion damage due to the extended use on hostile environmental applications. In many applications, the mechanical behavior and erosion characteristics of the polymer composites are the main requirements. In such a case, the polymer materials should have better properties. At present greater attention is focused on the abrasive behavior of polymer composites due to its potential usage in various engineering designs

Patnaik A, Satapathy A, Chand N, et al [34] reviewed about wear damage is the progressive loss of materials on a solid surface usually due to relative motion between two surfaces. Wear effects are studied widely in order to have effective utilization of the components. Lee GY, Dharan CKH [35] reported effects of modification in material preparation process can change the wear characteristics of the polymer composites to a larger extent.

Pei X and Friedrich K [36] when a solid or liquid particle strikes the target surface the surface tends to have local damage and removal of material. This type of wear is usually called as erosion visualizing the importance of polymeric composite in tribological application, lots of work already has been published. Abrasive wear of composites is intensely influenced by the filler loading and operating parameter. [37] has carried out a literature review for different fiber reinforced polymer composites and studied the effects of both material parameters such as type of filler, fiber length, filler content, fiber orientation and the operating parameters such as load, sliding distance, sliding velocity and temperature. Both parameters have a significant effect on the tribological properties of composite materials.

Chand et.al [38] studied the anisotropic abrasive wear behavior of bamboo. In bamboo the anisotropic wear behavior exists due to the vascular fibers orientation parallel to the sliding direction or the central axis of the bamboo. J.F. Archard and.D. Tabor [39,40]observed that the friction force and wear rate depend on roughness of the rubbing surfaces, relative motion, type of material, temperature, normal force, stick slip, relative humidity, lubrication and vibration. The parameters that command the tribological performance of polymer and its composites also include polymer molecular structure, processing and treatment, properties, viscoelastic behavior, surface texture etc.

Wang and Li [41] observed that the sliding velocity has more significant effect on the sliding wear as compared to the applied load and variations of wear rate with operating time can be distinguished by three distinct periods. These periods are running-in period, steady-state period and severe wear period

The researchers [42, 43, and 44] reported that the applied load exerts greater influence on the sliding wear of polymer and its composite than the sliding velocity. Friction and wear behavior of glass fiber reinforced polymer composite were studied and results showed that in general, friction and wear are strongly influenced by all the test parameters such as applied load, sliding speed, sliding distance and fiber orientations .Moreover, it was found that applied normal load, sliding speed and fiber orientations have more pronounced effect on wear rate than sliding distance.

The variables such as composition of the matrix, particle distribution, and interface between the particles and the matrix affect the tribological behavior of metal matrix composites. The principle tribological parameters such as applied load, sliding speed, and percentage of fly ash control the friction and wear performance. Unal et al. [45] studied the friction and wear of pure PTFE and glass-fiber-reinforced (GFR), bronze (B)-, and carbon (C)-filled PTFE polymers at sliding speeds of 0.32, 0.64, 0.96, and 1.28 m/s under low loads. The PTFE + 17% GFR composite exhibited the best wear performance

2.2.3 Polytetrafluoroethylene

Polytetrafluoroethylene (PTFE) is one of the most promising polymers for engineering applications as structural and lubricating materials, such as shaft seals, sliding bearings, piston rings, etc. It is a semi-crystalline polymer with the lowest friction coefficient, high melting point (~330 °C), excellent chemical resistance and outstanding anti-aging performance. However, the poor wear resistance is one of the largest drawbacks limiting the application of PTFE. Since, over nearly a half century it has been a research

Marcelo Kawakame, Jos´e Divo Bressan [46] has reported in his literature has investigated Normal load, velocity and air relative humidity were considered variable in the wear tests. The friction and the wear mechanisms are briefly reviewed. Various polymeric materials containing solid lubricants inside its microstructure were investigated. The self-lubricating characteristics of the added charge as well as the polymeric matrix were considered in the composite selection. Discs of pure PTFE (Teflon), composites PTFE graphite, PTFE + MoS2 + glass fibers, PTFE + bronze were tested against pins of quenched and tempered SAE 1045steel. Pins PTFE + MoS2 + glass fibers were also tested against 1045 steel disks. In all tests, debris and flakes of worn materials were deposited on the pin counter face and these particles defined the wear mechanism. Through the analyses of micrograph taken by scanning electron microscopy, the following conclusion can be drawn: friction and wear in polymers are fundamentally different from the mechanisms which occur in metals and ceramics, although they are due to the same wear micro-mechanisms: micro-plowing, micro-cutting and flake delaminating. A very important conclusion on wear resistance of polymers and composites is its strong dependence on the environmental relative humidity and normal load. Variations observed in the relative air humidity from 0 to 70% can duplicate the lost volume by wear and, consequently, to double the wear rate .Among the tested materials, the composites PTFE with additive graphite or MoS2 and glass fibers have shown the greatest sliding wear resistance.

.K. Friedrich, Z. Zhang [47] they stated that the friction coefficient and wear resistance are not real material properties, they depend on the system in which the material have to function. In most cases, it is of primary concern to develop polymer composites that possess low friction and low wear properties under dry sliding conditions against smooth metallic counterparts. On the other hand, a relationship between the wear of polymer composites and operating parameters is desirable to get better understanding about the wear behavior.

2.3 Fabrication of bamboo reinforced polymer composite

2.3.1 Effect of bamboo fiber extraction

To practically apply the benefits of bamboo fibers, it would be necessary to develop a process to extract long high quality fibers from bamboo plants. This extraction process might be carried out in a standardized way, and should be able to compete with existing methods for other natural fibers in terms of production volume, cost, environmental impact (e.g. waste water and chemicals) and uniform consistency in fiber properties.

These processes are classified as chemical, mechanical and combination of mechanical and chemical. The usual methods to extract fiber are enumerated as in the following [48]

2.3.1.1 Chemical Extraction

In chemical procedure alkali or acid retting and Chemical Assisted Natural (CAN) are used to remove the amorphous regions and reduce the lignin content of the elementary fibers [49]. In addition this treatment has effects on other components of bamboo microstructure such as pectin, and hemicellulose. In chemical procedure after removing the bamboo nodes the internodes are sliced into the defined dimensions. Bamboo strips with the size of chips was soaked. The chemical composition of bamboo fiber constitutes mainly cellulose, hemicelluloses and lignin. These components are actually same high-glycans, and make about 90% of total weight of bamboo fiber. The other constituents are protein, fat, pectin, tannins, pigments and ash. This method was repeated several times under a certain pressure for extracting fiber in the form of pulp [50]. The problem of this technique was that some macro meter size of fiber bundles were formed during extraction.

2.3.1.2 Mechanical Extraction

This method involves different mechanical procedures such as steam explosion or heat steaming, high pressure refinery, crushing and super grinding [51]. All these mechanical methods have some advantages and disadvantages. For instant: in heat steaming method the natural strength of the bamboo fibers reduce.

Kazuya et al. [52] used the same method but they were not able to remove lignin completely from the fibers.

Rao and Rao [53] compared both mechanical and chemical methods. The method that was used in chemical procedure was degumming and in mechanical the fibers were extracted with retting process. They found that chemical procedure to extract fiber in spite of being expensive, reducing the tensile strength and modulus; it could increase the strain in comparison with mechanical methods. Moreover mechanical process is more eco-friendly.

2.3.1.3 Combination of Mechanical and Chemical Extraction

There are two techniques such as compression molding and roller mill technique which are usually used after chemical treatment. In this method firstly the bamboo strips are treated by alkali in both techniques. Then the treated bamboo strips based on compression molding technique were pressurized between two plates with 10 tons loads. Starting bed thickness and time are two parameters were affected on the quality of the fibers. In the second technique the alkali treated strips were rolled by force between two rollers. The combination of these two methods separated fibers easily [54].

Comparisons between chemical extraction, mechanical extraction and Steam explosion are shown in Table .4

Table 3 physical and mechanical properties of bamboo fiber according to extraction process [55,56]

Table 4: comparison of different extraction method for bamboo fibers [57]

Extraction Procedure	Tensile Strength (MPa)	Young's Modulus (GPa)	Fiber Length (mm)	Fiber Diameter (µm)	Density (g/cm^3)
Mechanical					
Steam explosion	516	17	-	-	-
Steam explosion	441 ± 220	36 ± 13	-	15 to 210	-
Steam explosion	383	28	-	-	-
Steam explosion	441	35.9	-	0.8 to 125	-
Steam explosion	615 to 862	35.45	-	-	-
Steam explosion	308 ± 185	25.7 ± 14.0	-	195 ± 150	-
Rolling mill	270	-	220 to 270	100 to 600	-
Grinding	450 to 800	18 to 30	-	-	1.4
Retting	503	35.91	-	-	0.91
Crushing	420 ± 170	38.2 ± 16	-	262 ± 160	-
Chemical					
Chemical	341	19.67	-	-	0.89
Chemical	450	18	10	270	1.3
Chemical	329	22	-	-	-
Alkaline	419	30	-	-	-
Alkaline	395 ± 155	26.1 ± 14.5	-	230 ± 180	-
Combined mechanical and chemical					
Chemical + Compression	645 Max: 1000	-	> 10	50 to 400 HC: 150 to 250	0.8 to 0.9
Chemical + Roller mill	370 Max: 480	-	120 to 170	HC: 50 to 100	-

2.4 Effect of bamboo fiber composite treatment

The hydrophilic nature of the bamboo strands is due to its synthetic components, for example, lignin that can diminish bond with the hydrophobic framework materials. Numerous scientists have adopted concoction treatment based strategies, for example [58], alkalization, unite copolymerization and coupling operators with a specific end goal to dignify the bamboo.

