DEVELOPMENT AND EVALUATION OF A GREEN COMPOSITE MATERIALS FROM NATURAL FIBERS

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A thesis submitted to the Department of Mechanical & Production Engineering (MPE) in partial fulfilment of the requirement for the degree of

Master of Science in Mechanical Engineering

بسم الله الرحمن الرحيم

Department of Mechanical & Production Engineering (MCE)

ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)

24 December, 2019

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DEDICATION

This thesis is dedicated to my beloved parents, wife, children and all my well wishers helping me to accomplish this work.

ACKNOWLEDGEMENT

The author expresses gratefulness to the almighty Allah (SWT) for His blessings, which enabled to complete this thesis successfully.

The author expresses gratitude to his supervisor Dr. Md. Anayet Ullah Patwari, Professor, Department of Mechanical and Production Engineering (MPE), Islamic University of Technology (IUT) and Co-Supervisor Prof. Dr. Qumrul Ahsan of UTeM, Malaysia for their continuous guidance, helpful suggestions and supervision at all stages of this thesis work. Special thanks to the B. Sc. in Engineering (Mechanical) students of IUT, who helped the author with various research and analysis work. Also, the author expresses sincere thanks to Md. Shakhawat Hossain, Senior Operator (CAM lab), Md. Matiar Rahman, Senior Operator (Machine shop), Md. Rajaul Karim, Operator (Machine shop), Md. Mottalib (Machine shop) for their useful suggestions and cooperation which made it easier for me to carry out my experiments.

The author expresses his thanks to IUT authority for financial assistance to conduct the research and granting permission for using the lab facilities of the university. Special thanks to all the Faculty and Staff members of the Mechanical and Production Engineering Department (MPE), Islamic University of Technology (IUT) for their support and cooperation. Author is grateful to Dean, UTeM, Malaysia and DUET authority for allowing conducting some analysis in different laboratories of DUET and UTeM.

Finally, the author is indebted to his family members for providing the financial and mental support in pursuing the Masters degree and research work and without whose support none of this would have been. Although Author has given my best effort to complete this thesis paper, I seek excuses if there is any mistake found in this report.

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ABSTRACT

In the area of technological advancement, environmental awareness are always drawing the attention of the scientists for eco-friendly and recyclable products. Different kinds of composite materials are available in the world fabricated from different materials. Natural composite fabricated from natural fiber are attracted the researchers because of their unique characteristics like bio-degradable, availability, non-toxic nature etc. In this study, a new composite materials of epoxy matrix reinforced with three different fillers (banana fiber, jute fiber and jute fabricate bio-degradable polythene) have been prepared by different method namely die molding process, hand-lay method and vacuum infusion method. Different composite materials have been made using different types of fiber size, fiber types using epoxy resin. Assessment has been made to find out the different mechanical properties and comparison has been made accordingly to find out the suitable method for the fabrication of the green composite materials.

A mathematical model has been developed for the prediction and optimization of composite materials. The centre composite design protocol along with the response surface method has been adopted for compression testing of composite materials. A quadratic model has been proposed to predict the compressive load of the molded green composite materials within five levels of the two process parameters. Statistical tools are used for best fitting of the developed quadratic model and desirability analysis is coupled with it in order to find out the optimum process condition for which maximum compressive load is achieved. FEM simulation has also be made to predict the dynamic behavior of the fabricated composite and comparison has been made accordingly. From the experimental analysis, it has been observed that most of the conditions the fracture occurs at the middle position of the specimen and maximum tensile strength of 34.61 MPa obtained from the specimen using double layer hand lay method whereas specimen obtained from hand lay using small particle has the lowest tensile strength of 4.31 MPa considering all the methodological approaches. In compression testing the fabricated green composite cylinder can withstand maximum compressive load of 38KN.

NOMENCLATURES

H-L	Hand-Lay method
VIM	Vacuum Infusion Method
SEM	Scan Electron Micro-scope
UTM	Universal Testing Machine
W	Percentage of water absorption
M	Mass of the composite

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CHAPTER-ONE

INTRODUCTION

1.0 Introduction:

Natural fibers are eco-friendly, inexpensive and renewable resource which is readily available in nature and fiber has unique characteristics like low density, high specific properties and good mechanical properties. The applicability of natural fiber reinforcement composite is going to increase because those inherent properties of natural fibers that meet the expectations of the global market especially for those industries who are concerned in weight reduction or light weight products, i.e. automotive, aerospace and heavy machineries manufacturing [1–2].

Composite materials are simply mixture of two or materials. A composite material is one which is composed of two or more components combined in a way that allows the materials to stay distinct and identifiable. Both components add strength to a composite, and the combination often compensates for weaknesses in the individual components. In a composite material the components doesn’t completely blend or lose their individual identities. Rather they combine together and form a product which is improved then them. Most composites are made up of just two materials. One material (the matrix or binder) surrounds and binds together a cluster of fibers or fragments of a much stronger material (the reinforcement).composites can be called FRP (Fiber-Reinforced Polymer). Because they are made from polymer matrix that is reinforced with an engineered, man-made or natural fiber or other reinforced material. In composite material the matrix protects the fiber from environmental and external damages and also transfers the load between the fiber. In turn the fiber provides strength and stiffness to reinforce the matrix. A composite materials formation from Fiber or filament reinforcement along with the matrix is shown in Figure 1.1.

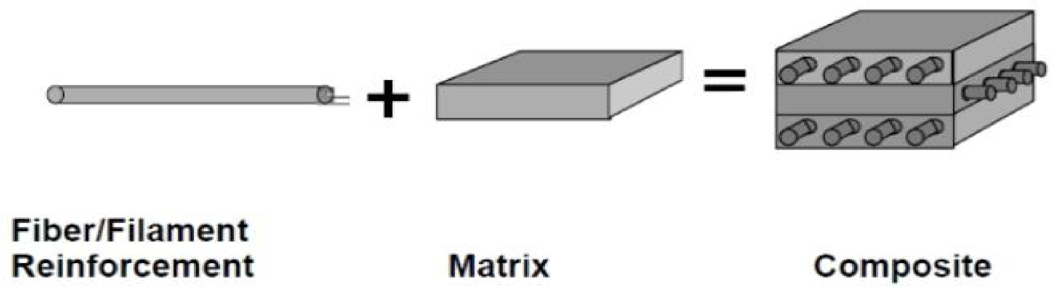


Figure 1.1: Formation of composite material

1.1 Research Philosophy: In our modern society people are getting more conscious about our environment and ecology. That's why more and more eco-friendly materials are used worldwide. As a result demand of products made of natural fibers is on the rise. They are good for our environment because after their usage they can be recycled which reduces the risk of environment pollution. Composites are improving the design process and end products across industries, from aerospace to renewable energy. Each year composites continue to replace traditional materials like steel and aluminum. Few useful characteristics of composite materials are given below:

- Composites have a high strength-to-weight ratio
- Composites are durable.
- Composites open up new design options.
- Composites are now easier to produce

In this research, a novel technique has been adopted for the fabrication of a new composite using two different types of natural fibers namely jute, banana and one bio-degradable natural fiber originated polythene. Detailed assessment has been made to find out the different mechanical properties of the fabricated green composite. Effect of different process variables on performance evaluation has been studied to investigate the applicability of the developed green composite materials.

1.2 Objective with Specific Aims:

(i) To fabricate a new green composite material composed of banana fiber, jute fiber and jute fabricated biodegradable plastic.

(ii) To investigate the effect of fiber size, and ratio of fiber-epoxy on fabricated material strength using compression, tensile, bending and impact test.

(iii) To develop a mathematics model for the prediction of fabricated composite strength in terms of process parameters using centre composite design with five level factors.

(iv) To investigate the behaviour of the composite fiber using finite element simulation and compare with physical parameter.

(v) To optimize the process parameter using couple algorithm by Desirability-RSM technique.

1.3 Possible Outcomes:

(i) A new green composite material will be fabricated for automotive and other industries.

(ii) A simulation based method will be developed for green composite and possibility of some other new composite material may be explored using the developed model.

(iii)A new optimization and mathematical model will be formulated for the prediction of fabrication of different composite materials.

1.4 Significance and Benefits of the Research

The research will have significant benefits in terms of industrial applications and cost savings. In the past, composites of coconut fiber/natural rubber latex were extensively used by the automotive industry. However, during the seventies and eighties, newly developed synthetic fibers due to better performance gradually substituted cellulose fibers. For the past few years, there has been a renewed interest in using these fibers as reinforcement materials, to some extent in the plastic industry. This resurgence of interest may be attributed to the increasing cost of plastics and the environmental aspects associated with using renewable and biodegradable materials From commercial and technological points of view, cotton, kenaf, sisal, flax, palm, coir, arecanut, jute and banana fibers acquire utmost significance, since reinforced plastics, strings, cords, cables, ropes, mats, brushes, hats, baskets and fancy articles such as bags are manufactured with those fibers. The outcome of this research will help to get a product with low specific weight, resulting in a higher specific strength and stiffness than glass fiber. This research therefore will develop and apply a new technique of introducing a new natural based composite with specific aims to improve the outputs.

1.5 Outline of the Methodology: The steps of research methodology are discussed below:

Step: 1: Selection of raw material (Jute, Banana, Jute bio-degradable plastic) which is mostly good in all properties and easily available. After selection of the different raw material, fabrication will be done by three different method namely hand layup process, casting process and vacuum assisted resin infusion process.

Step 2: Fabricated composite materials will be tested as per ASTM standard using tensile test, compression test, bending test and Impact test.

Step: 3. Mathematical model will be developed using statistical approach for the prediction of composite materials behavior in terms of fiber length and ratio of the resin and fiber composition. An optimization technique will be proposed by coupled algorithm using desirability approach and genetic algorithm.

Step 4: A finite element simulation using ANSYS will be made for calculating the structural behaviour of the proposed fabricated composite materials using four layer composite structures.

Step 5: Final comparisons will be made based on the actual and predicted results.

Step 6: An optimization technique will be proposed by coupled GA-RSM technique.

1.6 Thesis Organization

This thesis is arranged in five chapters. All the details about the study with general information and research background are described in those chapters. A brief summary of each of the chapters are as follows:

The first chapter is the introduction. It contains general description of the process and theory related with the study. The parameters necessary for the study with formulas are described. It also contains general information about the basics of composite materials along with problem statement, methodology, objective and benefits of the study.

In chapter two the background of the current study along with the research of contemporary scientists in related fields is described. It gives an idea about the potential of the current project and relates it with the work of others.

Chapter three is titled as experimental details. In this section the detailed description of each of the equipment used in the study is provided with specification and pictures. The techniques used in the study for measurement of fiber diameter, fiber strength, compressive load, tensile load calculation are also described in this section. The different process and method used in this study has also discussed in this chapter.

The Fourth chapter is the results and discussions. This chapter contains the graphs generated based on the experimental data and comparative analysis among different experimental conditions.

Chapter Five is the conclusions and recommendations where the decisions derived from the study are elaborately stated along with the scope of future work on this current study.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A detail related literature survey has been performed to find out the different related works on composite materials specially on natural fiber composite. A critical analysis of the existing works conducted by different researchers on natural fiber composite. The survey of literature pertaining to the scope of the present work has been done on literature review of past experimental works and their limitations on natural fibers.

2.2 Matrix formation of composite Materials: The key role of the matrix is to bind the reinforcement together so that the applied stress is distributed among the reinforcement and to protect the surface of the reinforcement from being damaged. They plays a vital role for the formation of composite materials. So high bonding strength between matrix and the fiber is ensured.

Composites are classified according to their matrix phase:

- Polymer Matrix Composites (PMC's)
- Ceramic Matrix Composites (CMC's)
- Metal Matrix Composites (MMC's)

2.2.1 Metal Matrix Composites (MMCs): Examples of matrices in such composites include aluminum, magnesium and titanium. The typical fiber includes carbon and silicon carbide.

Metals are mainly reinforced to suit the needs of design. For example, the elastic stiffness and strength of metals can be increased, while large co-efficient of thermal expansion, thermal and electrical conductivities of metals can be reduced by the addition of fibers such as silicon carbide.

2.2.2 Ceramic Matrix Composites (CMCs): Examples of matrices such as alumina, calcium, alumino silicate reinforced by silicon carbide. The advantages of CMC include high strength, hardness, high service temperature limits for ceramics, chemical inertness and low density. Naturally resistant to high temperature, ceramic materials have a tendency to become brittle and to fracture. Composites successfully made with ceramic matrices are reinforced with Silicon carbide fibers. These composites offer the same high temperature tolerance of super alloys but without such a high density. The brittle nature of ceramics makes composite fabrication difficult. Usually most CMC production procedures involve starting materials in powder form. There are four classes of ceramics matrices: glass (easy to fabricate because of low softening temperatures, include borosilicate and alumino silicates), conventional ceramics (silicon carbide, silicon nitride, aluminum oxide and zirconium oxide are fully crystalline), cement and concreted carbon components.

2.2.3 Polymer Matrix Composites: Most commonly used matrix materials are polymeric. The reason for this is twofold. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and doesn’t require high temperature. Also equipments required for manufacturing polymer matrix composites are simpler. For this reason polymer matrix composites developed rapidly and soon became popular for structural applications. Composites are used because overall properties of the composites are superior to those of the individual components for example polymer/ceramic. Composites have a greater modulus than the polymer component but aren’t as brittle as ceramics.

<u>2.3 Reinforcements:</u> The role of reinforcement in composite materials is primarily to add mechanical properties to the material such as strength and stiffness. As they do some property enhancement in composite materials they can be of any shape according to the composite we need. Figure 2.1 shows the matrix and dispearse phase of composites.

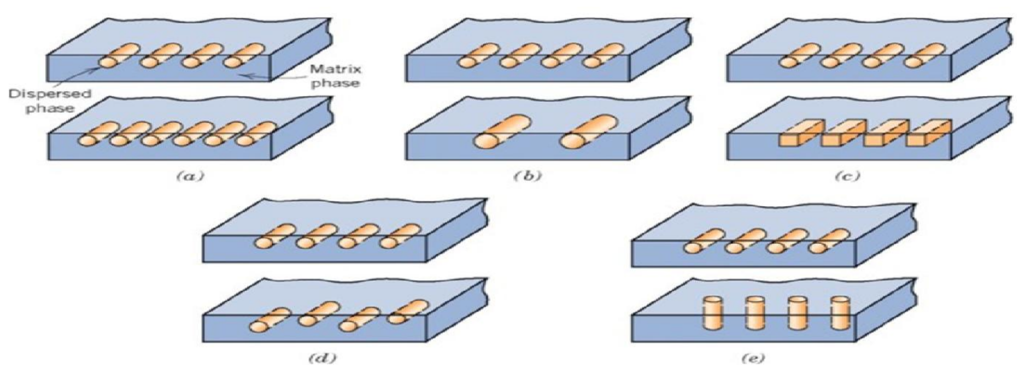


Figure 2.1: Matrix and dispearse phase of composites.