2.4.1 Alkaline treatment

Whenever the manufacturing of thermoplastics and thermoset, the most used chemical treatment of natural fibers is alkaline treatment. The excessive lignin, wax and oils present of the external surface of the fiber cell is removed by the alkaline treatment. The ionization of the hydroxyl group done by the NaOH treatment. The alkaline treatment has two effects over the fibers: One is being able to increase the roughness over the outer surface which in turn increases the mechanical interlocking and second being able to increase the amount of cellulose exposure on the fiber surface. [59]

2.5 Acetylation of Natural Fibers

The hygroscopic nature is reduced of the natural fiber after the acetylating, i.e. introduction of acetyl functional group into the compound. The sisal fibers are often treated with the acetylation treatment to increase the fiber-matrix adhesion. Benzoylation Treatment, Permanganate Treatment, Peroxide, Isocyanate Treatment and oil [60]

CHAPTER THREE

3 MATERIAL AND METHODOLOGY

The materials required, fabrication method and the experimental procedures followed for their characterization is presented in detail in this section. It also 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. PTFE filler (Friction Modifiers, act as lubricants, modifies wear and friction coefficient,)
3. Epoxy
4. Hardener

3.1 Material

Raw materials are the starting point for development of new materials and quality of new material itself is dependent upon the raw materials. Then the role of processing techniques to fabricate the new materials and characterizations techniques to ensure their quality, the materials and methods used for the processing of all the composites under this investigation are discussed in this section. It describes the details of the characterization techniques in terms of mechanical and chemical properties of the composite samples under study. This section describes about the material used in fabrication of composite, their physical properties and chemical properties etc. In this section, the method used to determine the mechanical, physical properties are also discussed.

3.1.1 Matrix Material

Matrix materials as being found in different types, polymer matrices are dominantly used due to their 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 .Matrix material is the material, which holds the relative position of the filler material. The composites shape, surface appearance, environmental tolerance and overall durability are dominated by it. Many materials when they are in a fibrous form exhibit very good strength property but to achieve these properties the fibers should be bonded by a suitable matrix. The matrix isolates the fibers from one another in order to prevent abrasion and formation of new surface flaws and acts as a bridge to hold the fibers in place. A good matrix should possess ability to deform easily under applied load, transfer the load onto the fibers and evenly distributive stress concentration. The frequently 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 good performance at elevated temperatures, outstanding adhesion to wide variety of fibers, 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

3.1.2 Reinforcement

Fiber is the reinforcing phase of a composite material. In the present study, the reinforcement material used in the epoxy matrix and filler to fabricate composites is the bamboo fiber. In general, bamboo is abundantly available in Ethiopia and it is an abundant natural resource across the world.

3.1.3 Bamboo fiber

Depending on the age, height, season, species and layer, the chemical composition of bamboo varies and also 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

3.1.4 Filler

Particulate fillers play a significant role for the enhancement of performance of polymers and their composites. Different types of fillers of natural or synthetic, both organic and inorganic is already being used as reinforcement in polymeric composites. Due to many advantages, specially wear resistance performance PTFE used as a filer. Depending on the sort of filler forms the addition strength to the mechanical properties and tribological properties of the polymer composite materials. In these fillers Polytetrafluoroethylene (PTFE) used as reinforcement it will increase the properties wear resistance

3.2 Methodology Preparation of Material

3.2.1 Preparation of bamboo Fiber

The bamboo hole used in the present investigation was arranged from Hawasa and the bamboo edge was around 3 years as per the farmer. The process of fiber extraction is shown below

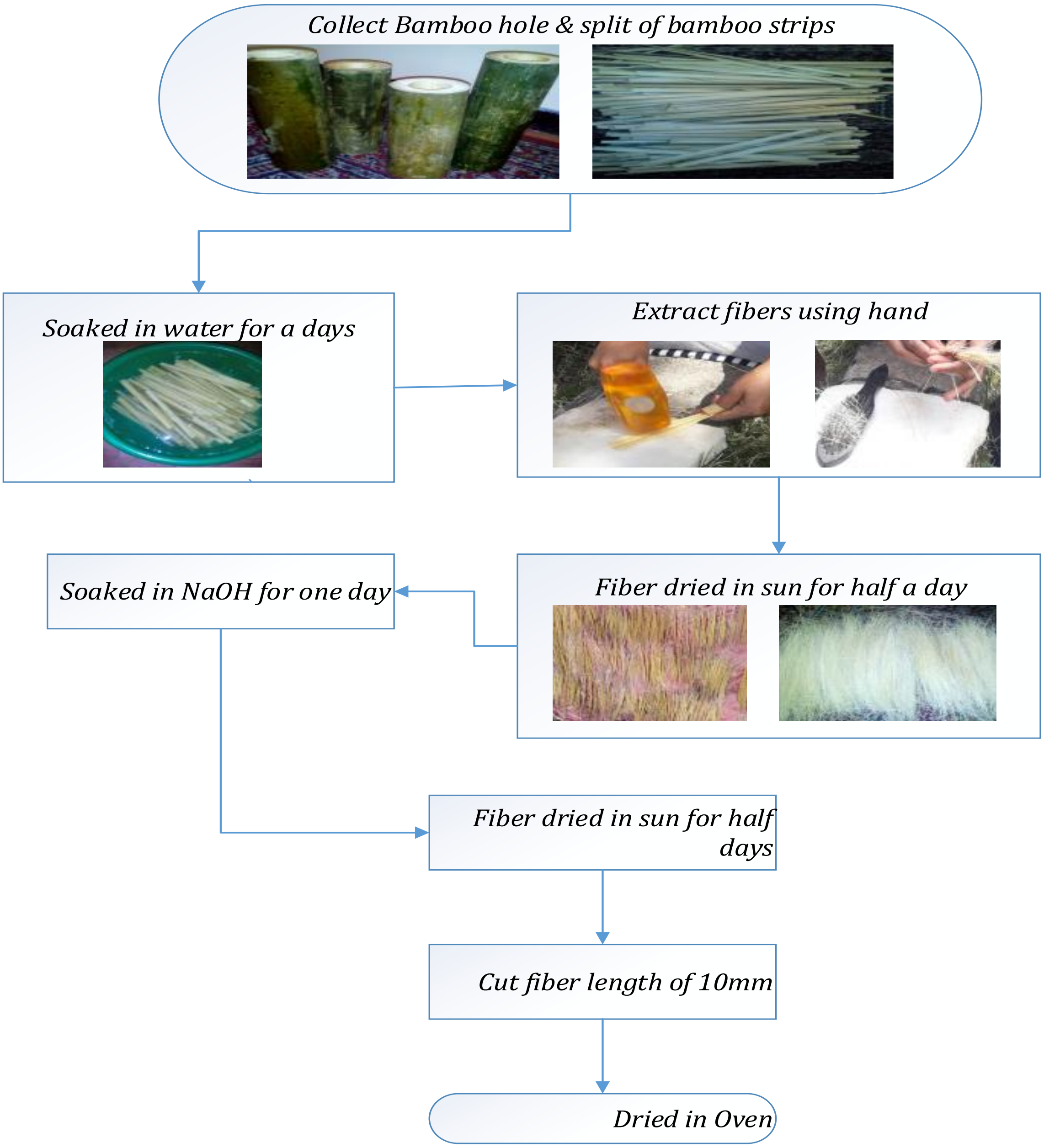


Figure 9: Bamboo fiber extraction process

3.2.2 Molds

The mold was made having a simple base and top made of steel and bamboo plywood having dimensions 200mm×100mm×40mm

Figure 10: Steel mold

3.3 Method of Operation

To minimize cost of material, reduce global waste problems and available material easily during heavy requirement of material. Here I use three materials to manufacture 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 I use Polytetrafluoroethylene (PTFE) as filler material to improve the different properties of the composite

3.3.1 Composite Fabrication

The short bamboo fiber and PTFE particulates are mixed with epoxy resin by the simple mechanical stirring and the mixture is poured into various molds conforming to the requirements of various testing conditions and characterization standards. The composite samples are prepared in four different percentages of Polytetrafluoroethylene (0wt%, 2wt% and 4wt% of PTFE) is used keeping bamboo fiber at a fixed percentages (i.e. 30wt %). A releasing agent is used to facilitate easy removal of the composite from the mold after curing. The entrapped air bubbles (if any) are removed carefully with a sliding roller and the mold is closed for curing at a temperature of 180°C for 10 minute and curing for 8 h at a constant pressure of 10 kg/cm2. After curing, the specimens with appropriate dimension are cut for abrasive tests.

Table 5: Designation of composites

Composites	Compositions
EB+PTFE-1	Epoxy + Bamboo Fiber (30 wt. %) + PTFE (0 wt. %)
EB+PTFE-2	Epoxy + Bamboo Fiber (30 wt. %) + PTFE (2 wt. %)
EB+PTFE-3	Epoxy + Bamboo Fiber (30 wt. %) + PTFE (4 wt. %)

3.3.2 Weight Fraction of the Fiber and the Matrix content of the composite

The volume of the composite was calculated by multiplying the length, width and breadth of the mold prepared for molding the composite material eq (1) and the density of the composite was calculated by a method which enable the rule of law of mixture to be applied and was obtained first by adding the volume fraction of the epoxy resin ,Polythetrafluroethyle and bamboo fiber for each fiber/matrix ratio the density of the composite obtained as shown in eq(2) after getting the density of the composite multiplied by the volume of the composite eq(2) then the mass of the composite obtained then the mass of the composite multiplied by each fiber, PTFE/matrix ratio then the mass of each bamboo fiber ,PTFE and epoxy resin obtained.

Zakikhani et al [61] reported that the density of bamboo fiber is different based on the extraction process, which is the density of bamboo fiber 0.8-0.9 g/cm^3 for combination of chemical and mechanical extraction process

Calculation To Find the Mass of the Fiber for Specimen

Volume of the die = 200 x100x 40 = 800000mm^3=800cm^3 ………………..eq(1)

Density of the Fibers/PTFE/Epoxy in g/ cm(Density= Mass/Volume (or) Volume=Mass/Density)

1. Bamboo Fiber =0.9 g/ cm^3
2. Polytetrafluoroethylene (PTFE)=2.2 g/ cm^3
3. Epoxy Resin =1.2 g/ cm3

Vc = VBamboo + Vptfe + Vepoxy

$m_c/\rho_c = m_{Bamboo}/\rho_{Bamboo} + m_{Epoxy}/\rho_{Epoxy} + m_{PTFE}/\rho_{PTFE}$……… eq (2)

For specimen -1-

$$1/\rho_c = \left(\frac{0.30}{1}\right)\left(\frac{1}{0.9}\right) + \left(\frac{1}{0.7}\right)\left(\frac{1.2}{1}\right)$$

ρ_c =2.046 g/ cm3

$m_c = \rho_c * V_C$………………………………………………………….(3)

m_c = 2.046*800=1636.8

For specimen -2-

$$1/\rho_c = \left(\frac{0.30}{1}\right)\left(\frac{1}{0.9}\right) + \left(\frac{1}{0.68}\right)\left(\frac{1.2}{1}\right) + \left(\frac{0.02}{1}\right)\left(\frac{1}{2.2}\right)$$

ρ_c = 2.106 g/ cm3

$m_c = \rho_c * V_C$

m_c =1684.8

For 2% PTFE Composite material), m_c = 1684.8

Similarly calculated for 4% and 6% PTFE Composite material

$$1/\rho_c = \left(\frac{0.30}{1}\right)\left(\frac{1}{0.9}\right) + \left(\frac{1}{0.66}\right)\left(\frac{1.2}{1}\right) + \left(\frac{0.04}{1}\right)\left(\frac{1}{2.2}\right)$$

ρ_c = 2.169g/ cm3

m_c= 1735.2

$$1/\rho_c = \left(\frac{0.30}{1}\right)\left(\frac{1}{0.9}\right) + \left(\frac{1}{0.64}\right)\left(\frac{1.2}{1}\right) + \left(\frac{0.06}{1}\right)\left(\frac{1}{2.2}\right)$$

ρ_c =2.235 g/ cm3

m_c= 1788

Table 6: Fiber and Matrix Mass composition

Designation	Composition (%)			Mass (gms)				No. of sample
	Bamboo	Epoxy	PTFE	Bamboo	Epoxy	PTFE	Total	
EB+PTFE-1	30	70	0	491.04	1145.76	0	1636.8	2
EB+PTFE-2	30	68	2	505.44	1145.66	33.69	1684.8	2
EB+PTFE-3	30	66	4	520.56	1145.23	69.40	1735.2	2

3.3.3 Volume Fraction of the Fiber, PTFE and the Matrix content of the composite

Fiber and matrix volume fraction (V_F, V_M, V_{PTFE})

Volume of fibers, PTFE, matrix and composite is given by

$$V_F = \frac{W_F}{\rho_F} \;;$$

$$V_{PTFE} = \frac{W_{PTFE}}{\rho_{PTFE}} \;;$$

$$V_M = \frac{W_M}{\rho_M}$$

$$V_c = V_F + V_{PTFE} + V_M$$

$$V_C = V_{PTFE} = V_F = V_M = 1$$

Where

Vf: Volume of fibers, (cm3)

Vm: Volume of matrix, (cm3)

$V_{PTFE;}$ Volume of PTFE

Vc: Volume of Composite specimen (cm3)

VF: Fibers Volume fraction

Table 7: Fiber and Matrix volume content

Specimen		Vf	Vptfe	Vm	Vc
EB+PTFE-1		545.6	0	954.8	800
EB+PTFE-2		561.6	15.31	954	
EB+PTFE-3		5784.	31.55	954.36	

3.3.4 Preparation of the Specimen

The layers of fiber reinforcement are cut to the required shapes and placed on the surface of the mold. The resin mixed with other ingredients and infused onto the surface of reinforcement already positioned in the mold using a help brush to uniformly spread it . And then the other mats are placed on the preceding polymer layer and pressured using a roller to remove any trapped air bubbles and the excess of polymer as well. The mold is then closed and pressure is released to obtain a single mat. After curing at room temperature, the mold is opened and the woven composite is removed from the mold surface

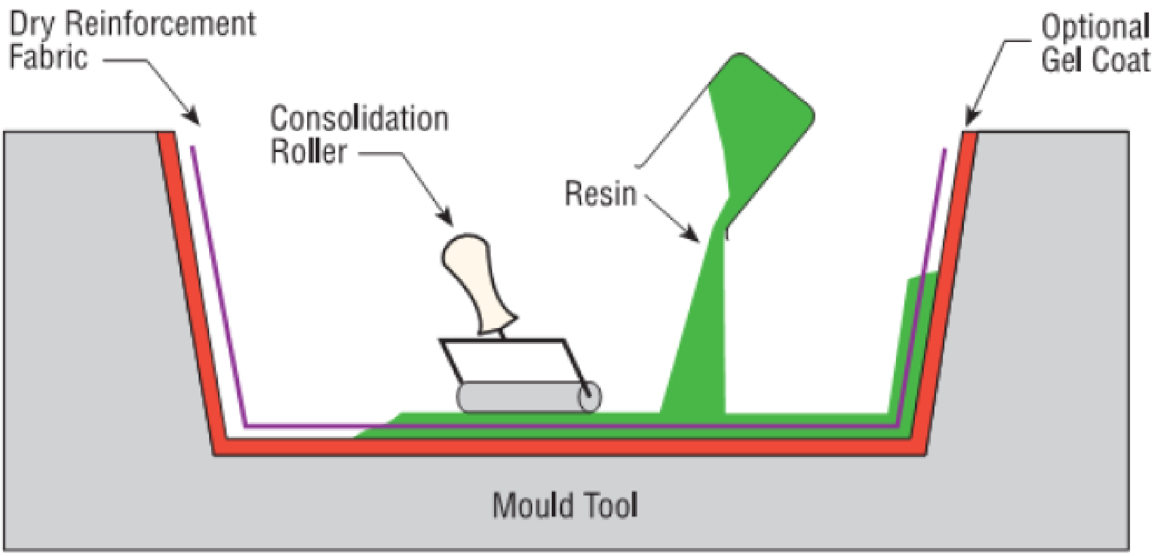


Figure 11: Hand lay - up process

3.3.5 The treated and dries fiber are cut into 10mm

Short-fiber-reinforced polymers (SFRP) become good impact resistance and low weight with the high stiffness and strength of reinforcing fibers the dried fiber cut into 10mm

Figure 12 Fiber sizing process

3.3.6 Preparing the mold

The mold surface is treated by release an adhesive agent to avoid the sticking of polymer to the surface then, a thin plastic sheet is applied at the top and bottom of the mold plate to get a smooth surface of the product

Figure 12: Pattern mold

3.3.7 Pattern making

W. D. Callister [62] investigated that Fibers are responsible for high strength and stiffness ratio to weight of the composite. This classification can be further subdivided into continuous and discontinuous fibers. Continuous fibers are those which have lengths normally greater than 15 times the critical length (l >15) and discontinuous fibers have lengths shorter than (< 15mm) . The discontinuous fibers can be aligned or randomly oriented. It is obvious that for better strength of the composite and better load transfer the fibers should be continuous

Figure 13: Compression and curing

3.3.8 Compression and Curing

Composites were prepared with matrix reinforcements as the given method in the above pictures poured in a test specimen. The whole setup is placed into the steel mould. The kneading was continuously conducted on Bamboo hot press machine for 20 minute under 185^{0} C at a pressure of 15mpa for improving the matrix homogenized .after cooling for 8 hour in the machine the composite plate was taken and kept of sun light for removing of moisture in composites (if there is)

Figure 14: Figure 14 Bamboo hot press machine

3.3.9 Fabricated Specimen

Figure 15: Fabricated specimen

3.3.10 Effects of void content

Voids in hybrid composites were determined as per ASTM-D-2734-70. The void content was calculated by using following Equations (1)–(4).

r = MF/MB *100………………………………………………………………………1

$R=100-r_m-r_{ptfe}$……………………………………………………………………..2

$Td = 100/(R/D + r/d+ r_{ptfe}/d_{ptfe})$………………………………………………...3

Void Content=100(Td-Md)/Td………………………………………………………

Where

R is the weight % of the resin in the composite

r is the weight % of the reinforcement in the composite

r_{ptfe} is the weight of filler(PTFE)

MF is the mass of fiber

MB is mass of composite

D is the density of the resin matrix

d is the density of the reinforcement,

d_{ptfe} is the density of the PTFE

Md is measured density

Td is theoretical density

Table 8: Result of theoretical and measured density value

Theoretical Value				**Measured Value**			
	A	B	C		A	B	C
Mass(g)	1636.8	1684.8	1735.2		1471	1510	1675
Volume(cm^3)	800	800	800		760	744	787
Td	2.046	2.106	2.169	Md	1.93	2.0	2.1

Table 9: Void content

Specimen	Void %
A	5.6
B	5.0
C	3.2

3.4 Experimental procedures and setup

3.4.1 Experimental Setup

According to the test machine, I have seen different enterprises, factories and research centers which includes universities but I did not get the machine and there is no fabricated and available in local market but I have adopted and modified the test machine (pin on disk) as per the standard setup and all the machines measurements, material type, and setup structure are the same as the authenticated measuring machine.