Composite materials can also be classified in many ways. Mainly there are three kinds of composite materials as shown in Figure 2.2. They are:

1. Particle reinforced composites.
2. Fiber reinforced composites.
3. Structural composites.

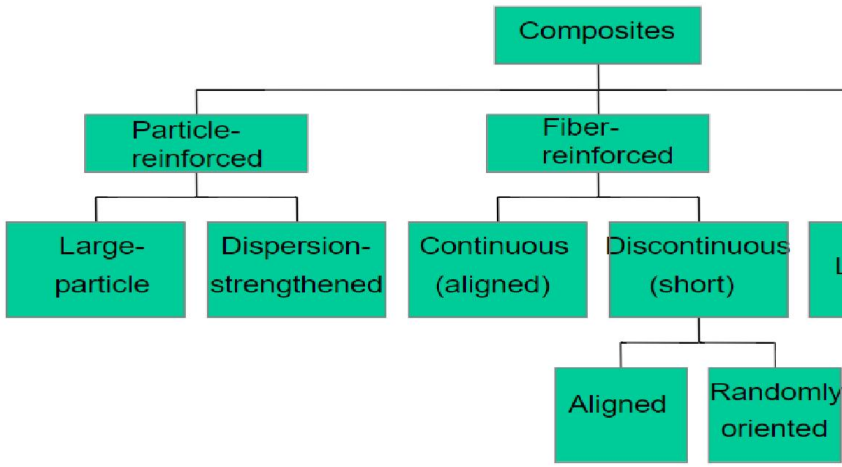


Figure 2.2: Clafficiation of different composites.

2.3.1 Particle reinforced composites : As particles are harder and stiffer then the matrix materials they increase modulus of the matrix. To decrease the permeability of the matrix. These particles are used to produce inexpensive composites. Particles can be found in micro, macro or Nano-size is shown in Figure 2.3.

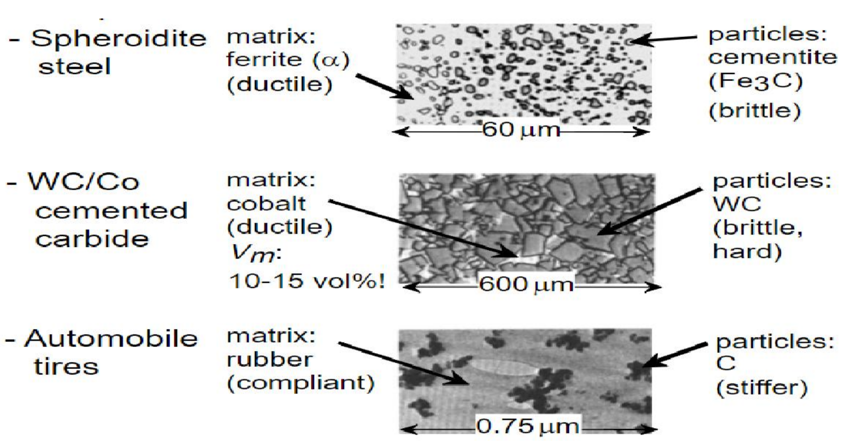


Figure 2.3 Particle Reinforced Composite

2.3.2 Fiber reinforced composites : These composites provide significant strength to their material. They have better mechanical properties then particle reinforced composites. But in these types the bond between the matrix and the fiber is essential for the distributiom of load.

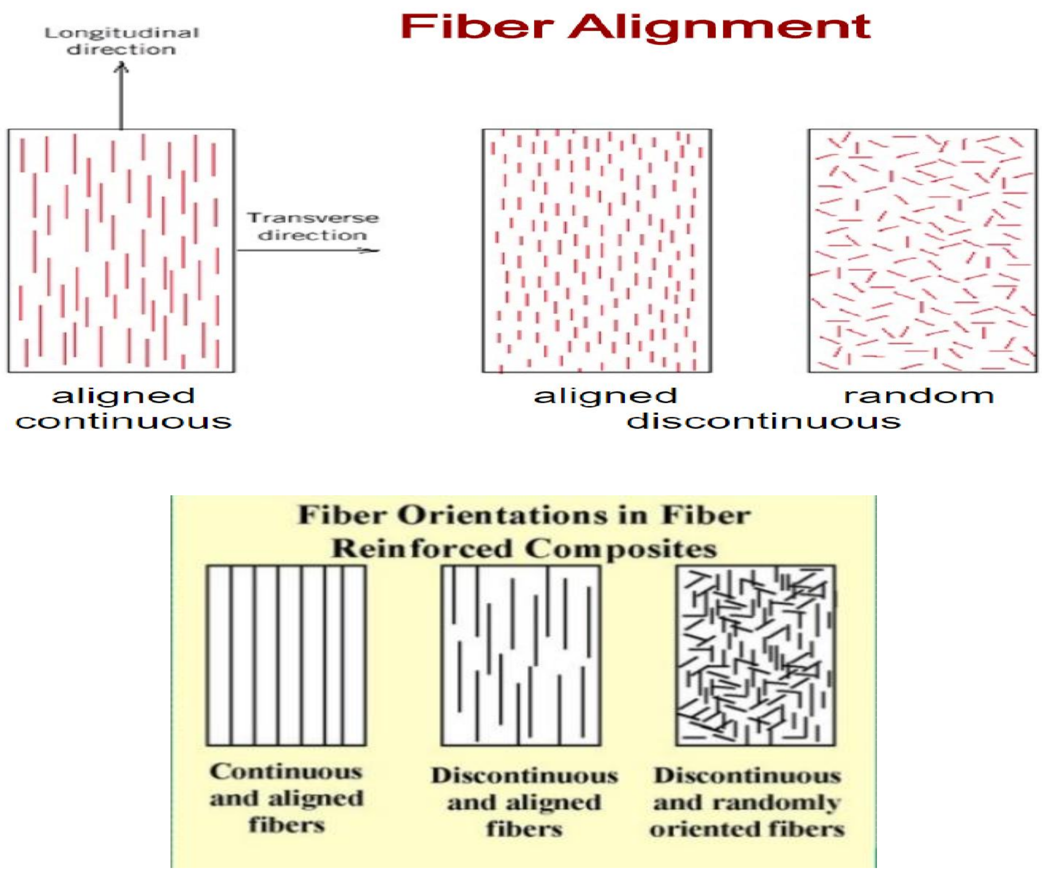


Figure 2.4 Fiber reinforced composites

2.3.3 Structural composite: In this types of composite the properties are dependent on the constituent and the geometry.

2.4 Fabrication of Natural Fiber: Different types of natural fibers like jute, banana, wood are very much available in our environment. Easy availability and expense always attracted the researchers to do some works on natural fiber based composite materials to pave the way in the modern civilization which is eco-friendly. The extraction of natural fibers can be different type. Different researchers have used different types of processes to extract fibers from trees or other natural resources. Different types of fiber are extracted from different sources like plant, animal. Fibers collected from different sources like wood, stem, leaf, see, fruit, grass etc are considered as natural or lignocelluloses fibers. Classification of fibers from different sources is shown in Figure 2.5.

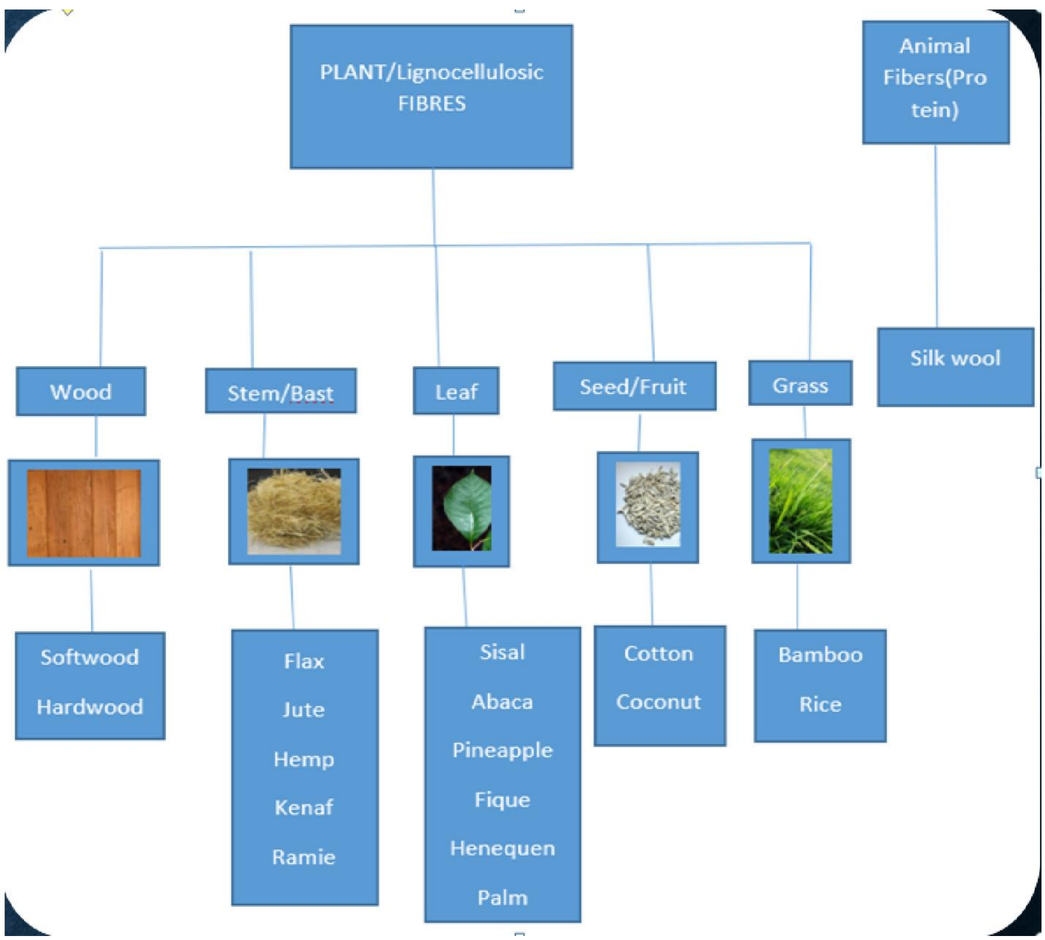


Figure 2.5: Classification of fibers from different sources

Some of the natural fibers are extracted from sisal, banana, coconut, jute, palm fibers from various local sources. Some extraction procedure is listed below:

Vakka The source of this fiber is the foliage of the tree, which falls on to the ground, when it ripens. It contains leaves with their stem in the form of a sheath. The sheath is separated from leaves and leaf stem and dried for two to three days in shade. It is then immersed in a water-retting tank for 15 days. The sheath contains layers of fiber throughout its thickness. In the first 15 days, the top layers on either side of the sheath loosen. Then, these layers are removed, washed and immersed in another water-retting tank for three more days. Later, they are removed, hand rubbed and rinsed in sufficient water. The water retting process takes 18–25 days to extract fibers completely. The fiber extraction is simple and economical, and requires no other process, since, the gums present in the sheath dissolve in water completely.

Date (L) The pinnate leaves and surface layers of the stalks are chopped off with a knife and the resulting stems are dried in the shade for five days. The stems are beaten with a thick round mallet until the fleshy matter is dusted off. The resulted fiber is kept in a water retting tank for three days. Then, the fibers are removed and scraped with sharp knife to remove any foreign matter. Date (A) The fiber is collected from amplexicaul, the sheathing leaf base, which surrounds the stem. It has a netted in structure, which is covered by soft or ground tissues. The amplexicaul is carefully collected from the tree. It is dried in shade at room temperature for a period of two days in order to remove any excess moisture content. The pulp (parenchyma) which is present on the individual fiber is removed by combing. Finally, the fiber is scraped to remove the pulp completely.

Bamboo (mechanical extraction) The node portions and very thin layer of exodermis (bark) of the bamboo are removed and the rest of the hollow cylindrical portion of culm is taken for extracting the fiber. The cylindrical portion of culm is peeled in the longitudinal direction to make strips of 0.5–1.5 mm thick and about 10 mm width. The strips are bundled and are kept in water for three days in order to soften them. After removing these strips from the water, they are beaten gently in order to loosen and to separate the fiber. The resulting fiber bundle is scrapped with sharp edged knife and combed. The process of combing and scrapping is repeated until individual fibers are separated. **Bamboo (Chemical extraction)** The manually decorticated bamboo fibrous strips are dried off in the sun. These strips of fiber removed from the culms contain tissues and gums. After decorticating, the dry fiber is extracted by means of a chemical process of decomposition called degumming, in which the gummy materials and the pectin are removed. The method of degumming designed by Gangstad et al. cited by Maiti [18] has been taken as a basis for chemical extraction. The chemical extraction process yields about 33% of fiber on weight basis

Extraction of Banana Fiber from bark of Banana plant. The extraction of the natural fiber from the plant required can be done either by manual approach or by automated approach but is absolutely necessary to take certain care to avoid damage. Adopting the initial manual and mechanical approach, the banana plant sections need to be cut from the main stem of the plant and then rolled lightly to remove the excess moisture. Impurities in the rolled fibers such as pigments, broken fibers, coating of cellulose etc. need to be removed manually by means of comb, and then the fibers is cleaned and dried. This mechanical and manual extraction of banana fibers is very tedious, time consuming, and caused damage to the fiber. Consequently, this type of technique cannot be recommended for industrial application. A special machine may be designed and developed for the extraction of banana fibers in a mechanically automated manner.

2.5 Overview

A composite material is a material which is formed by the two or more other materials. Many researchers had worked with the composite materials using natural fibers. N. Venkateshwaran et. al [1] found that due to low density a banana fiber reinforced composite holds high tensile strength, high tensile modulus and low elongation at the break point. As a result, banana fiber reinforced composites have good potential at various sectors like construction, automotive, machinery etc. Banana fiber and its composites can be further attractive if a suitable cost-effective design method of fiber separation and its composite production may increase its application to a greater extent. K. Kannan et. al [2] used in their study banana and jute fiber reinforced vinyl ester composite in treated and untreated conditions and found that untreated composite natural fiber has good mechanical properties compared to treated one. K. Bakkal et. al [3] investigated the mechanical properties for different forms glass fibers composite laminates reinforcement and found that glass fiber has positive hybridization effect and increased tensile strengths, elastic modules and impact strengths in laminar hybrid composites. R.H. Hu et al. [4] made a review study on Natural fiber reinforced composites materials that are used in many industries specially on automotive industry considering the superiority of natural fiber reinforced composite materials to glass fiber reinforced composite material, and its recent developments. R. R. Firly et al [5] in their study evaluated the flexural properties of Bambu Tali (Gigantochloa Apus) composite for its applicability in industries. C. Umachitra et al. [5] studied the applicability of different surface treatments techniques (NaOH, SLS, $KMnO_4$) for the improvement of mechanical properties of the Banana/Cotton Woven Fabric Vinyl Ester Composite. P. P. Gohil et.al.[7] made an experimental investigation for the evaluation of mechanical property of unidirectional banana reinforced polyester composites. It is becoming increasingly difficult to ignore the important role of natural fiber composites in advanced technology.