3.5 Description of wear test machine

Table 10: Specifications of the pin on Disk wear and friction monitor

Items	Description and size	Material
Rotating disk	diameter 200 mm	steel

3.5.1 Experimental procedure of wear test

By using a pin-on-disc machine, a dry sliding wear tests for different number of specimens was conducted as shown in Figure 16

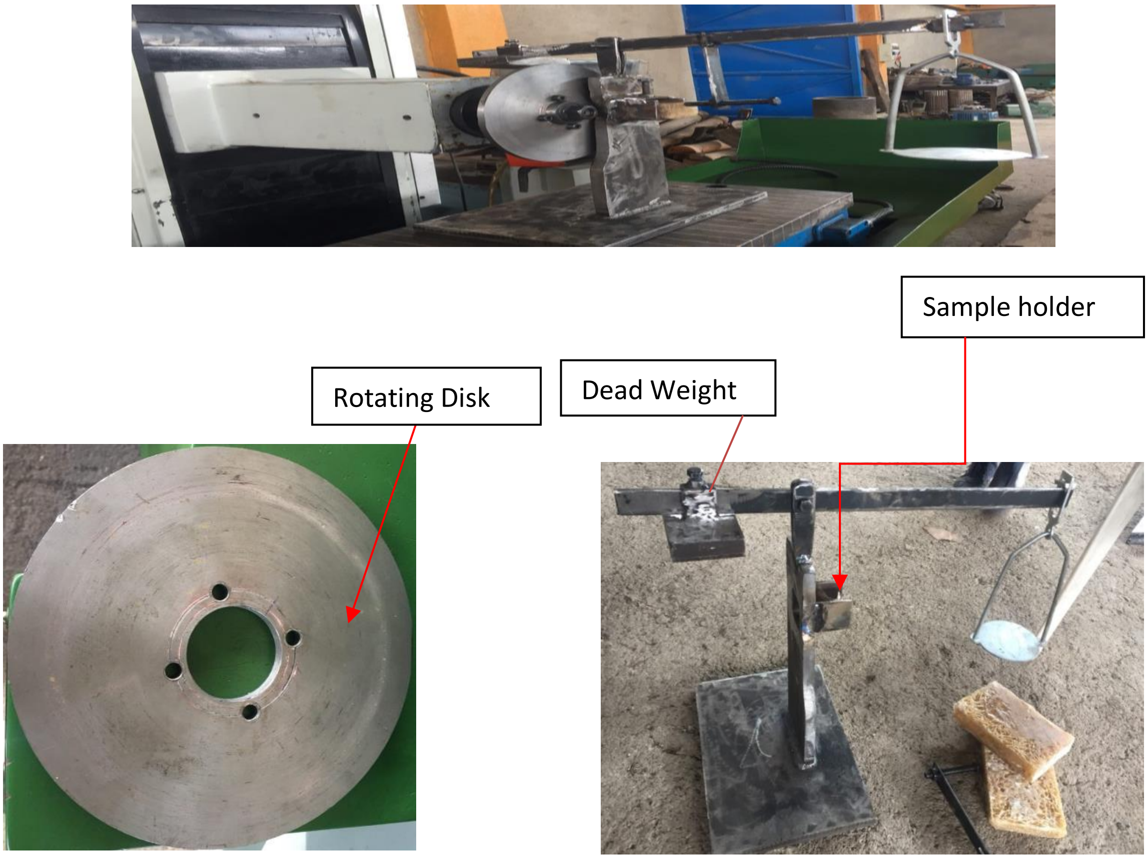


Figure 16: Wear test machine (modified)

The pin was held against the counter face of a rotating disc (steel disc) with wear track diameter 120 mm. The pin was loaded against the disc through a dead weight loading system. The wear test for all specimens was conducted under the normal loads of 15N, 30N , a sliding velocity of 2 and 4 m/s at the distance of 1000m.

The surfaces of the pin samples were primarily ground by using emery paper (80 grit size) prior to test in order to ensure effective contact of fresh and flat surface with the steel disc. The height loss technique is used to calculate the wear rate and expressed in terms of wear volume loss per unit sliding distance.

In this experiment, the test was conducted with the following parameters:

1. Speed
2. Load
3. Distance

Table 11: Parameter taken invariable during sliding wear test

Pin Material	Composite (Bamboo +PTFE+ Matrix)
Disk Material	Steel(200mm)
Sliding Speed	2,4,
Normal Load	15,30
Distance	1000

3.5.2 Wear Testing method

In this study, Pin-on-Disc testing method was used for all characterization. The test procedure is as follows:

- Initially, pin surface was made flat such that it will support the load over its entire cross-section called first stage. This was achieved by the surfaces of the pin sample ground using emery paper (80 grit size) prior to testing
- Run-in-wear was performed in the next stage.
- Constant state wear is the final stage of the actual testing. This stage is the dynamic competition between material transfer processes (transfer of material from pin onto the disc and formation of wear debris and their subsequent removal). Before the test, both the pin and disc were cleaned with ethanol soaked cotton

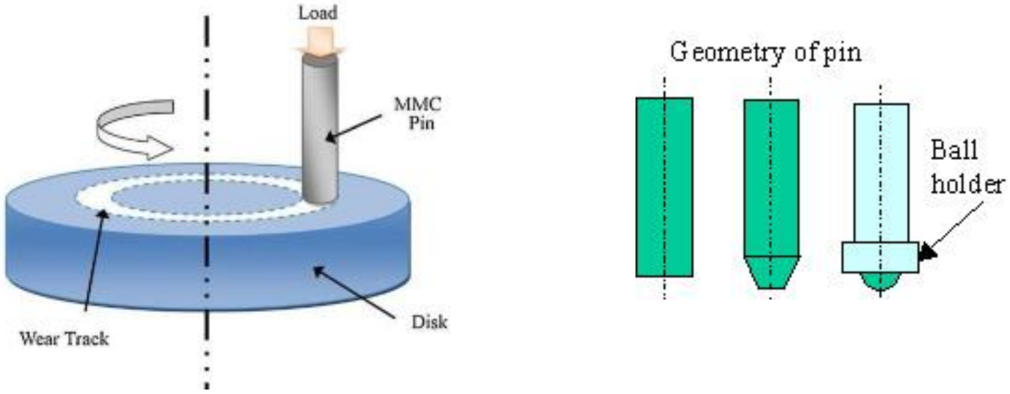


Figure 17: Schematic views of the pin - on- disk apparatus

Figure 18: Sample preparation

3.6 Experiment result

3.6.1 Weight Loss

The composite samples are cleaned. Each sample is then weighed using a digital balance. After that, the sample is mounted on the pin holder of the wear test. For all experiments, the sliding speeds are adjusted to 2 and 4 m/s. The specific wear rates of the materials were obtained by $W = \frac{\Delta w}{L\rho F}$

Where W denotes specific wear rates in mm^3 /N-m, Δw is the weight loss measured in gram, L sliding distance in meters, ρ density of worn material in g/mm^3 and F is the applied load in N ·Weight loss of composite samples in grams is shown in below table.

Specimen test result

Table 12: Data of cumulative wear loss of composites at 15N load and distance of 1000m at sliding speed 2m/s

Specimen	Sliding Speed 2m/s								
	Test -1-			**Test -2-**			**Test -3-**		
	Initial weight (gm)	**Final weight (gm)**	**Weight loss (gm)**	**Initial weight (gm)**	**Final weight (gm)**	**Weight loss (gm)**	**Initial weight (gm)**	**Final weight (gm)**	**Weight loss (gm)**
A	114.041	114.016	0.025	114.016	113.993	0.023	113.993	113.968	0.025
B	114	113.98	0.020	113.98	113.957	0.024	113.957	113.935	0.021
C	114.3	114.288	0.012	114.288	114.275	0.013	114.275	114.26	0.015

Table 13: Data of cumulative wear loss of composites at 15N load and distance of 1000m at sliding speed 4m/s

Specimen	Sliding Speed 4m/s								
	Test -1-			**Test -2-**			**Test -3-**		
	Initial weight (gm)	**Final weight (gm)**	**Weight loss (gm)**	**Initial weight (gm)**	**Final weight (gm)**	**Weight loss (gm)**	**Initial weight (gm)**	**Final weight (gm)**	**Weight loss (gm)**
A′	113.78	113.751	0.029	113.751	113.724	0.027	113.724	113.695	0.029
B′	114.2	114.177	0.0231	114.177	114.156	0.0211	114.156	114.132	0.0241
C′	114	113.98	0.0194	113.98	113.96	0.0192	113.96	113.94	0.0197

Table 14: Data of cumulative wear loss of composites at 30N load & distance of 1000m at sliding speed of 2m/s

Specimen	Sliding Speed 2m/s								
	Test -1-			**Test -2-**			**Test -3-**		
	Initial weight (gm)	**Final weight (gm)**	**Weight loss (gm)**	**Initial weight (gm)**	**Final weight (gm)**	**Weight loss (gm)**	**Initial weight (gm)**	**Final weight (gm)**	**Weight loss (gm)**
D	114.01	113.981	0.029	113.981	113.957	0.024	113.957	113.929	0.028
E	114.54	114.516	0.0241	114.516	114.491	0.0243	114.491	114.466	0.025
F	113.76	113.741	0.019	113.741	113.724	0.017	113.724	113.705	0.0192

Table 15: Data of cumulative wear loss of composites at 30N load & distance of 1000m at sliding speed of 4m/s

Specimen	Sliding Speed 4m/s								
	Test -1-			**Test -2-**			**Test -3-**		
	Initial weight (gm)	**Final weight (gm)**	**Weight loss (gm)**	**Initial weight (gm)**	**Final weight (gm)**	**Weight loss (gm)**	**Initial weight (gm)**	**Final weight (gm)**	**Weight loss (gm)**
D′	114.02	113.989	0.031	113.989	113.956	0.033	113.956	113.926	0.030
E′	114	113.971	0.029	113.971	113.944	0.027	113.944	113.918	0.026
F′	114.43	114.409	0.021	114.409	114.386	0.023	114.386	114.365	0.021

Table 16: Weight loss at Load 15 N and Sliding Speed 1000m

2m/s			4m/s		
Specimen	**Average weight**	**Average weight loss**	**Specimen**	**Average weight**	**Average weight loss**
A	113.99	0.0243	A′	113.723	0.0283
B	113.957	0.0217	B′	114.155	0.0227
C	114.274	0.0133	C′	113.973	0.0194

Table 17: Weight loss at Load 30N and Sliding Speed 1000m

2m/s			4m/s		
Specimen	**Average weight**	**Average weight loss**	**Specimen**	**Average weight**	**Average weight loss**
D	113.95	0.027	D′	114.240	0.0313
E	114.491	0.0244	E′	113.944	0.0273
F	113.733	0.0184	F′	114.389	0.0216

3.6.2 Wear Calculation

1. Area

Cross sectional Area, A=bh

2. Volume loss

Volume loss = Height loss x Cross sectional Area

3. Wear rate

Wear rate = Volume loss / Sliding distance

4. Wear resistance

Wear resistance = 1/ Wear rate

5. Specific wear rate

Specific wear rate = Wear rate/load

3.6.3 Volume Loss

Wear volume is normally calculated from the wear track (scar) depth, length, width and/or scar profile according to the geometry of the wear track/scar. The reporting unit of wear volume loss is mm3 . Wear volume loss enables a better comparison of wear among materials having different densities

Table 18: volume loss result

No.	Specimen	Area($mm^{2)}$	Height loss(mm	Volume Loss(A*$H_{loss)}$ mm^3
1	A		1.4mm	1274
2	B		1.3	1183
3	C		1.1	1001
4	A′		1.9	1729
5	B′		1.6	1456
6	C′	910	1.4	1274
7	D		2.2	2002
8	E		1.9	1729
9	F		1.6	1456
10	D′		2.7	2457
11	E′		2.5	2275
12	F′		2.1	1911

3.6.4 Wear Rate

Wear rates are calculated results reflecting wear mass loss, volume loss or linear dimension change under unit applied normal force and/or unit sliding distance. Wear rate can be expressed in many different ways

Wear rate = Volume loss / Sliding distance

Table 19: Wear rate (mm3/m) at a load of 15N

Wear Rate at load 15N and Sliding speed 1000m			
Specimen	**2m/s**	**Specimen**	**4m/s**
A	1.274	A′	1.729
B	1.183	B′	1.456
C	1.001	C′	1.274

Table 20: wear rate (mm3/m) at a load of 30N

Wear Rate at load 30N			
Specimen	**2m/s**	**Specimen**	**4m/s**
D	2.002	D′	2.457
E	1.729	E′	2.275
F	1.456	F′	1.911

3.6.5 Resistance

Wear resistance is a term frequently used to describe the anti-wear properties of a material. However, the scientific meaning of wear resistance is vague, and there is no specific unit to describe wear resistance. Nevertheless, the inverse of mass loss or volume loss is sometimes used as the (relative) wear resistance. The ratio of wear loss for a reference material over that of the investigated material under same testing conditions can also used as relative wear resistance

Wear resistance = 1/ Wear rate

Table 21: Wear resistance (mm3/m) at load 15N

Wear Resistance at load 15N			
Specimen	**2m/s**	**Specimen**	**4m/s**
A	0.784	A′	0.578
B	0.845	B′	0.686
C	0.999	C′	0.785

Table 22: Wear resistance (mm3/m) at load 30N

Wear Resistance at load 30N			
Specimen	**2m/s**	**Specimen**	**4m/s**
D	0.499	D′	0.407
E	0.578	E′	0.439
F	0.686	F′	0.523

3.6.6 Specific Wear Rate

Specific wear rate = Wear rate/load

Table 23: Specific wear rate (mm3/Nm) at load 15N

Specific wear Rate at load 15N			
Specimen	**2m/s**	**Specimen**	**4m/s**
A	0.085	A′	0.115
B	0.079	B′	0.097
C	0.067	C′	0.085

Table 24: Specific wear rate (mm3/Nm) at load 30N

Specific wear Rate at load 30N			
Specimen	**2m/s**	**Specimen**	**4m/s**
D	0.067	D′	0.082
E	0.057	E′	0.076
F	0.048	F′	0.064

3.6.7 Wear Behavior

The ultimate target of this experiment is to find the important sole factors and the combination of those influencing the wear process to achieve the minimum wear rate and COF. The experiments were developed based on an OA, with the aim of relating the influence of sliding speed, applied load and sliding distance. These design parameters are distinct and intrinsic characteristic of the process that influence and determine the composite performance. As Taguchi recommends, analyzing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

The above mentioned (the modified one) pin on disc test apparatus was used to determine the sliding wear characteristics of the composite. The composite sample contact surface was made rectangular so that it should be in contact with the rotating disk. During the test, the pin was held pressed against a rotating disc by applying load that acts as a counterweight and balances the pin. The track diameter was 120mm and the parameters were varied in the range given in the above table, i.e. the load, sliding speed and sliding distance. The experiment was conducted weight loss of each specimen was obtained by weighing the specimen before and after the experiment by a single pan electronic weighing machine with an accuracy of 0.0001g after thorough cleaning with acetone solution.

The results for various combinations of parameters were obtained by conducting the experiment. The measured results were analyzed using the commercial software MINITAB 18 specifically used in DOE applications.

Table 25: Process Parameters

Level	**Load(N)**	**Sliding Speed S(m/s)**	**Sliding Distance D (m)**
1	15	2	1000
2	30	4	

3.6.8 Plan of experiments

The dry sliding wear test was performed with three parameters: applied load, sliding speed and sliding distance and varying them for two levels. According to the rule that DOF for an OA should be greater than or equal to the sum of those wear parameters, a L12 OA which has 12 rows and 3 columns was selected as shown below:

Table 26: Orthogonal array L12 of Taguchi

Sliding Speed	Load	%PTFE	Wear	S/N
2	15	0	0.008145	41.78
2	15	2	0.007273	42.78
2	15	4	0.004458	47.01
2	30	0	0.004525	46.88
2	30	2	0.004089	47.76
2	30	4	0.003017	50.4
4	15	0	0.009486	40.45
4	15	2	0.007609	42.37
4	15	4	0.006368	43.91
4	30	0	0.005246	45.6
4	30	2	0.004575	4.79
4	30	4	0.00362	48.82

The numbers of levels of the factors and the desired experimental resolution or cost limitations, a total of 12 experiments were performed based on the run order generated by the Taguchi model. The response of the model is wear rate and COF. In OA, the first column is assigned to applied loads, second column is assigned to sliding speed and third column is assigned to sliding distance and the remaining columns are assigned to their interactions. The objective of the model is to minimize the wear rate and COF. The Signal to Noise (S/N) ratio, which condenses the multiple data points within a trial, depends on the type of characteristic being evaluated. In this study, "smaller the better" characteristic was chosen to analyze the dry sliding wear resistance. The response table for signal to noise ratios shows the average of selected characteristics of each level of the factor. This table includes the ranks based on the delta statistics, which compares the relative value of the effects. S/N ratio is a response which consolidates repetitions and the effect noise levels into one data point. Analysis of variance of the S/N ratio is performed to identify the statistically significant parameter

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Experimental Result

The aim of the experimental plan is to find the sole important factors and the combination of those influencing the wear process to achieve the minimum wear rate and COF. The experiments were developed based on an OA, with the aim of relating the influence of sliding speed, applied load and sliding distance. These design parameters are distinct and basic characteristic of the process that influence and determine the composite performance. Taguchi recommends analyzing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

4.2 Weight Loss

The specimen was fabricated with 30% Bamboo fiber, 0,2 and 4 % of PTFE of variable ratio and 70,68 and 66 % of matrix material using bamboo hot press machine and the test was carried out by using the modified wear test machine and measuring digital weight and digital caliper units.

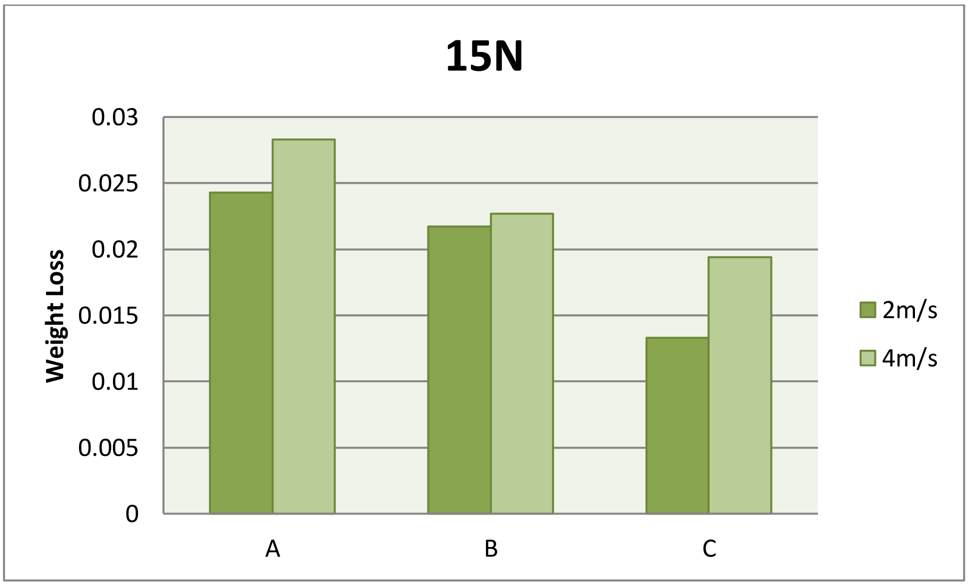


Figure 19: Weight loss of composite with 15N

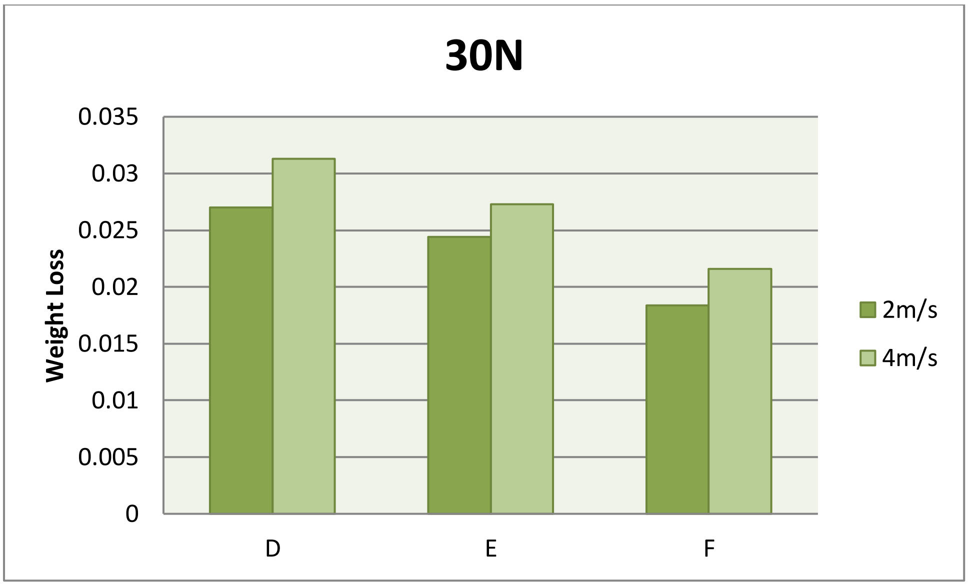


Figure 20: 20 Weight loss of composite with 30N

Figures 20 show the cumulative weight loss of the composite specimen after addition of 2& 4%PTFE produced with the help of hand lay-up technique. After addition of reinforced material the sliding wear decreases significantly or says that weight loss is decreasing as 4 % PTFE addition is increasing the resist of weight loss as compared to matrix composite (0% PTFE).