Also other researchers have worked on the properties of banana reinforced composite materials. Changes in temperature and moisture can drastically effects the properties of a composite material. According to Lai Botsis et. Al [8] moisture absorption hampers the physical and mechanical properties of different polymers. They experimented on different polymers and found out that there are severe effects of temperature and moisture on the physical and mechanical properties of the polymers. Few researches [9] experimented that fibers like banana can be affected by the change in moisture contents and temperature. They also found that the tensile strength of these kind of fibers can be affected temperature higher then 100-degree. Li [10] have worked on evaluation and correlation of the compressive strength, flexural strength, toughness, specific gravity and water absorption rate of hemp fiber reinforced composites (HFRC) with various compositions. The water absorption ratio and the linear specific gravity of the composite material gradually decreases by the addition of the hemp fiber with concrete matrix. They observed that the fiber content by weight is very important. Because it affects the compressive and flexural strength of HFRC. Hemp fiber has better reinforcement property while increasing tensile property and strong toughness in an alkali environment [11-12]. The natural fiber reinforced composites were fabricated with hemp/paper/epoxy and flax/paper/epoxy by adding the paper on the both surfaces of hemp or flax unidirectional fibers and the products are tested under tensile loading conditions [13]. After that tensile properties of those composites have been compared with unidirectional composites with absence of paper between layers of composites. They had found out that the unidirectional natural fiber composite with one or two layers of thin paper holds the minimum variability in tensile strength and elastic modulus. The tensile strength and delamination characteristics of laminated composites with paper were improved when compared to without paper unidirectional composites and the modulus are slightly lessened when compared to epoxy composites. Banerjee et al. [14] have analysed the micromechanics structure of hybrid composites by using FEA software (ABAQUS/CAE 6.9-2). Various hybrid laminates are prepared by using short carbon fibers and glass fibers which is reinforced with polypropylene for the study. They have found out that the elastic constant and strength properties have evaluated by using analytical formula and the results are compared with FEA results. They have experimented the negligible variability in elastic constants and longitudinal strength properties. Also their research showed that the significant variability in transverse strength properties.

There are many researchers who have reviewed the experimental data about hybrid composites and found out that rule of hybrid mixtures is the prime factor to predict the mechanical properties of unidirectional interplay hybrid composites [15-18]. Ramesh et al. [19] also carried out an experiment of evaluation of the tensile and flexural properties of hybrid composites and compared the results. Form the experiment, they have found out that the combination of natural fibers such as sisal/jute with glass fiber improve the tensile and flexural strength and these composites play a vibrant role in the field of engineering and technology. They suggested that these hybrid composites can be used for medium strength applications for day to day life.

The mechanical properties of natural and synthetic fibers reinforced polymer composites having various fiber volume were evaluated by Ramesh et al. [20]. The result indicated that, there is the noteworthy development in mechanical properties and the process of hybridization decreases the risks related to the environmental concern. Sapuan et al [21] fabricated the composites by using banana fiber as a waste product of banana cultivation because it is easily available in tropical countries like malaysia and south india and they have cultivated in huge number there. This fiber has different advantages such as holding high mechanical strength when compared to the synthetic fibers. For the experiment they have arranged three samples with different geometric size and estimated the maximum stress value and young's modulus. They also determined the maximum deflection under the maximum load conditions.

Zainudin et al. [22] experimented on the thermal deprivation of banana pseudo-stem (BPS) filled un-plasticized polyvinyl chloride (UPVC) composites. The result of the experiment indicated that the thermal constancy of acrylic modified BPS/UPVC composites was greater than that of original BPS/UPVC composites. Samal et al. [23] also fabricated and evaluated the properties of banana and glass fiber reinforced polypropylene (BSGRP) composites. From his study, they have found out that the BSGRP composites in the presence of MAPP is cost effective had improved storage modulus, crystallization and thermal degradation temperature, enhancement in melting point, and optimum viscosity. From the degradation studies of the polycaprolactone banana fiber reinforced composites it has been conducted and concluded that the banana fibers treated with alkali solution resulted in an increase in surface roughness, and increase in density [24-25]. Shaktawat et al. [26] worked on the temperature necessity of thermo-mechanical properties of banana fiber reinforced polyester composites and found the alkali treated composites had the maximum phase transition temperatures. Zaman et al. [27] investigated the effect of acrylic monomer and starch on the fiber/low density polyethylene (LDPE) composite materials. To do so they made banana fiber-reinforced low-density polyethylene composites by using the fibers treated with monomer solution along with 2% Darocur-1173 photo initiator and cured under UV radiation. From their experiment they found that there was an amazing improvement on properties of the composites after monomer treatment.

Jiang et al. [28] studied PVC-based WRPCs with L and S type GF and from their experiment they have found that impact strength improved upon adding 5% of type LGF but not upon adding type S. Kitano et al. [29] also studied the effects of long and short GF, along with other natural fibers, on the properties of high-density polyethylene (HDPE)-based composites containing 20 vol % of fibers. They found that tensile strength decreased upon growing the fiber content when long fibers were used, while the short fibers did not show this pattern. For this they did not use any coupling agent. Rozman et al. [30-31] worked on the properties of a hybrid of GF and empty fruit bunch in a PP matrix and found substantial increases in properties when they used suitable coupling agents and when the fibers were subjected to an oil extraction pre-process before actual molding. Arbelaiz et al. [32] experimented the flax-fiber/GF hybrid composites in a PP matrix, differing from the GF ratios from 0% of fibers to 100%, and found developments in properties when MAPP was used as a coupling agent. In all these experiments, the amount of GF used was usually quite high.

The and Liao [33] worked on hybrid bamboo-GF composites in a PP matrix and found MAPP to be an good coupling agent. The GF content ranged from 0 to 20%. They examined the mechanical properties of bamboo-GF-reinforced polypropylene matrix hybrid composites (BGRP) both before and after the environmental aging. They initiated that before environmental aging, both modulus and strength in tension and flexural tests increased with incorporation of

GF, while the mechanical properties reduced after environmental aging. From their study they strongly suggested that hybridization of GF could improve sturdiness of bamboo fiber-reinforced polypropylene (BFRP). From their experiment it is also found that the fiber length, orientation, and distribution in the composites were vital variables on the mechanical properties of the composites. From their experiment they also reported that the moisture sorption and strength reduction are further blocked by using maleic anhydride polypropylene (MAPP) as a coupling agent in both types of composite system. [34]. Aseer et al. [35] prepared chemically treated banana fiber composites and examined the physical, thermal and morphological properties of that composite. Their experiment indicated that, the NaClO treated banana fibers showed good physical properties and low moisture absorption characteristics with respect to unprocessed raw banana fiber. Their study showed that Chemically treated fibers have good adhesion with hydrophobic resins and improved crystallinity index of 71%. Also it was discovered that the percentage of weight loss in treated fibers is few compared with raw fiber which may be qualified to the removal of cellulose and hemicellulose while treating. Their surface treatment result indicated that preserved banana fibers are better option as reinforcement in the production of bio-composites.

Stocchi et al. [36] fabricated a laminated composite with four layers of jute woven fabrics. Their experiment impregnated in the resin matrix, the jute fabrics were treated with alkali in the biaxial tensile stress state. An important improvement of the mechanical stiffness was achieved in the composite under applied stress while the fibers treated with alkali. Pothan et al. [37] also made a woven fabric from banana and glass fibers for use in unsaturated polyester bio-composite. In their woven fabric, banana yarns were used for all of the warp yarns, while glass yarns comprised the weft yarns by alternating them with the banana yarns. Dhakal et al. [38] worked on the low velocity impact testing of hemp fiber reinforced composites for this they prepared unsaturated polyester resin and a needle punched non-woven mat of hemp fibers. It was confirmed in [38] that the total energy absorbed by the hemp fiber reinforced bio-composites was comparable to that absorbed by E-glass fiber reinforced unsaturated polyester composites. Cut natural fiber reinforced PP composites have been widely studied by different researchers to benefit from the cost and mechanical properties of these natural fibers. Zampaloni et al. [39] studied the fabrication of kenaf fiber reinforced polypropylene sheets that could be thermoformed for different applications using a compression molding process utilizing the layered sifting of a microfine polypropylene powder and chopped kenaf fibers. Wambua et al. [40] prepared kenaf fiber reinforced PP composites using compression molding by sandwiching PP film with kenaf mats, whereas Shibata et al. [41] fabricated the same composites from PP and kenaf fibers by the press forming of stacked layers of their mats. Then again, extrusion technology was also adopted to process chopped (50-80 mm) natural fibers with micron size PP powder [42].

Paiva Junior et al. [43] experimented using plain weave hybrid ramie-cotton fabrics as reinforcement in polyester matrix and showed the high potential of ramie fiber and weak contribution of cotton fiber as reinforcement in lignocellulosic fiber composites. Jacob and coworkers [44-45] also studied the mechanical properties and cure properties of sisal oil palm hybrid fiber reinforced natural rubber composites. In this study, banana fibers and sisal fibers were selected to hybridize and reinforce a polyester matrix to develop high performance and cost effective composites. The physical properties of natural fibers are mainly determined by chemical and physical compositions, such as structure of fibers, cellulose content, lumen size, microfibrillar angle, and degree of polymerization. When compared to other natural fibers, sisal and banana have good mechanical properties. The microfibrillar angle and lumen size of sisal fiber is higher than of banana fiber. Hence sisal fiber reinforced composites show comparatively high impact strength. Pavithran et al. [46] reported the impact strength of unidirectionally aligned sisal fiber/polyester composites. In general, the strength of a fiber increases with increasing cellulose content and decreasing spiral angle with respect to the fiber axis. The cellulose content of banana and sisal fiber is almost same, but the spiral angle of banana (118) is much lower than sisal (208). Hence the inherent tensile properties of banana fiber will be higher than sisal. The diameter of banana fiber is lower than that of sisal [47].

An analysis by Ismail et al. [48] on the effect of a silane coupling agent (Si69) on curing characteristics and mechanical properties of bamboo fiber filled natural rubber composites highlighted various aspects of this phenomenon. It was concluded that the presence of a silane coupling agent, Si69 improves the adhesion between the fiber and rubber matrix and consequently enhances the tensile strength, tear strength, hardness and tensile modulus. Ismail et al. [49] examined the curing characteristics and mechanical properties of bamboo fiber reinforced natural rubber composites, as a function of fiber loading, and phenol formaldehyde and amethylenetetramine bonding agents. It was concluded that adhesion between the bamboo fiber and natural rubber can be enhanced by the use of bonding agents. As a result, the tensile modulus and hardness of composites increase with increasing filler loading and the presence of bonding agents.

Yao and Li [50] carried out a thorough investigation into the preparation and flexural properties of bamboo fiber reinforced mortar laminates. The laminate was a sandwich plate combined with reinforced bamboo plate and extruded PVA fiber reinforced mortar sheet. The results of the investigation show that the flexural strength values can be improved to greater than 90 MPa for laminates with reformed bamboo plate on the bottom, which formed a tension layer and the fiber-reinforced mortar sheet on the top that acts as compressive layer. Among the well-known natural fibers (jute, coir, straw, banana, etc.), bamboo has low density and high mechanical strength. The specific tensile strength and specific gravity of bamboo are considerably less than those of glass fibers. However, cost considerations make bamboo an attractive fiber for reinforcement. Okubo et al. [51] undertook an in-depth analysis into the mechanical properties of polypropylene composites using bamboo fiber, extracted by steam explosion technique. The tensile strength and modulus of the polypropylene based composites increase about 15% and 30%, respectively due to better impregnation and reduction of the number of voids, compared to those of fibers that were mechanically extracted. Thwe and Liao [52] examined the effect of fiber content, fiber length, bamboo to glass fiber ratio, and coupling agent (maleic anhydride polypropylene) on tensile and flexural properties of bamboo fiber reinforced polypropylene (BFRP) and bamboo-glass fiber reinforced polypropylene hybrid composite (BGRP). It was shown that hybridization with synthetic fibers is a viable approach for enhancing the mechanical properties and durability of natural fiber composites.

Natural fiber composites have better formability, abundant, renewable, cost effective, possess tool wearing rates, thermal insulation properties, acoustic properties, sufficient energy requirements and safer towards health [53]. Many innumerable demerits such as hydrophilic in nature, poor fiber/matrix interfacial adhesion and poor thermal stability of natural fibers can be overcome by chemical treatment or compatibilizer which amended the adhesion between the fiber and matrix. Composite of polymers and kenaf fiber possess the variances and incomparability in terms of their polarity structures [54]. Based on the origin natural fibers are categorized as animal based and plant based. Animal-based fibers are wool, silk, etc. and natural fibers based on plant includes sisal, coir, ramie, jute, bamboo, pineapple and many more [54]. Lignocellulosic fibers possess many compensations of being financially reasonable to manufacture such as lightweight, eco-friendly, harmless to health, high stiffness and specific strength which provides a probable substitute to the synthetic or artificial fiber [55-56]. The reinforcing capability of the fibers mainly influenced by various aspects such as polarity of the fiber, mechanical strength of the fibers, surface appearances, and existence of reactive centres [57]. Moreover many of the natural fibers properties are administered by several factors such as climate, harvest, maturity, diversity, decortications, retting degree, fragmentation (steam explosion treatment, mechanical), fiber modification, technical and also textile processes (spinning and carding) [58]. In spite of these capable features shown by natural fibers certain major drawbacks are also underlined like water absorption, strength deprivation, lack in thermal stability lowered impact properties [59-60] but it has been found that these can be improved and overcome by hybridization with either natural or synthetic fiber. Bast fibers achieved from natural fibers such as hemp, flax, kenaf and jute have high specific strength with low density and are extremely concerned in several industrial applications [61]. Kenaf fibers are acceptable widespread throughout the world and even in Malaysia as the significant natural materials source paying towards the development of eco-friendly assets for the automotive, sports industries, food packaging and furniture [62], textiles, paper pulp, and fiber-board based industries [63]. Inferior thermal resistance are displayed by kenaf as compared to artificial or synthetic fibers such as (aramid, glass fibers) like all other natural fibers [64]. Kenaf is in an advantageous position when compared with other lignocellulosic fiber crops since it has a short plantation cycle, flexibility to environmental conditions and requires relatively lowered quantity of pesticides and herbicides [65]. Kenaf fibers receive much attention owing to its prospective probability as polymer reinforcements in the natural fiber composite industry. Researchers claimed that mechanical strength and thermal properties of kenaf composite are superior to other type of natural fiber polymer composites, thus regarded as a suitable applicant for high performance natural fiber polymer composite [63].