4.3 Wear Rate

The experimental results of abrasive wear rate showed that the PTFE content had a significant effect on the abrasive wear as shown in Figs. It can be credited to increase in hardness of the material due to the attendance of filler material.

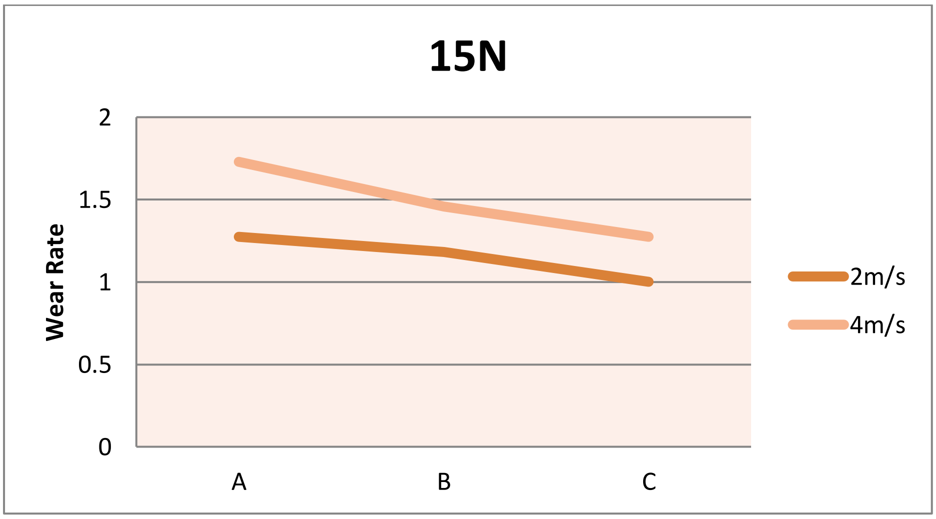


Figure 21: Specimen vs wear rate with 2 & 4m/s at 15N

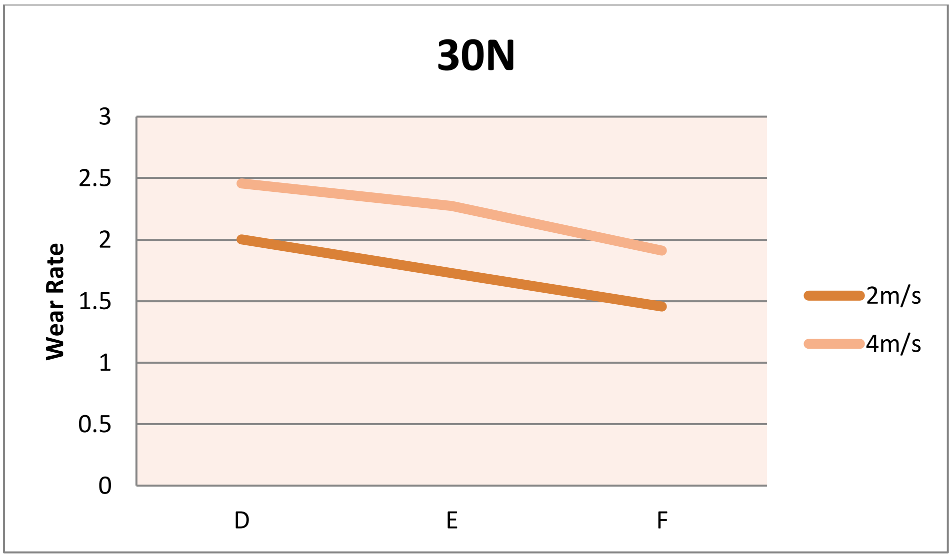


Figure 22: Specimen vs wear rate with 2 & 4m/s at 15N

Comparing the wear properties of composites reinforced with PTFE at 2% and 4 % with different speed (2m/s and 4m/s) under load variation of 15N and 30N, it is observed that despite their higher hardness, composites reinforced with PTFE under 2m/s and 15N (sample C) show improved wear resistance as compared to the remaining composite specimens with different sliding speed and applied load materials

4.4 Wear Resistance

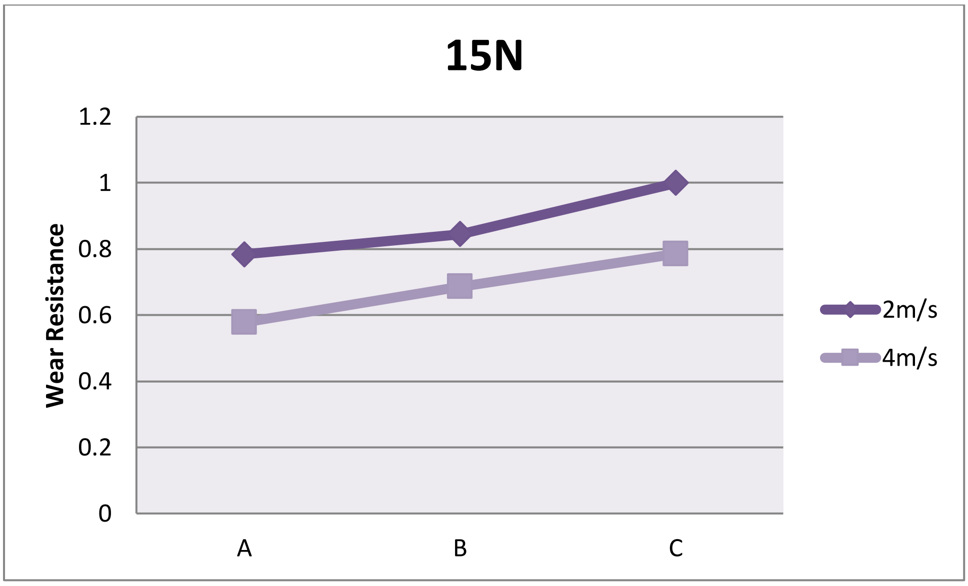


Figure 23: Specimen vs wear resistance with 2 and 4 m/s at 15N

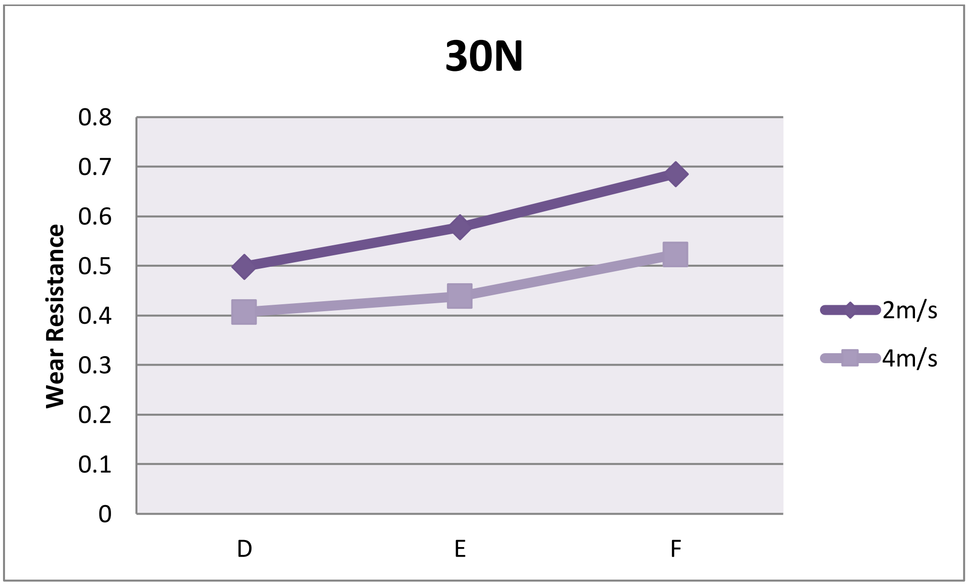


Figure 24: Specimen vs wear resistance with 2 and 4 m/s at 30N

4.5 Specific Wear Rate

Effect of increase in the value of normal load sliding speed on specific wear rate is noticed for different wt. % of PTFE content. Effect of increase in the value of normal load sliding speed on specific wear rate is noticed for different wt. % of PTFE content. The figure shows that the value of normal load increases with the increase in the value of composite without filler. Specific wear rate increases with the increase in the value of normal load and sliding speed