Chai [66] and other researchers worked on the influence of natural fiber due to fire response. They worked with two kinds of fibers: natural fiber and glass fiber. They showed the difference between the two fibers how they response towards flame. From their experiments, it is obtained that natural fiber showed much deformation than glass fiber. The natural fiber is less stiff than glass fiber. As a result, natural fiber produces more heat and the time of ignition for natural fiber is earlier than that of glass fiber. The glass fiber has a strong structural bondage for that it doesn't change too much when the flame is applied. Holbery [67] worked on the applications of natural fiber-based composites are increasing day by day. In Europe, the usage of natural fiber composites had been drastically increased in the automotive sectors in the last decade. The manufacture cost of natural fiber composites is low. The fuel combustion rate is also low. As a result, it maintains a good carbon dioxide balance on the vehicle lifetime. Again, the emission rate of greenhouse gases is almost to 0%. So usage of natural fiber composites is also hygiene for our environment. Considering these factors, the usage of natural fiber in automotive sectors is increasing day by day. It has not only spread in Europe but also in other countries in the world.

Though the usage of natural fibers is beneficial, there are also some problems. Further researches and experiments are needed to overcome these problems.

Seena Joseph [68] researchers worked on the effects of different environmental factors on the banana fiber reinforced composites. They worked with the two fibers and then made a comparison between them. The changes of structures of the natural fiber are different for different factors. From their experiments, it was found that water aging increased the weight and tensile properties of the natural fiber while hot oven aging decreased the weight of the natural fiber. These results are completely different for the glass fiber. Again, surface modifications lower the tensile strength of the natural fiber. The modulus of the composites is being affected by the outside weathering condition but it doesn't decrease too much after soil immersion. From this experiment there is a clear difference between the natural fiber and glass fiber and the changes in glass fiber is less than that of natural fiber. Further experiments are required in order to improve the quality of the natural fiber. Ryszard Kozlowski and Maria Wladyka-Przybylak [69] experimented the uses of natural fiber reinforced composites are increasing day by day. These kinds of fibers have some good feedback in the recent research works and for that they are proved beneficial for applying in various sectors. Now a day they are being used in manufacturing various household materials, automotive parts etc. and also used in military purposes. These kinds of fibers are very much available in our surrounding and also they hold a low density. Again the manufacture cost of these kinds of composites are very low comparing to the other raw materials. Considering these factors, the natural fiber reinforced composites are becoming popular towards various manufacturing purposes day by day. Also they are very easy to recycle. Recycling is the important factors for growing natural fibers in the future. A new big potential market for natural fiber can emerge in the near future if the homogeneity and equality during manufacturing can be improved.

Pothan [70] also worked on There is a research on the changes of different structural properties of the banana fiber reinforced composites in according to the various environmental factors. The flexural, tensile, impact and aging behavior of the composites changes in according to the fiber length and fiber strength. The addition of the fiber increases the tensile strength of the composite which makes it more ductile. The value of flexural and impact strength of the natural fiber depends on the percentage of the loadings given. From the experiment, a decision regarding the banana fiber reinforced composite has been taken. It has been proved that banana reinforced composite has a moderate tensile and flexural strength but higher tensile strength than other composites. It has a smooth surface finish and as a result the usage of banana fiber reinforced composites in the building industry are increasing day by day.

Pothan [71] worked on various surface treatments of the banana fiber reinforced composites. Initially the surface of the banana fiber is not compatible for perfect bonding. Various treatment had been done in order to get the perfect interface. The final performance of the composite mostly depends on the nature of the interface and also the bonding between the resin and the fiber. Sufficient interaction between the resin and the fiber is needed to get the desired performance. Various chemical materials are used in order to modify the surface of the fiber. The mechanical properties of the fiber are being improved by the chemical modification. From the experiment, it had been seen that alkali is the best chemical which improves the mechanical properties most. In 2004, Pothan [72] worked on the water absorption properties of the banana fiber reinforced composite. The rate of water absorption is being changed with some factors like temperature, the hybridization of the fiber etc. The diffusion rate of water for the fiber is low at the room temperature. This rate starts to increase with the time being of increasing of the surface temperature. Also changing the chemical properties by adding various chemical can change the water diffusion rate for the fiber. From the experiment, the most important thing that is obtained that water transportation is a key factor to evaluate the strength of the interfacial adhesion of the banana fiber reinforced composites. Further in 2007, Pothan [73] worked on the electrical properties of the banana fiber reinforced composites. Like the mechanical properties, electrical properties also depend on the fiber content as well as the surface modification. The value of the dielectric constant of the composite varies along with the changes of surface modification. Also fiber loading plays a vital role in the changing of the value of the dielectric constant of the composite. From the value of the dielectric constant, the interaction between the fiber and the matrix can be easily investigated. From the electrical properties of the composite, we can easily determine the quality and overall performance of the composite.

D. Nabi Saheb [74] researched on the use of natural fiber in various sectors is increasing day by day. Comparing to other conventional fibers, natural fibers are advantageous to some extents. That is why the usage of the natural fiber is increasing day by day. But there are also some drawbacks in using natural fibers. So further experiments are needed to overcome these drawbacks. Recently, the usage of natural fiber reinforced composites are hugely used in the automotive industry. It is because of the low cost, low density and higher impact strength of the composite. It is a major problem that the thermal stability of the natural is not so satisfactory. So the scientists are trying to overcome this problem as this could be a major threat for this newly improved industry of natural fiber composite. Samrat Mukhopadhyay [75] worked on the facture and variability behavior of the banana fiber reinforced composite. From their experiment, it is found that banana fiber has shown high variability. Various properties like tenacity, diameter of the fiber etc. are changed eth time being.

Summary: From the literature review, it has been found that that the scientists used different approaches and raw materials for the fabrication of the composite materials. It showed different types of findings and the approach is not limited. Many research works have been conducted based on the combination of jute and banana fiber but still now the approach of combination of natural fiber like jute, Banana with bio-degradable natural fiber based polythene has not been adopted. Even limited works has been conducted for mathematical model development and FEM simulation.

In this present study, three different types of fiber materials like jute fiber, banana fiber and jute fabricated bio-degradable plastic of different loading have been used for the fabrication of a new composite materials with epoxy resin and a mathematical model has been utilized as reinforcement in epoxy resin composite to optimize the composite strength from analytical results by experiment and mathematical model using CCD and RSM. FEM simulation has also been conducted for predicting the dynamic behaviour of the green composite materials.

CHAPTER: 3

DETAILS OF EXPERIMENTATION

3.1 INTRODUCTION:

Primarily the experiment is carried out by considering three different approaches namely casting processes, hand-lay method and vacuum infusion method for different types of natural fiber. Natural fiber has been collected in fiber, sheet and grain type. Different composite materials have been fabricated with the different combination of natural fiber using different techniques and its effectiveness has been assessed by tensile or compression test as shown in Figure 3.1.

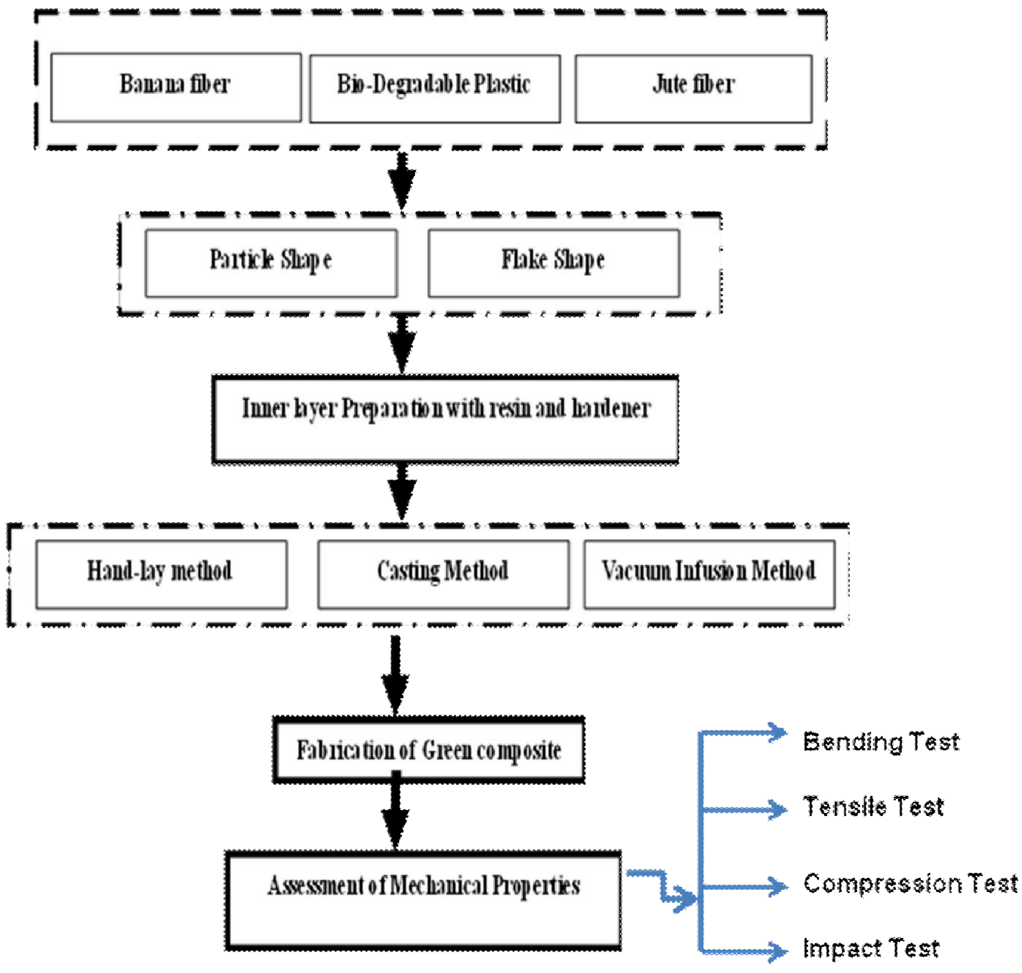


Figure 3.1 Fabrication sequence for green composite used in this study.

3.2 Process variables and their values

In the present experimental study, three method has been adopted and green composite has been made for different combination of fiber type, fiber size which are provided in Table 3.1.

Table 3.1 : Process variables and their related values

Fiber type	Fiber size (mm)	Method used
Banana-1) Grain		
2) Fiber		
3) Sheet	0.28,	1) Casting Method
Jute-1) Grain	0.75,	2) Hand lay method
2) Fiber	1.88,	3) Vacuum Infusion Method
3) Sheet	3.0,	
Bio-polythene	3.47	
1) Grain		
2) Fiber	Ratio of grain (A)and resin (B)	
3) Sheet	wt in gm	

3.3 Equipments and apparatus used

3.3.1 Scanning Electron Microscope:_A scanning electron microscope scans a focused electron beams over a surface to create an image. The electrons in the beam interact with the sample in order to produce various signals from which it can obtain information regarding the surface and its composition. The different micro-structure of the fibers and formed composite microstructure has been observed under scanning electron microscope of SUI510 model as shown in Figure 3.2. The details specifications of the SEM are shown in Table 3.2. The process sequences for the analysis of the fiber structure are shown in Figure 3.3.

Figure 3.2 Scanning Electron Microscope of SUI510 model

Table 3.2 Specification of SUI150 Scanning Electron Microscope

Features	Specifications
Resolution SE:	3.0 nm at 30 kV (High Vacuum Mode)
Resolution BSE:	4.0 nm at 30 kV (Variable Pressure Mode)
Magnification:	×5 to ×300,000
Accelerating Voltage:	0.3 to 30 kV
Low Vacuum Range:	6 to 270 Pa through graphic menu
Image Shift:	±50 µm (WD=15 mm)
Maximum Specimen Size	153 mm in diameter
Specimen Range:	X: 0 to 80 mm Y: 0 to 40 mm Z: 5 to 50 mm R: 360° T: -20° to 90° Observable Area: 126 mm in diameter (with rotation) Maximum Height: 60 mm (WD=15 mm)

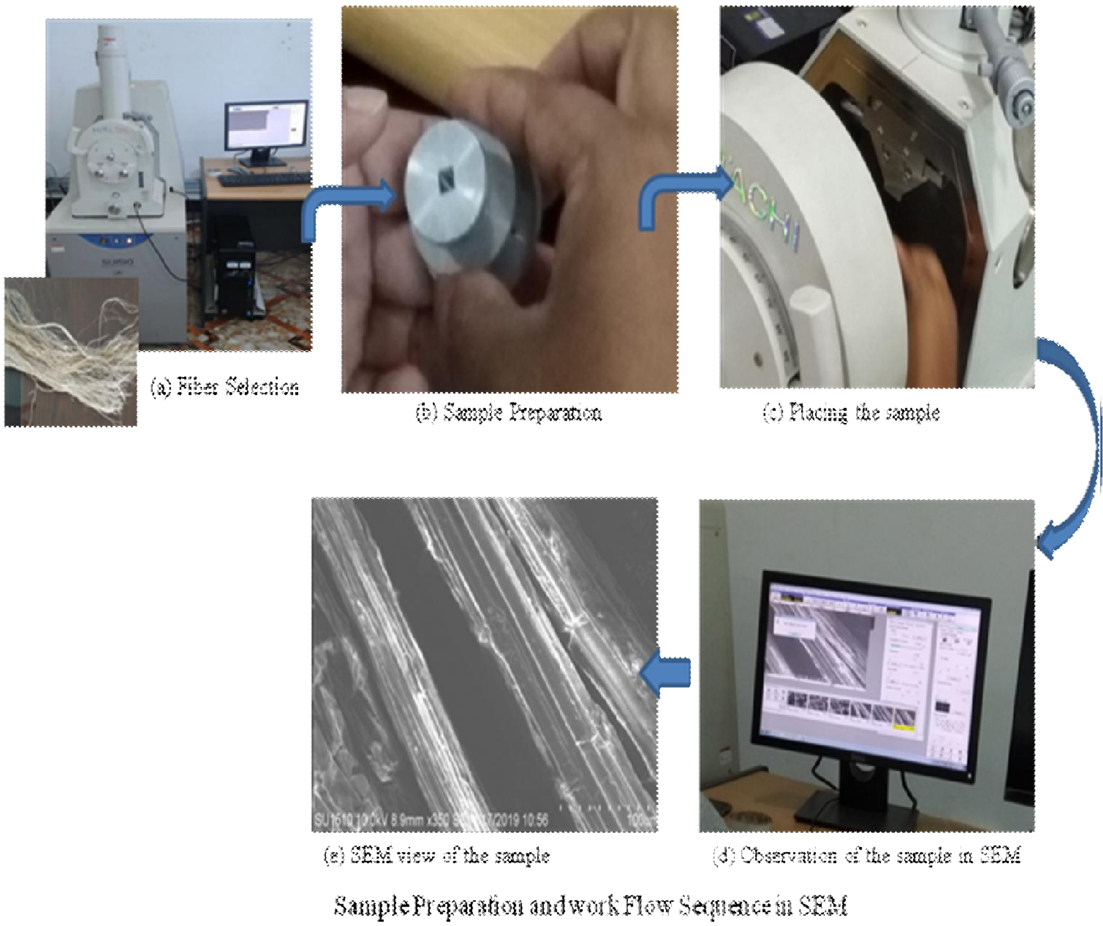


Figure 3.3: Process sequence for SEM view under Scanning Electron Microscope of SUI510 model

3.3.2 Compression Testing Machine: After the molding process green composite cylindrical block has been made and compression test has been conducted using compression machine of model C13A02as shown in Figure 3.4. This machine has a good load capability of load cells without any damage and has high accuracy. The details specification of the machine is shown in Table 3.3.

Figure 3.4 Compression Machine of Model C13A02

Table 3.3 Specification of C13A02

Features	Specifications
Capacity Force Maximum	1500 kN
Ram Area	22698 mm^2
Ram Stroke	50 mm
Machine Weight	363 Kg
Hydraulic oil	ISO VG32+68
Power	750 watt
Voltage	220 Volt

3.3.3 Leaser Scan Micro-Meter: A laser scan micro-meter has been used to measure the fiber diameter of Jute and banana. The details of the Laser scan Micrometer of Model LSM-500S are shown in Figure 3.4 and the details specification is shown in Table 3.5.

Figure 3.5: Laser Scan Micrometer of Model LSM-500S

Table 3.4 Specification of LSM-500S

Features	Specifications
Applicable Display Unit	LSM-6200
Laser Scanning Range	upto 12.5 mm
Measuring range	0.005 to 2 mm; 0.1 to 2mm
No of laser scan	3200/sec
Laser scanning rate	76m/sec
Operation Environment	0^0C and 40^0C
Storage Environment	-15^0C-55^0C

3.3.4 Table-Top universal testing instrument: The tensile strength of the natural fiber extracted from Banana and Jute has been measured by using Table-Top universal testing instrument of model EZ-LX as shown in Figure 3.6.

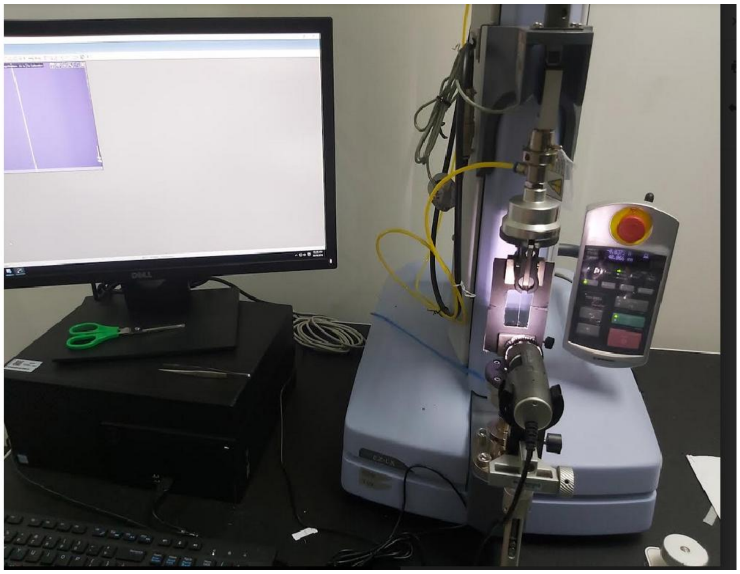


Figure 3.6 Table-Top universal testing instruments, model Ez-LX

Following the standard procedure the griping of the natural fiber was made for using Table-Top universal testing instrument. Each of the fiber was gripped by using a hard-board type rectangular gripping frame. Fiber was placed in the middle of the multi-layer hard board gripper as shown in Figure 3.7.

Figure 3.7 Fiber gripper with multi-layer hard board.

The middle part of the hard board gripper was cut to transfer the load to the fiber and tensile test was conducted accordingly. The specification of the Autograph EZ-LX series machine is shown in Table 3.5.

Table 3.5 Specification of Table-Top universal testing instrument

Features	Specifications
Maximum Capacity	1 KN
Maximum Stroke	920 mm
Test speed range	0.001tp 2000 mm/min
Maximum return speed	3000 mm/min
Maximum grip space	755 mm
Depth of test space	100 mm
Power capacity	850 VA

3.3.4.1 Universal testing instrument: The tensile strength of the fabricated composite materials using different types of fiber sheet, fiber particle have been measured by using universal testing instrument of model AG-X Plus as shown in Figure 3.8.

Figure 3.8 Universal testing instruments, model AG-X plus series

The specification of the Autograph AG-X plus series machine is shown in Table 3.6.

Table 3.6 Specification of universal testing instrument

Features	Specifications
Maximum Capacity	300 KN
Grip capacity	33 kg
Grip face	File teeth for flat specimen
Extensometer	Non-Contact digital video
Maximum grip length	75 mm
Grip width	50 mm

3.3.5 Impact Tester: An impact test as shown in Figure 3.8 has been conducted for assessing the impact load capacity of the casted green fiber. The pendulum is mounted on antifriction bearings. It has two starting positions, the upper one for Charpy and the lower one for Izod test. On release, the pendulum swings down to break the specimen and the energy adsorbed in doing so is measured as the difference between the height of drop before rupture of the test specimen and is read from the maximum pointer position on the dial scale. Impact tester used in this study is shown in Figure 3.9and the specifications are shown in Table 3.7.

Figure 3.9: Impact tester used in this study

There are two strikers and one combined support anvil available for fitting in to the pendulum and on the base of machine for the Izod, Charpy test respectively. Changing from one striker to another is achieved simply by fixing the new striker into its position.

Table 3.7 Specification of Impact tester

MODEL	IT-30	IT-30 (D)	IT-30 (ASTM) Charpy Test	IT-1.5	IT-0.5
Maximum Capacity	300 J/168 J	300 J/170 J	300 J	15 J	5 J
Maximum Scale Graduation	2 J	0.5 J	2 J	0.1 J	0.05 J
Overall Size (Approx.)	1.1m x 0.45m x 1.65 m (H)	1.32m x 0.45m x 1.05 m (H)	1.4m x 0.5m x 1.9 m (H)	0.5m x 0.3m x 0.52 m (H)	0.5m x 0.3m x 0.52 m (H)
Net Weight (Approx.)	375 kg.	375 kg.	450 kg.	70 kg.	70 kg.

3.3.5.1: Fabrication procedure for Impact test specimen: Impact test specimen has been prepared from jute, plastic and banana fiber particle. In the fabrication procedure, special Teflon die has been made with three chambers. In one casting process, three specimens can be fabricated. The process sequence for the fabrication of the composite materials is shown in Figure 3.10. Three different size particles 0.75mm, 0.88 mm and 3 mm have been used to find out the impact strength of the materials. Standard Specimen was prepared as per ASTM A370 standard.

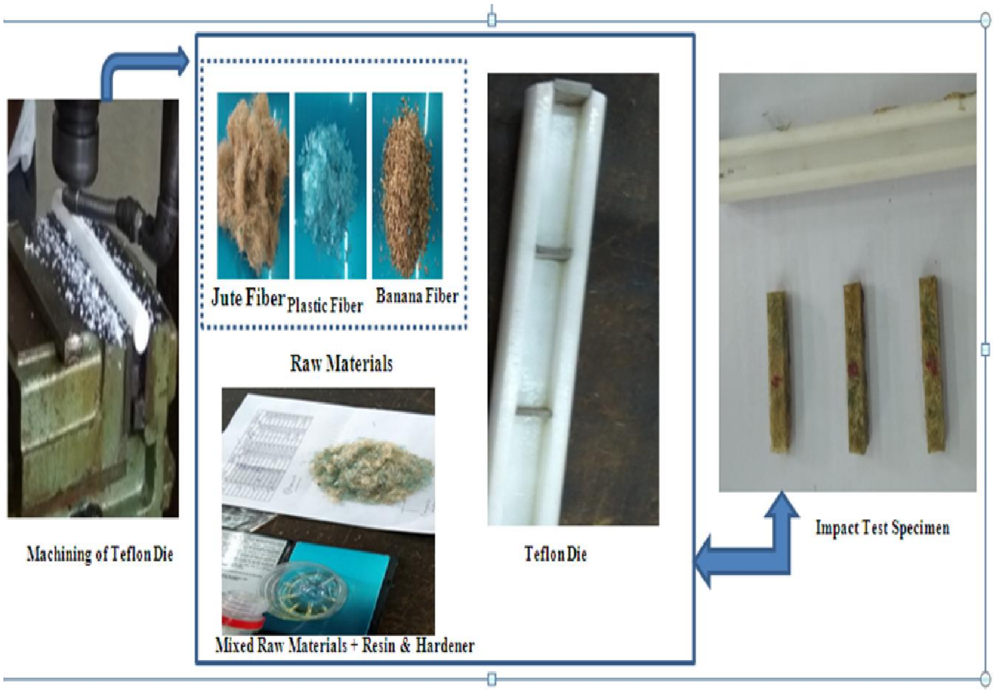


Figure 3.10: Process sequence for the fabrication of the composite materials used for Impact test.

3.3.6 Teflon Die and Spacer: For our experiment, we use Teflon die and spacer. It is used as a template. A Teflon die is generally a small disc with a centrally located hole. For our experiment, we use a Teflon die which diameter is 25 mm and the length is also 25 mm. So the ratio of diameter and length is 1. We also use Teflon made spacer which is used for pressing the reinforced fibers in order to compact the three fibers. Teflon has high melting point. As a result, it does not affect by high temperature. Teflon is a low elastic material. For this, it gives less deformation. For this our reinforced composite fiber doesn't affect. The different teflon die used in this study are shown in figure 3.11 and specification of the Teflon materials are shown in table 3.8.

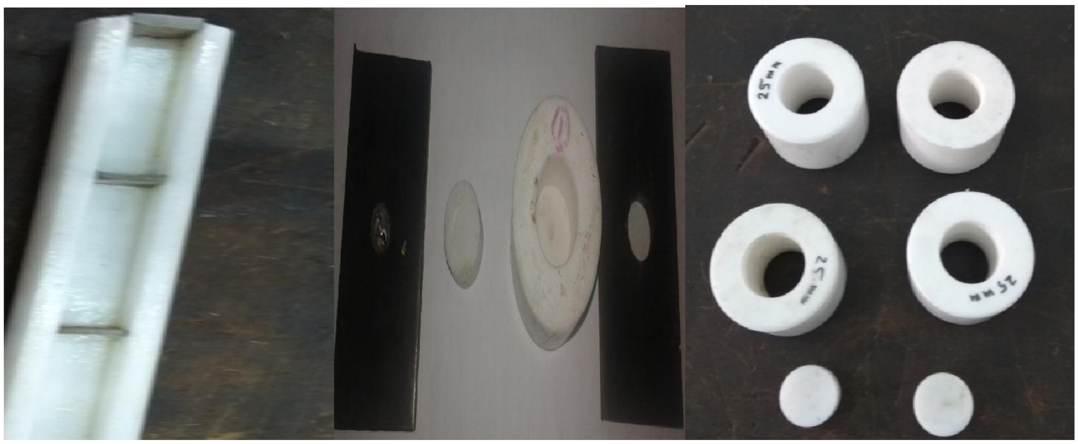


Figure 3.11: Different teflon die used in this study

Table 3.8 Specification of Teflon materials

Features	Specifications
Material	Teflon
Kind:	Engineering Plastic Sheet
Water Absorption	0.1%-0.3%
Contraction percentage	: <0.4%

3.4 Hand-Lay Method: Hand Lay Method is a method where fiber reinforcements are placed by hand and then it is being wetted by resin. In this experiment, reinforced fibers are fabricated by dint of hand lay method. Hand lay method is a suitable process for fabrication because desired shape can be given to the reinforced fibers and also proper control the ratio of resin and fibers can be made. Also this is a very simple process for fabrication of reinforced fibers. Initially three types of fibers: jute, banana and plastic fiber are selected. Process of selecting the fiber and its extraction process for banana are shown in Figure 3.12.

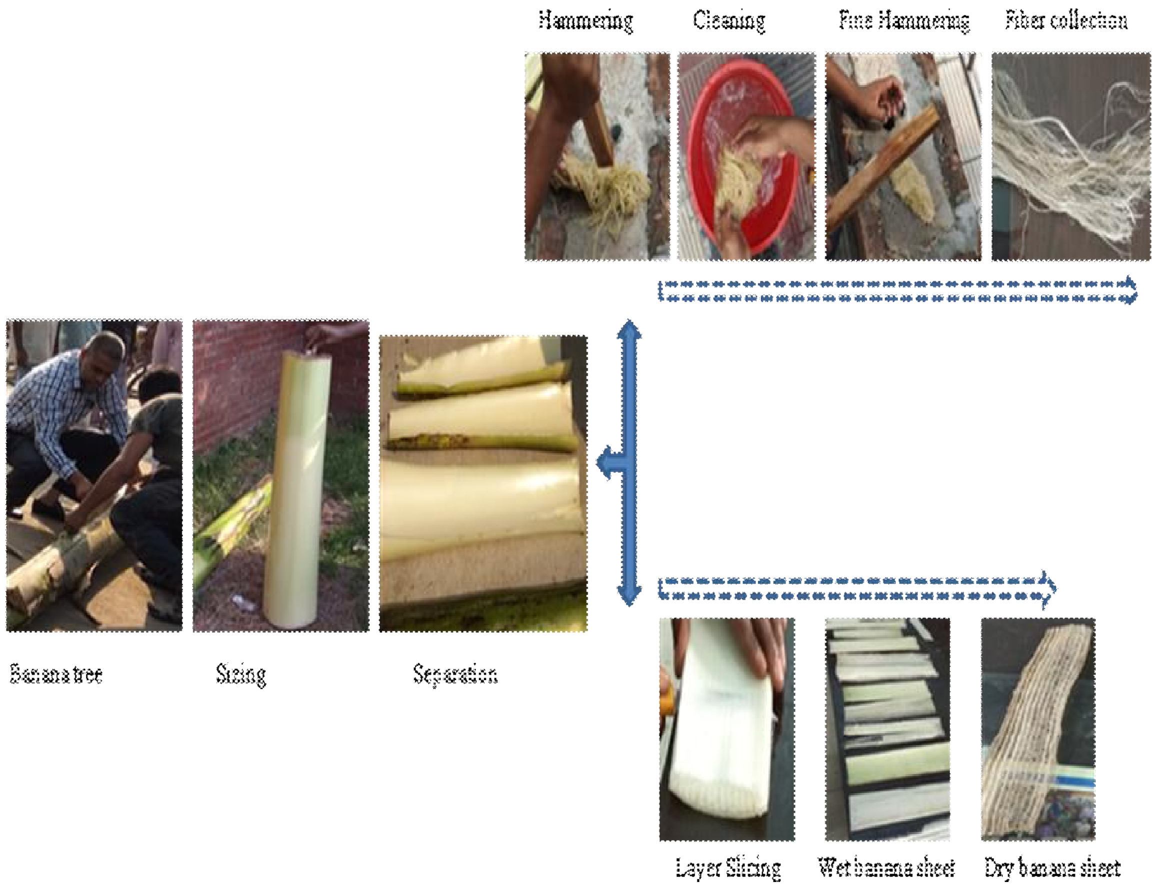


Figure 3.12: Process of extraction for getting the banana fiber

After extracting the fiber from different materials, the proper categorization of the fiber has been made in the form of fiber particle, fiber sheet and fiber. Different categories of fiber have been used in our hand lay method. Proper ratio of the resin, hardener and fiber has been mixed for the fabrication of the green composite and the process sequence is shown in Figure 3.13.