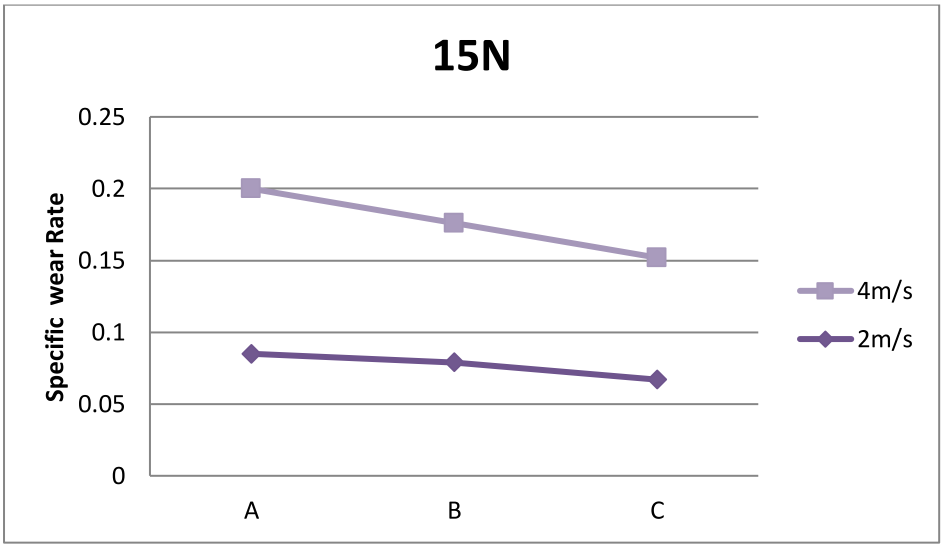


Figure 25: Specimen vs specific wear rate with 2 and 4m/s at 15N

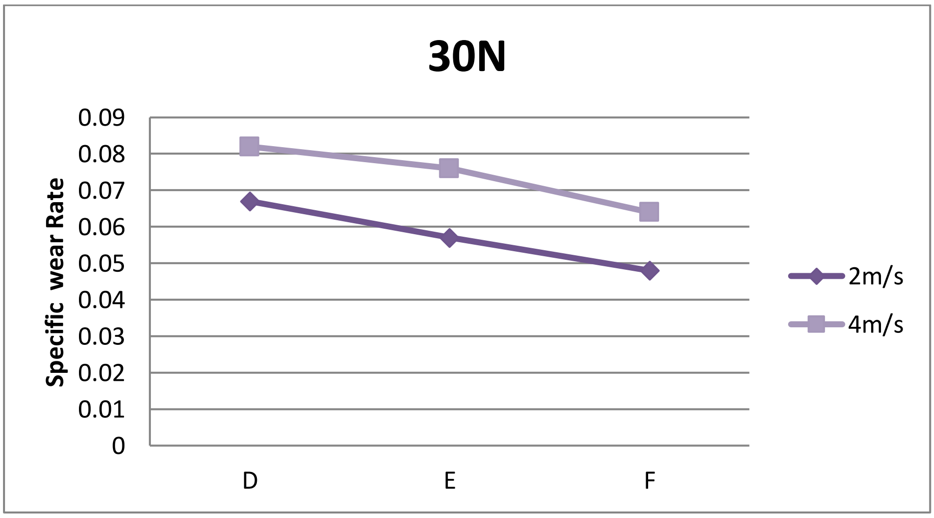


Figure 26: Specimen vs specific wear rate with 2 and 4m/s at 30N

The summary of specific wear rate of the fillers/epoxy composites is presented in Figure 26 Generally, it is found that the optimum PTFE about 4% at the sliding speed of 2m/s, which leads to the lowest specific wear rate in the steady state.

4.6 Analysis of Variance Results for Wear Test

The experimental outputs were analyzed with ANOVA, which is used to investigate the influence of the considered wear parameters, namely, applied load and sliding speed that considerably affects the performance measures. By performing analysis of variance, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent variable.

Considering the different factors the S/N ratio was computed for the wear loss of the material as the response. The S/N ratio was calculated using the equation 1 for smaller is better quality characteristic.

$$S/N=-10\log_{10}(1/n)\Sigma(y_i^2) \quad (1)$$

Where,

n is the number of observation, and

y is the observed data

The S/N ratios and the response were plotted for each factor against each of its levels with a smaller-the-better condition for wear loss and are as shown in the Figure below

Taguchi Design

Design Summary

Taguchi Array L12(2^2)

Factors: 2

Runs: 12

Columns of L12(2^11) array: 1 2

Taguchi Analysis: Wear versus Sliding Speed, Load

Response Table for Signal to Noise Ratios

Table 27: Responses table for S/N ratio of wear

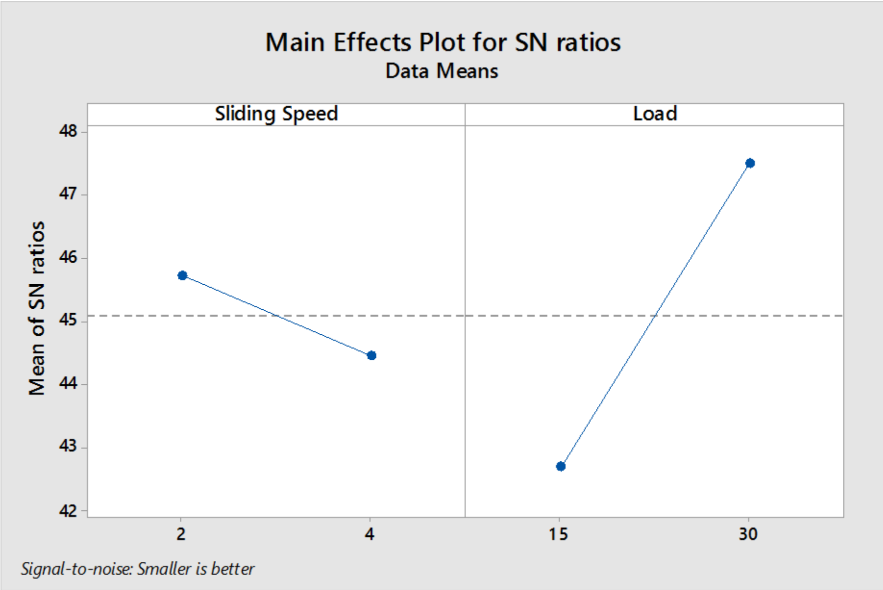
Smaller is better

Level	Sliding Speed	Load
1	45.73	42.68
2	44.45	47.50
Delta	1.28	4.82
Rank	2	1

Table 28: Main effects for plot for S/N ratios

Response Table for Means

Level	Sliding Speed	Load
1	0.005251	0.007223
2	0.006151	0.004179
Delta	0.000899	0.003045
Rank	2	1



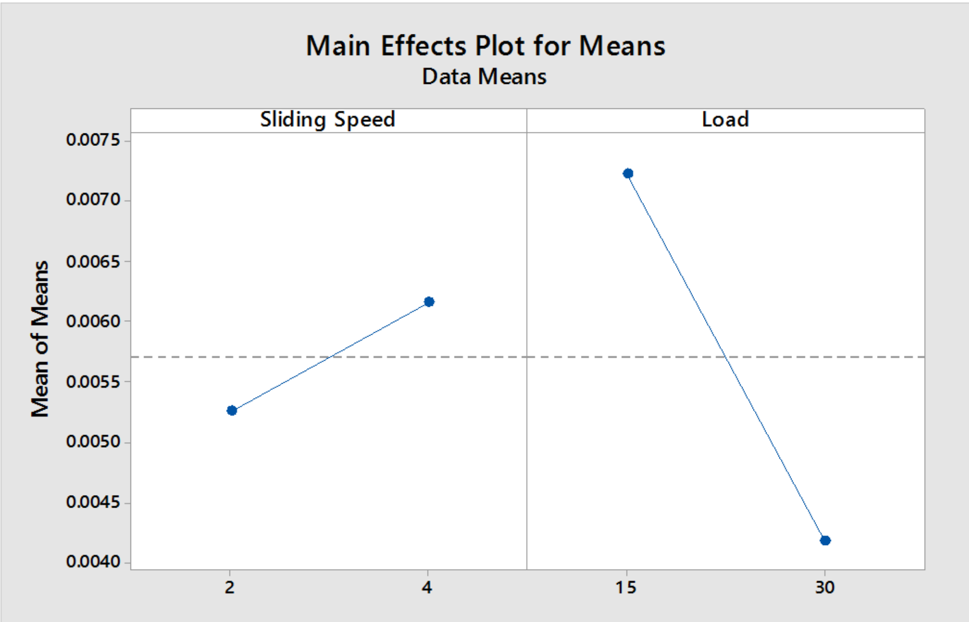


Figure 27: Noticeable Major effects - Plot for Signal to noise ratios - wear rate

4.7 ANOVA

One-way ANOVA: Wear versus Sliding Speed

Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05

1. *Equal variances were assumed for the analysis.*

Factor Information

Factor	Levels	Values
Sliding Speed	2	2, 4

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sliding Speed	1	0.000002	0.000002	0.56	0.470
Error	5	0.000043	0.000004		
Total	6	0.000045			

Means

Sliding Speed	N	Mean	StDev	95% CI
2	6	0.005251	0.001998	(0.003366, 0.007137)
4	6	0.006151	0.002145	(0.004265, 0.008036)

2. *Pooled StDev = 0.00207276*

One-way ANOVA: Wear versus Load

Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05

3. *Equal variances were assumed for the analysis.*

Factor Information

Factor	Levels	Values
Load	2	15, 30

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Load	1	0.000028	0.000028	15.82	0.003
Error	10	0.000018	0.000002		
Total	11	0.000045			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0013260	61.26%	57.39%	44.22%

Means

Load	N	Mean	StDev	95% CI
15	6	0.007223	0.001703	(0.006017, 0.008429)
30	6	0.004179	0.000786	(0.002972, 0.005385)