Figure 3.13: Process sequence of hand lay method for different composite

3.5 Casting process: Three different types of raw materials like banan fiber, jute fiber and bio-degradable jute plastic fiber has been used having different fiber size with same weight ratio. Sample picture of the raw materials and fabricating steps for casting are shown in Figure 3.14.

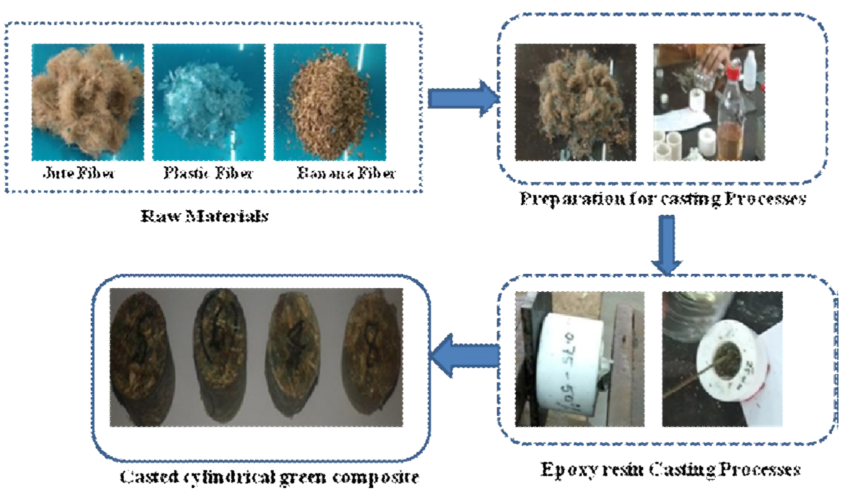
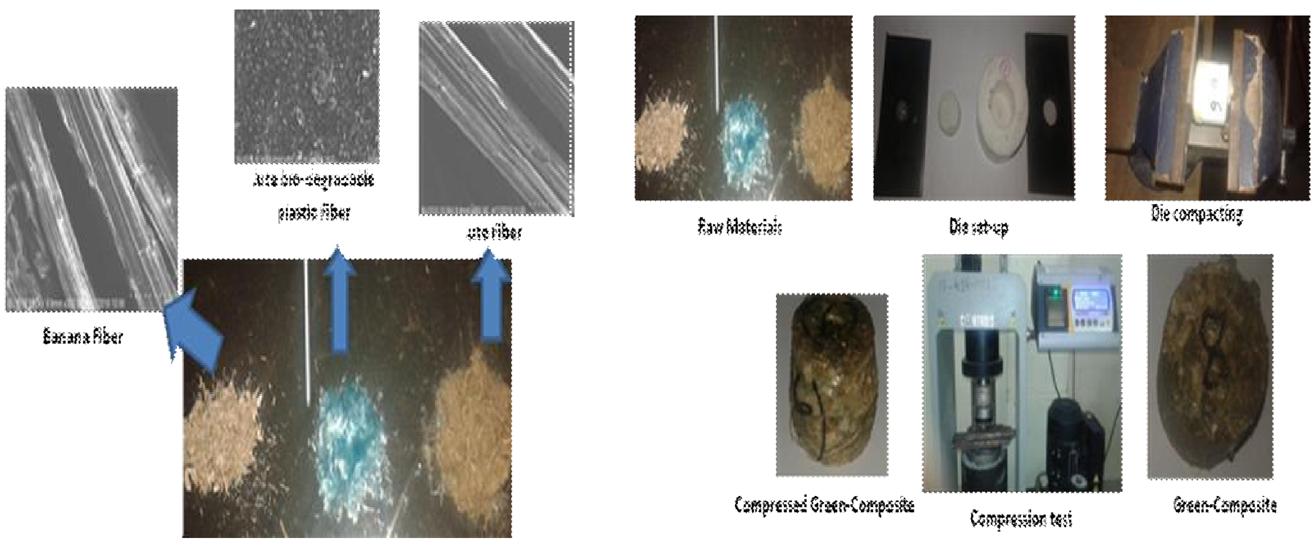


Figure: 3.14 Fabricating steps for casting process

Epoxy resin with hardnerer has been used with 10:1. The process sequence for the resin molding process of the green composite with die-set-up, die comapcting and compression test are shown in Figure 3.15. In this study, teflon die with 25 mm diameter has been used with lubicant for easy removal of molded composite. For the compression test, compression machine, model C13A02 with maximum load capacity of 1500 kN has been used to measure the compressive strength of the casted green composite.



(a) (b)

Figure 3.15. (a) Different types of Raw materials used in this study with SEM view (b) Process sequence for the resin casting of the green composite materials.

3.6 Vacuum Infusion process: In Vacuum Infusion Process (VIP) as shown in Figure 3.16 vacuum pressure is used to drive resin into a laminate. In these process three different sheets from natural fibers of jute, banana and bio-degradable plastic made from jute has been used as laminating materials. Laminating materials are laid into the mold layer wise and the vacuum is applied before resin is introduced. It is very important to ensure the full vacuum within the mould of the chamber and then resin is literally allowed for in feeding into the laminate via carefully placed tubing. In the vacuum process, a leak-tight flexible film is placed over the laminate and sealed to the mould beyond the perimeter of the laminate.

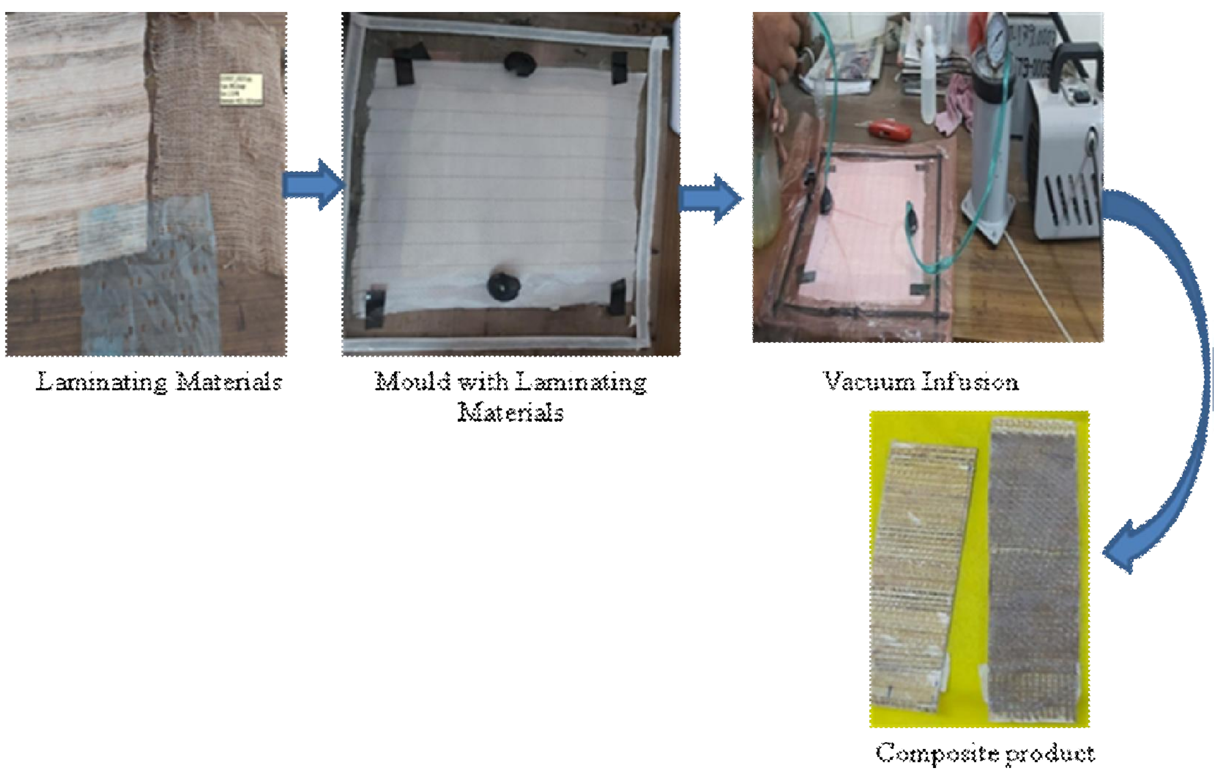


Figure: 3.16 Fabricating steps for Vaccum infusion process

A minimum of two connections are made to the bag for permitting air to be removed from the cavity between the bag and the mould and to allow liquid resin to enter. For the evacuation procedure the bag and mould should be temporarily closed off from the vacuum pump and the level of vacuum remaining in the part observed on a vacuum gauge. If the vacuum level remains constant, or at least reasonably constant, the mould and bag will be considered sufficiently leak-tight and the process can continue to the next stage. If, however, the vacuum level deteriorates at a faster level than can be accepted, air will be leaking into the evacuated cavity and the process should not continue. In this case, the air leaks must be found and eliminated before proceeding further. Acceptable leak back rates will vary depending on part size and desired laminate quality. Once a satisfactory level of leak-tightness has been achieved, the line to the vacuum pump can be reopened. The resin supply container can be filled with mixed resin and the line to the resin supply can be opened. With the resin supply line open, liquid resin will be forced into the part.

3.7 Jute Fiber: Jute is most commonly used natural fiber as reinforcement in green composites. Jute is a type of best fibers from Tiliaceae family. It is one of the low-cost natural fiber with the maximum production volume. Jute is intuitive to the Mediterranean but now a day's Bangladesh, India, China, Nepal, Thailand, Indonesia, and Brazil provide the finest type for the growth of jute. The overall world production of jute fiber is around 2300×10^3 to 2850×10^3 tones. Jute can grow 2–3.5 m in height and are very brittle, with a low extension to break because of the high lignin content (up to 12–16%) [76]. Jute fiber has some unique physical properties like high tenacity, bulkiness, sound & heat insulation property, low thermal conductivity, antistatic property etc. Due to these qualities, jute fiber is more suited for the manufacture of technical textiles in certain specific areas. Moreover, the image of jute as a hard and unattractive fiber does not affect its usage in technical textiles. Jute is 100% bio-degradable and thus environment-friendly. Jute fibers are always known as strong, coarse, environment friendly, and organic. The use of jute was primarily confined to marginal and small manufacturers and growers, but now it is used as important raw materials for several industries.[77] . Jute fiber reinforced hybrid composites are the category of the composites in which more than one reinforcement material would be there along with the matrix material. In development the hybrid composites in used jute fiber along with another natural fiber as reinforcement and polymer as the matrix material. Since jute has properties like higher tenacity, insulation property and features such as strong, coarse, and organic they can be made into composites that provide higher tensile module than bamboo or kenaf based reinforced hybrid material.[78] The flexural and impact strength of jute/glass woven composites are lower than those of jute woven composites.[79] Thus it is observed that jute fiber based composites due to their physical and structural properties provide better mechanical properties for the hybrid composite. The properties of jute fibers are given below:

Properties	Jute Fiber
Cellulose (%)	64.4
Hemi-cellulose (%)	12
Lignin (%)	11.8
Pectin (%)	0.2
Waxes (%)	0.5
Moisture content (%)	1.1
Density (g/cm)	1.46
Tensile strength (MPa)	393-773
Young's modulus (GPa)	13-26.5

3.8 Banana Fiber: It is a well-known fact that banana is one of the oldest cultivated plants in the world. The word 'banana' comes from the Arabic language and means 'finger'. It belongs to the Musaceae family and there are approximately 300 species, but only 20 varieties are used for consumption. Approximately 70 million metric tons of bananas are produced every year by the tropical and subtropical regions of the world. [80-82].

The Properties of banana fiber are given below:

Properties	Banana Fiber
Cellulose Content	63-64%
Hemicellulose	19%
Lignin	5%
Moisture Content	10-11%
Initial Modulus	21-51MPa
Tensile Strength	520-750MPa
Density	1.35g/cc

A number of investigations have been made in predicting the various mechanical proper-ties like tensile strength, flexure strength, etc., of banana fiber and banana fiber reinforced with polymers. All the results show the excellent mechanical properties exhibited by the banana fibers] The tensile test was conducted according to the ASTM-D3379-75. The plot of stress vs. percentage strain of various fibers is approximately linear; with banana having a stress value of around 560 MPa when the percentage of strain is 3.5%. Also it was predicted that banana fibers are stiffer and stronger than sisal fibers.

3.9 Biodegradable polythene by Sonali fiber: Cost-efficient and biodegradable jute oriented polythene has been invented by a group of Bangladeshi scientists. In the invention process approach, jute has been used as local resource and from jute cellulose and finally the team had been able to develop a jute made packaging material which has the compatible with the traditional poly-bag used for commercial purpose. The bag is able to carry 1.5 times higher load with enhanced thermal properties. It has been found that microorganisms of this bag can easily be decomposed, so it is biodegradable. The bag is compostable and can be used to fertile soil to grow plants. This is also soluble in the water depending on the surface and time, for instance, it can be degraded in water in hours or it can take months to degrade in water. The chemical composition of the jute oriented bio-degradable polythene are given below: [83]

Chemical composition:-

Cellulose: 65.2%
Hemi-cellulose: 22.2 %
Lignin: 12.5 %
Water soluble matter: 1.5 %
Fat and wax: 0.6 %

3.10 Resin and Hardener: The hybrid composites are made by adding resin to create a fiber matrix to join the fibers together. There are mainly two types as thermosets and thermoplastic. These resins are made of polymers (large molecules made up of long chains of smaller molecules or monomers). Thermoset resins are used to make most composites. They're converted from a liquid to a solid through a process called polymerization, or cross-linking. When used to produce finished goods, thermosetting resins are "cured" by the use of a catalyst, heat or a combination of the two. Once cured, solid thermoset resins cannot be converted back to their original liquid form. Common thermosets are polyester, vinyl ester, epoxy, and polyurethane. In this experiment epoxy resin has been used to form hybrid composite made of jute, banana fiber and bio-degradable polythene. Epoxy resins have a well-established record in a wide range of composites parts, structures and concrete repair. The structure of the resin can be engineered to yield a number of different products with varying levels of performance. A major benefit of epoxy resins over unsaturated polyester resins is their lower shrinkage. Epoxy resins can also be formulated with different materials or blended with other epoxy resins to achieve specific performance features. Epoxies are used primarily for fabricating high performance composites with superior mechanical properties, resistance to corrosive liquids and environments, superior electrical properties, good performance at elevated temperatures, good adhesion to a substrate, or a combination of these benefits. Epoxy L12 as epoxy based resin and Hardener K6 as hardener of Atul limited has been used in our experimentation. The specification of resins and hardeners are given below:

Resins	**Hardener**
Lapox L-12	Hardener K-6
Epoxide equivalent gm/eq 182-192 **Epoxy value eq/kg 5.2-5.5** **Viscosity at 250C mPa.s 9000-12000**	Visual appearance Pale Yellow liquid Refractive index at 250C 1.4940-1.5000 Water content 1% max. Shear strength on A1 alloy lap joint

CHAPTER 4

RESULTS & DISCUSSIONS

4.0 OVERVIEW

This chapter presents results of experiments conducted for evaluating the composite fiber in terms of fiber strength, compressive stress and tensile strength. In this current approach, it is necessary to conduct experiments to assess the applicability of the fabricated composite. Based on the objectives, the result and discussion section of this chapter are divided into three parts. The first part shows the experimental findings of the natural fibers and their comparison. In the second part, detailed experiments are conducted in terms of tensile load calculation for different fabricated materials using different approaches and impact test results. In the third section, the experimental results for fabrication of composite cylinder and its mathematical model discussion is made. The chapter also presents the related discussions and analysis of the finite element simulation results. The chapter is divided into several sections and sub-sections.

4.1 Investigation of different fiber diameter and fiber strength: It is very diffcult to get the same size and shape fiber. It has been observed that the diameter of the different fiber extracted from either jute or banana is different. In some cases, the difference is very signinificant. The diamter of the fiber has been mesaured using Laser scan Micrometer of Model LSM-500S. The details of the micro-meter has been provided in chapter 3. The tensile test of the fibers has been tetsed under Table-Top universal testing instrument as shown in chapter 3.

4.1.1 Analysis of Jute and Banana Fiber diameter: The different jute and banana fiber has been extracted, collected and mesaured in laser type micrometer. It has been observed that the diameter is not uniform. Six reading was taken from the six location of the fiber and average value has been recorded accordingly. The diameter for the different fibers has been repeated for six different samples for both jute and banana fiber. Figure 4.1 shows the variation of diameter for different samples for both the fibers of jute and banana.

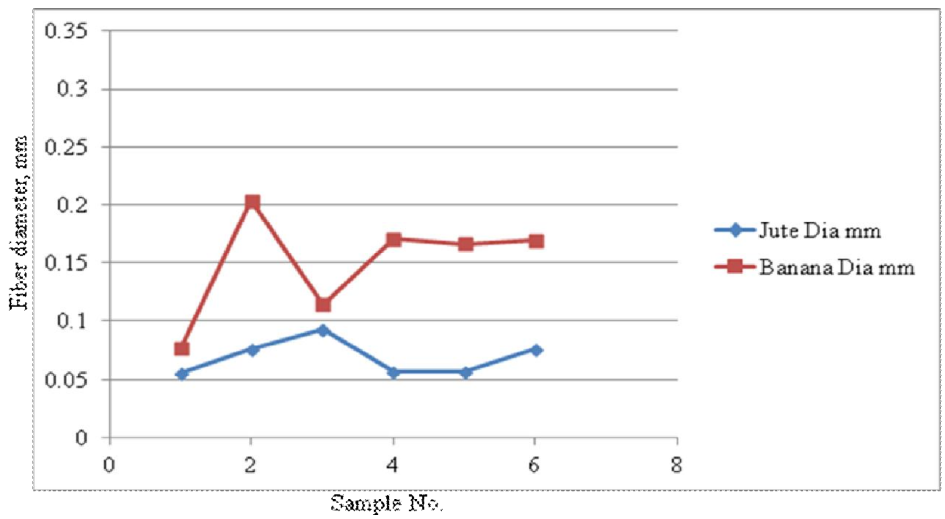


Figure 4.1 Measurement of diameter of natural fiber

4.1.2 **Analysis of jute and banana fiber strength:** A table top testing machine has been used to find out the strength of the natural fiber. It is very diffcult to grip the fiber with in the testing machine. Gripping mechnaism has been explain and shown in Figure 3.6 of chapter 3. Six different samples both from banana and jute has been tested and tensile stregth has been recorded accordingly. Figure 4.2 expresses the stroke versus force curve of similar diameter fiber. Same diameter of 0.0765 mm has been taken for banana and jute fiber and comparison has been made to identify the maximum force withstand by the fibers. It has been observed that jute fiber has high strength compared to banana but banana fiber has higher elongation compared to jute fiber.

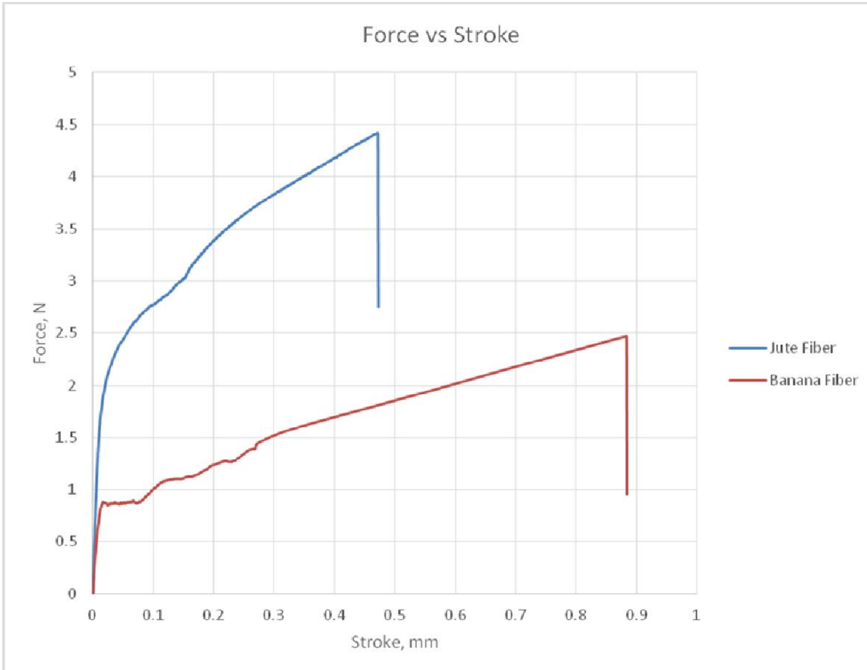
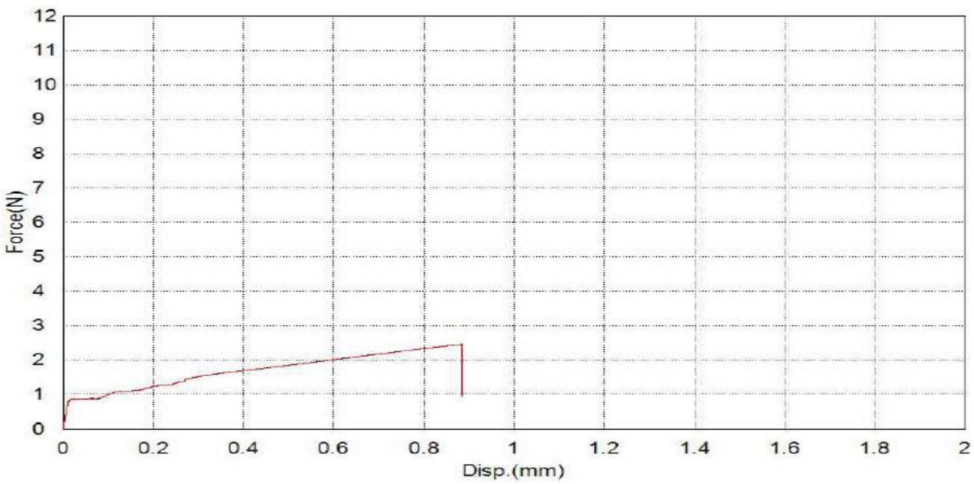


Figure 4.2 Force-stroke relationship of natural Fiber

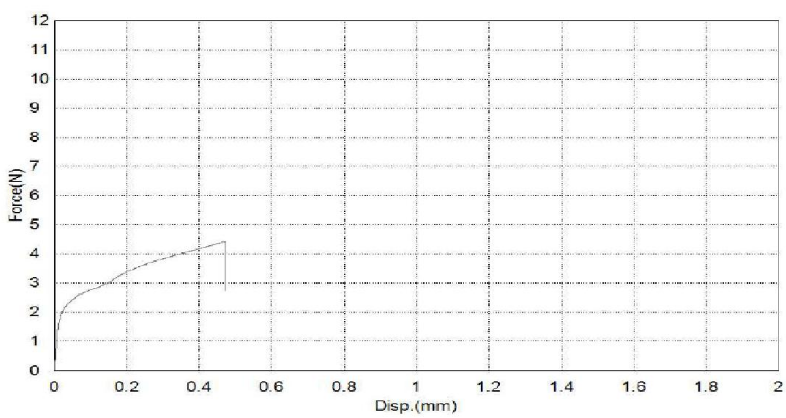
The stress-strain curve obtained using the result from banana specimens and jute specimen shown in Figure 4.3 and Figure 4.4 respectively. Figure 4.3 reveals the average tensile strength of banana fiber and found that the tensile strength is approximately 535.952 MPa for a banana fiber having the diameter of 0.0765 mm and the elongation is 0.88 mm. But with the variation of fiber diameter the tensile strength varied along the maximum elongation capacity.

Figure 4.4 reveals the average tensile strength of jute fiber and found that the tensile strength is approximately 969.325 MPa for a jute fiber having the same diameter of 0.0765 mm and the maximum elongation of the jute fiber is 0.47 mm. But with the variation of the fiber diameter the tensile strength and elongation capacity also varied.



Name	Slope_Standard	Break_Stress	Break_Disp.
Parameters	Stress 10 – 20 N/mm2	Sensitivity: 10	Sensitivity: 10
Pass/Fail			
Unit	N/mm	N/mm2	mm
Banana 1 Of 1	214.867	535.952	0.88
Average	214.867	535.952	0.88
Standard Deviation	-.-	-.-	-.-
Maximum	214.867	535.952	0.88
Minimum	214.867	535.952	0.88

Figure 4.3 Stress-strain relationship of Banana Fiber



Name	Slope_Standard	Break_Stress	Break_Disp.
Parameters	Stress 10 – 20 N/mm2	Sensitivity: 10	Sensitivity: 10
Pass/Fail			
Unit	N/mm	N/mm2	mm
Jute 1 Of 2	144.100	969.325	0.47
Average	144.100	969.325	0.47
Standard Deviation	-.-	-.-	-.-
Maximum	144.100	969.325	0.47
Minimum	144.100	969.325	0.47
TotalAverage	144.100	969.325	0.47

Figure 4.4 Stress-strain relationship of Jute Fiber

Table 4.1 shows the variation of ultimate strength of jute and banana fiber at different fiber diameter. It has been observed that ultimate tensile strength of jute varied from 253.16 MPa to 1801.76 MPa with the diameter variation of 0.0927 mm to 0.0566 mm because of lack of proper homogeneity.

Table: 4.1 Jute, Banana, UTS Comparison

Jute		Banana	
Dia, mm	UTS, MPa	Dia, mm	UTS, MPa
0.0553	687.08	0.0765	535.95
0.0762	969.39	0.2031	113.92
0.0927	253.16	0.1144	786.62
0.0566	1801.76	0.1705	319.23
0.0566	486.48	0.1665	320
0.0758	790.93	0.1693	248.2

It has also been observed that for banana fiber the ultimate strength varied from min 113.92 MPa to Maximum 786.62 with the fiber diameter variation from 0.2031 mm to 0.1144 mm as the fiber was not homogenous.

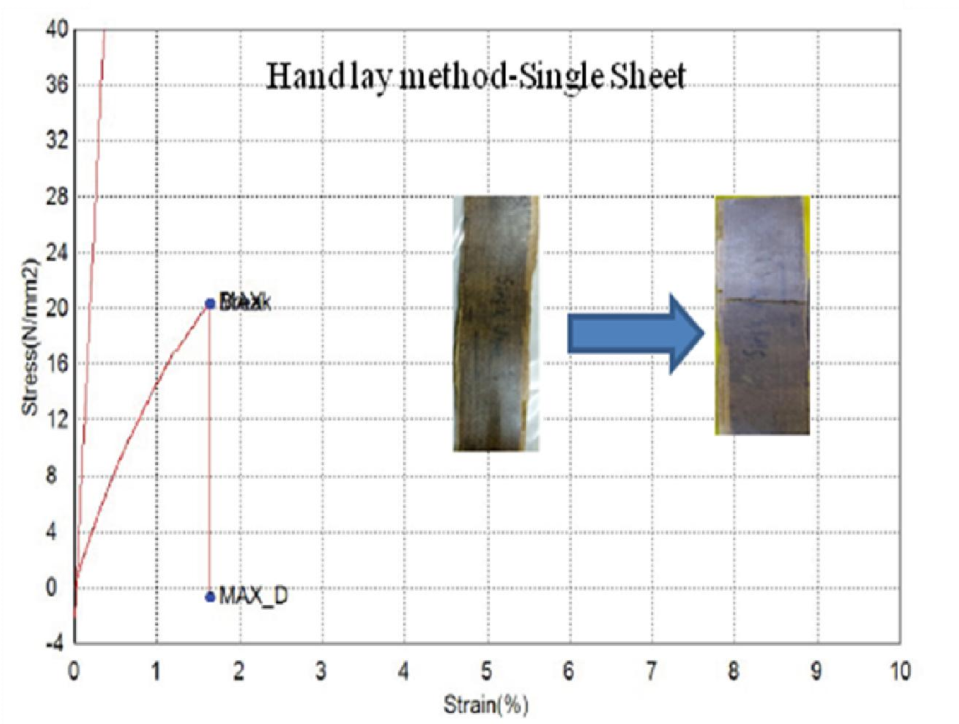
4.**2 Invesigation of mechanical properties of the green composite materials using different fabrication methods:** Mechanical properties of the fabricated green composite in terms of tensile strength has been invetsigated throughly to find out the best fabrication method. Three methods has been adopted for the fabrication of the green composite namely hand-lay, casting and vaccum infusion method.