4. *Pooled StDev = 0.0013259*

4.8 Comparison of wear test machine

The modified wear test machine included specific standard measuring method and units, for the sake of machine accuracy and validity of test result, perform wear test of other research work on the same material and measured the result. Accordingly the selected composite material is hybrid composite pins are prepared with diameter of 10 mm by using glass fiber and natural bamboo fiber with Epoxy as a matrix by using metal mold. The reference material taken from Gujjala Raghavendra (2012), ‘‘Abrasive wears behavior of bamboo – glass fiber reinforced epoxy composite using Taguchi approach”

4.9 Sample history

With the use of metal mold, the composite pins were prepared with diameter of 10 mm by using high strength glass fiber and natural bamboo fiber with Epoxy as a matrix. Different set of composites are prepared those are given in table below

Table 29: Composite material ratios

Sl .no	Composite	Name eroded surface
1	C1	Epoxy
2	C2	Epoxy+bamboo10%+glass
3	C3	Epoxy+bamboo20%+glass

Table 30: Comparison works on Abrasive wear behavior of bamboo –glass fiber reinforced epoxy composite

Reference					Actual	Error	Limitation
Sl. no	**Fiber content**	**load**	**Sliding velocity**	**Wear rate**	**Wear rate**		-Specimen porosity -specimen adjustment On test machine -specimen preparation
1	0	5	0.837	0.0000149	0.0000147	1.34%	
2	0	5	1.256	0.0000160	0.0000158	1.25%	
3	0	5	1.675	0.0000238	0.0000235	1.26%	
4	10	10	0.837	0.0000132	0.0000130	1.51%	
5	10	10	1.256	0.0000164	0.0000161	1.81%	
6	10	10	1.675	0.0000217	0.0000214	1.38%	
7	20	15	0.837	0.0000085	0.0000084	1.17%	
8	20	15	1.256	0.0000107	0.0000105	1.86%	
9	20	15	1.675	0.0000136	0.0000134	1.47%	
10	10	15	0.837	0.0000160	0.0000157	1.87%	
11	10	15	1.256	0.0000184	0.0000181	1.63%	
2	10	15	1.675	0.0000218	0.0000215	1.37%	
13	20	5	0.837	0.0000072	0.0000071	1.38%	
14	20	5	1.256	0.0000082	0.0000081	1.23%	
15	20	5	1.675	0.0000143	0.0000141	1.39%	
16	0	10	0.837	0.0000199	0.0000196	1.5%%	
17	0	10	1.256	0.0000216	0.0000213	1.39%	
18	0	10	1.675	0.0000258	0.0000255	1.16%	
19	20	10	0.837	0.0000096	0.0000095	1.0%	
20	20	10	1.256	0.0000110	0.0000108	1.81%	
21	20	10	1.675	0.0000127	0.0000125	1.57%	
22	0	15	0.837	0.0000570	0.0000566	1.0%	
23	0	15	1.256	0.0000645	0.0000643	1.23%	
24	0	15	1.675	0.0000713	0.0000711	1.16%	
25	10	5	0.837	0.0000136	0.0000134	1.41%	
26	10	5	1.256	0.0000121	0.0000119	1.1%	
27	10	5	1.675	0.0000222	0.0000221	1.16%	

4.10 Discussion

Bamboo fiber has been developed day by day due to their superior properties. In this part, the Investigation of the abrasive wear behavior of bamboo composite with filler material of PTFE randomly oriented of different PTFE weight fractions are carried out.

4.10.1 Experimental Result

4.10.1.1 Weight Loss

The above result shows the comparison between % of PTFE composition verses weight loss, wear and coefficient of friction of composites with different loads at 2m/s and 4m/s sliding velocity. it is observed that the BPC +4% PTFE at 2m/s sliding speed shows lower weight loss, wear and coefficient of friction when compared to pure composites and other composites due to PTFE impacts on the matrix and reinforcements

4.10.1.2 Wear Rate

The result shows the specific volumetric wear rate as a function of applied load, sliding distance, and sliding speed, the specific wear rate decreases with increasing grit loads, sliding distance for all the test sample/specimen. The specific wear rate is very high initially for load 30N and sliding speed 4m/s. The wear rate decreases when tested against load 15N, sliding speed 2m/s and 4%PTFE. This is followed by the load, sliding distance and wt% PTFE compression respectively

4.10.1.3 Wear resistance

The result shows the results of the three different composite having different PTFE content. From the results the composite having 4% PTFE content shows greater wear resistance comparing with the other. This is because PTFE material is good friction and wear resist material by itself and modifying the bamboo properties

4.10.2 Taguchi result

Interaction Effect of Parameters on Wear factor

The figure shows interaction effect of load and velocity of sliding on wear at maximum sliding distance 1000m. The interaction effect of load and sliding distance on wear at maximum velocity 4m/s and interaction effect of velocity of sliding and sliding distance on wear at maximum load 30N kg

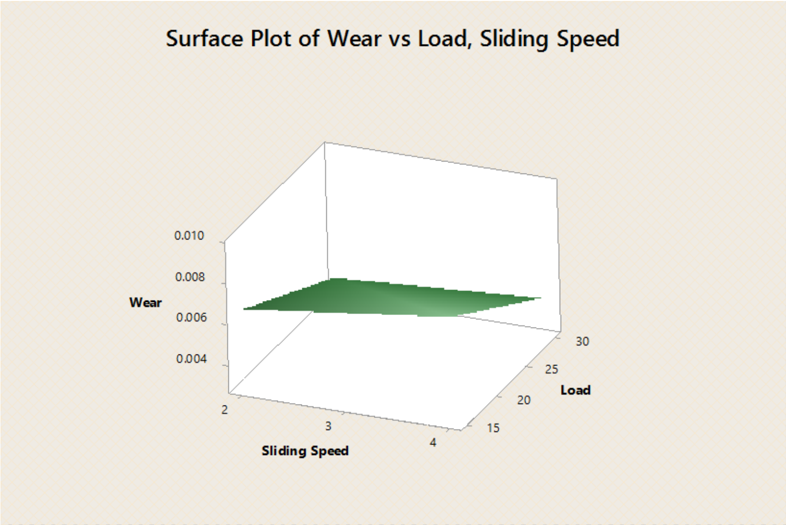


Figure 28Graph of Interaction of Load and Velocity of Sliding with Wear result

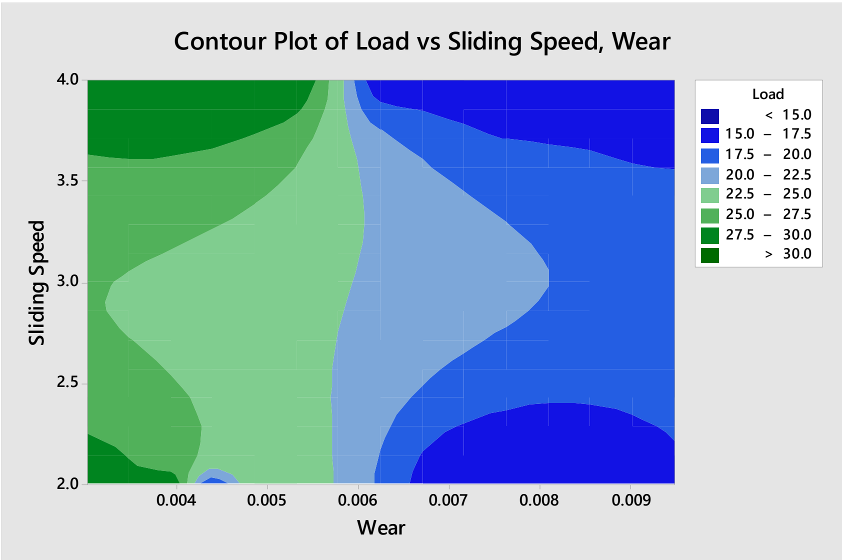


Figure 29 Contour plot for wear rate versus sliding speed and applied load

4.10.3 Comparison test

The reference working on abrasive wear behavior of bamboo-glass fiber reinforced composite test result compared with the modified abrasive wear test machines with the same composite material. From table 31 the wear properties result is closer with the standard test machine results, there is an error which around 1.37 %. This result is the mean value of 27 run of tests

CHAPTER FIVE

5 CONCLUSION & RECOMMENDATION

From the experimental investigation on bamboo fibers reinforced composites with PTFE the following conclusions have been arrived

BPC reinforced composite +PTFE has been fabricated successfully by using hand lay-up technique for low cost, light weight and eco-friendly and the modified abrasive wear test machine is successfully fabricated and conducted the reference composite material for authenticate the research work result is accurate

- The composites with defined constitutes of fiber, filler and matrix the wear rate proportionate due to increase in the normal applied load and sliding velocity, the coefficient of friction increase on 0%PTFE composite. The results demonstrate that there is a direct relationship between the sliding distance and wear rate as the sliding distance increases proportionately wear rate increased
- Addition of filler (PTFE) material causes an increase in hardness and wear resistance, Wear of pure BPC without filler is decreased the hardness properties and increase wear result
- After addition of reinforced material the sliding wear decreases significantly or says that weight loss is decreasing as 4 % PTFE addition is increasing as compared to matrix composite (0% PTFE)
- It is observed that the addition of PTFE filler to BPC improves wear resistance significantly as compared to pure composite
- It is found that the composites BPC + 4%PTFE shows lower weight loss, low wear and coefficient of friction with different loads at 2m/s sliding velocity when compared to pure composites
- The best possible process parameters, which minimize the volume loss was the factors of combinations of bamboo fiber and PTFE. That was, the experiment carried out at 15 N load against 2m/s sliding speed under the total slide of 1000m distance would lead to a minimum volume loss
- The above result is correct and actual in 98.63 % ,there was an error during the comparison test composite material but the error is very small and they may cause the composite fabrication, specimen void and arrangement of test machine

5.1 Future work

There is a very wide scope for future researchers to investigate this research area. This work can be further inclusive to study other aspects of such composites like use of PTFE fillers for development of different hybrid composites and evaluation of their abrasive wear behavior and the resulting experimental findings can be similarly study.

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