4.2.1 Tensile test analysis for hand-lay method using single and double layer: Hand-lay method has been conducted for single layer and double layer. In single layer, only one layer of casting has been made and layer orientation has been selected considering the experimental findings. Initially bio-degradeable plastic has been placed at first layer but by visual inspection it has been observed the bonding between the fibers if jute plastic is placed in initial level or top level is not significant as shown in figure 4.5 but if the jute plastic is placed in between the jute and banana fiber layer the bonding will be strong enough.

Figure 4.5 Selection of layer arrangement for hand lay and vacuum infusion method

Different specimens were prepared for single layer and double layer arrangement. In single layer arrangement, jute-plastic has been placed in between the jute fiber and banana fiber sheet and with the same arrangement double layer has been origanized for necessary fabrication using eopoxy resin. Methodology for the fabricationof the green composite with hand lay method has been discussed in Article 3.4 and procee sequence is shown in figure 3.12 of chapter 3. The stress-strain curve obtained using the result from different single layer and double layer are shown in Figure 4.6 and Figure 4.7 respectively. Figure 4.6 reveals the average tensile strength of single layer sheet of three materials. The gauge length was fixed at 50 mm where width was

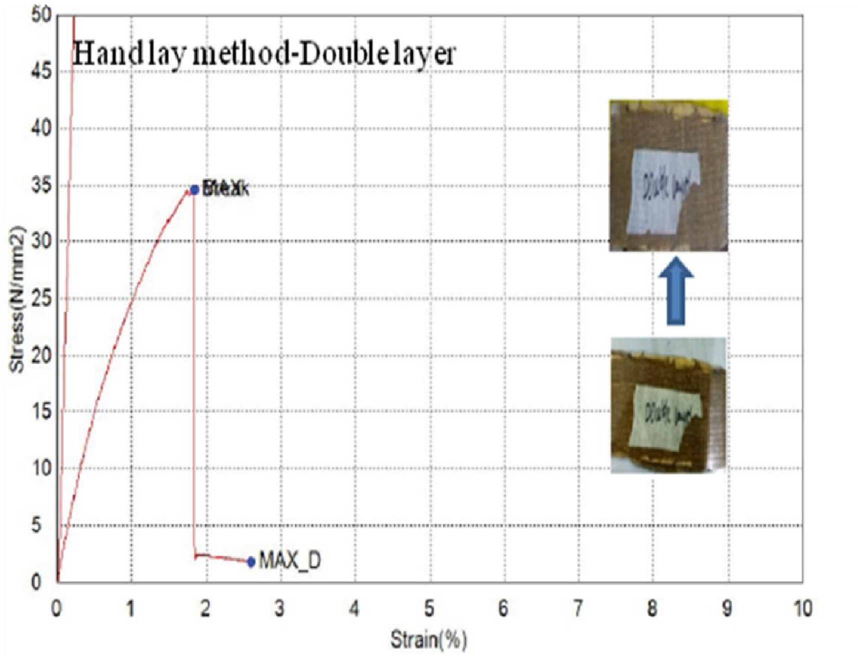
Name	Thickness	Width	Gauge_Length
Unit	mm	mm	mm
S5	1.8700	43.3900	50.0000



Name Parameters Unit	YP(%YP)_Time 0.2 % sec	Max_Force Calc. at Entire Areas N	Max_Stress Calc. at Entire Areas N/mm2	Max_Disp. Calc. at Entire Areas mm
S5	-.-	1650.29	20.3389	0.82142
Average	-.-	1650.29	20.3389	0.82142

Figure 4.6 Stress-strain relationship of single sheet fiber from hand lay method

Name	Thickness	Width	Gauge_Length
Unit	mm	mm	mm
S6	1.8200	39.5300	50.0000



Name	YP(%YP)_Time	Max_Force Calc. at Entire Areas	Max_Stress Calc. at Entire Areas	Max_Disp. Calc. at Entire Areas
Parameters	0.2 %			
Unit	sec	N	N/mm2	mm
S6	-.-	2490.38	34.6152	0.92139
Average	-.-	2490.38	34.6152	0.92139

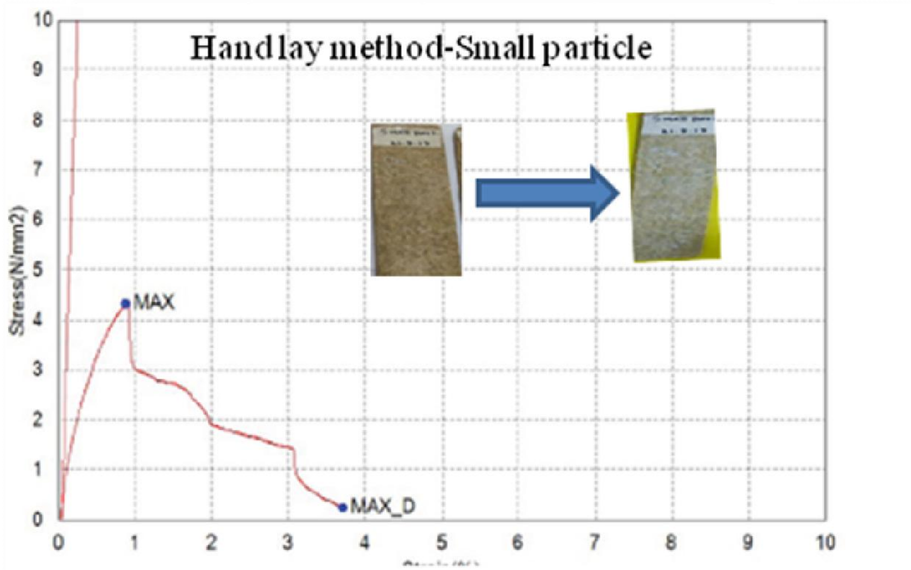
Figure 4.7 Stress-strain relationship of Double layer using hand-lay method

mesaured 43.39 mm and thickness approximately 1.87 mm. It has been observed that maximum utimate strength 20.3389 Mpa and fracture occure almost in the middle span of the specimen. Figure 4.7 reveals the average tensile strength of double layer specimen having the width approximately 39.53 mm and thickness 1.82 mm keeping the gauge length 50 mm. It has been found that the tensile strength is 34.61 MPa which is 73% higher that the single sheet layer specimen.

4.2.2 Tensile test analysis for hand-lay method using small and large particle: Two different types of particles having the fiber size 0.7 mm and 1.8 mm has been taken for the fabrication of casting process using hand lay method. All the different fibers namely banana, jute and jute plastic has been taken with equal quantity to do the casting process for the fabrication of the green composite materials for the tensile test analysis. The stress-strain curve obtained using the result from different small particle and large particle are shown in Figure 4.8 and Figure 4.9 respectively. Figure 4.8 reveals the average tensile strength of small particle fabricate green composite of three materials.

The gauge length was fixed at 50 mm where width was mesaured 44.96 mm and thickness approximately 5.32 mm. It has been observed that maximum utimate strength was 4.31449 Mpa and fracture occure almost in the middle span of the specimen. Figure 4.9 reveals the average tensile strength of large particle specimen having the width approximately 45.58 mm and thickness 3.98 mm keeping the gauge length 50 mm. It has been found that the tensile strength is 9.23 MPa which is more than double strength compared to single particle fabricated specimen.

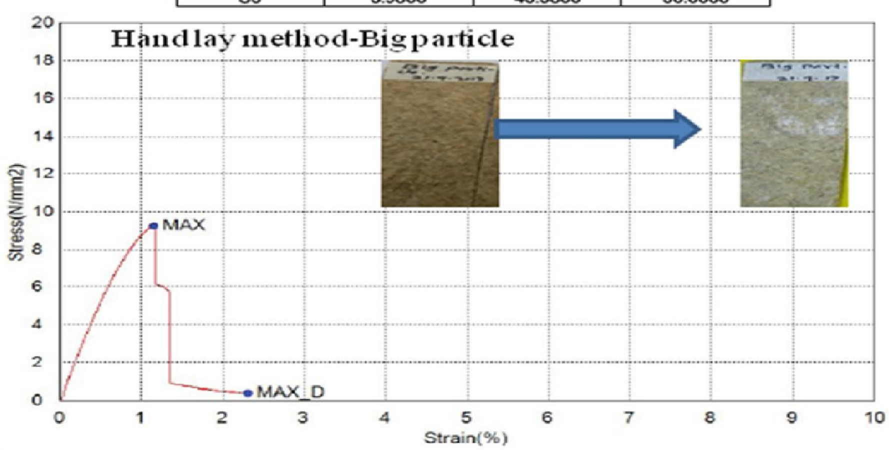
Name	Thickness	Width	Gauge_Length
Unit	mm	mm	mm
S4	5.3200	44.9600	50.0000



Name	YP(%YP)_Time	Max_Force	Max_Stress	Max_Disp.
Parameters	0.2 %	Calc. at Entire Areas	Calc. at Entire Areas	Calc. at Entire Areas
Unit	sec	N	N/mm2	mm
S4	-.-	1031.97	4.31449	0.43806
Average	-.-	1031.97	4.31449	0.43806

Figure 4.8 Stress-strain relationship of small particle casting using hand-lay method

Name	Thickness	Width	Gauge_Length
Unit	mm	mm	mm
S3	3.9800	45.5800	50.0000



Name	YP(%YP)_Time	Max_Force	Max_Stress	Max_Disp.
Parameters	0.2 %	Calc. at Entire Areas	Calc. at Entire Areas	Calc. at Entire Areas
Unit	sec	N	N/mm2	mm
S3	-.-	1675.46	9.23586	0.57808
Average	-.-	1675.46	9.23586	0.57808

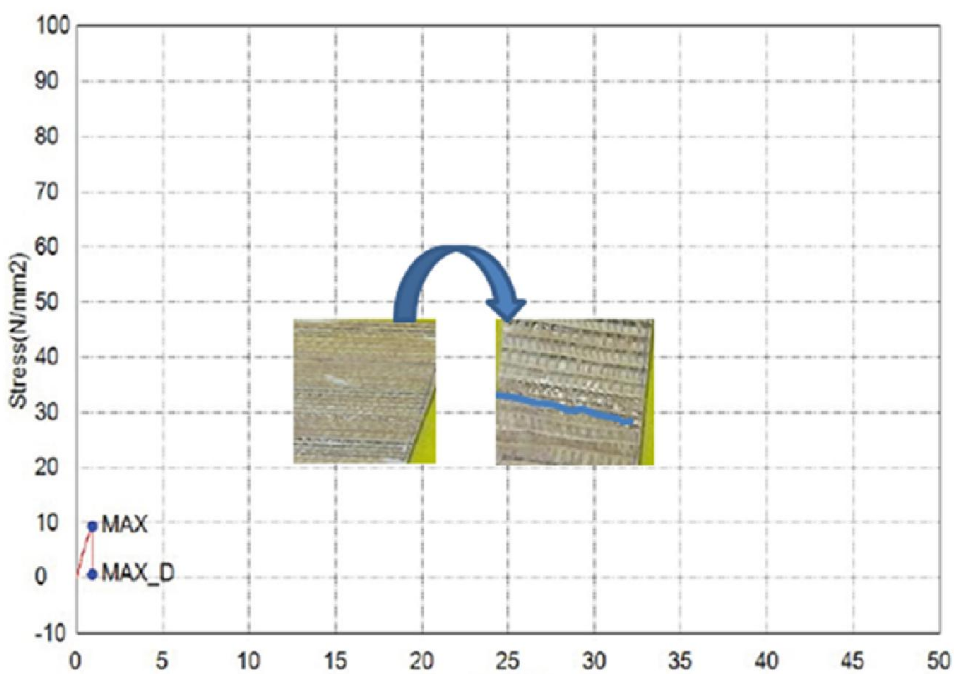
Figure 4.9 Stress-strain relationship of large particle casting using hand-lay method

4.2.3 Tensile test analysis for vaccum infusion method using single and double layer:

Vaccum infusion process has been used to fabricate composite materials from three different tyeps of fiber sheets using single layer and double layer arragment. The layer orientation was adopted keeping the jute fiber polythene in the middle section of the fibers of Banana and jute and repetaed accordingly. Fabrication of the green composite was made following the process sequence as mentioned in clause 3.5 of chapter 3.

Vacuum Infusion method (Single layer):

Name	Thickness	Width	Gauge_Length
Unit	mm	mm	mm
S1	2.0500	40.5300	50.0000

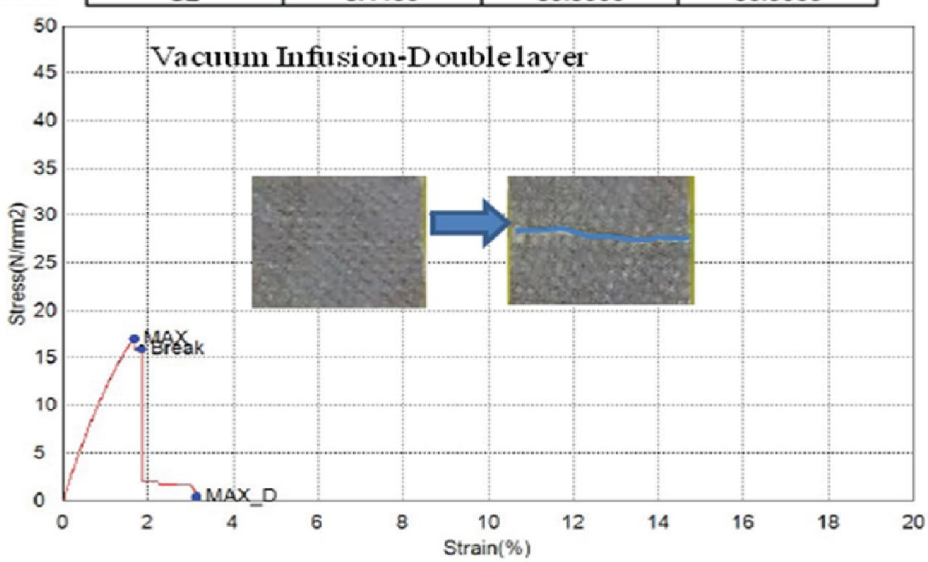


Name	YP(%YP)_Time	Max_Force	Max_Stress	Max_Disp.
Parameters	0.2 %	Calc. at Entire Areas	Calc. at Entire Areas	Calc. at Entire Areas
Unit	sec	N	N/mm2	mm
S1	-.-	761.890	9.16985	0.43705
Average	-.-	761.890	9.16985	0.43705

Figure 4.10 Stress-strain relationship of single layer using vacuum infusion method

The stress-strain curve obtained using the result from different single layer arrangement and double layer are shown in Figure 4.10 and Figure 4.11 respectively. Figure 4.10 reveals the average tensile strength of single fiber fabricated green composite using three materials. The gauge length was fixed at 50 mm where width was mesaured 40.53 mm and thickness approximately 2.05 mm. It has been observed that maximum utimate strength was 9.1695 Mpa and fracture occure almost in the middle span of the specimen. Figure 4.11 reveals the average tensile strength of large particle specimen having the width approximately 39.5 mm and thickness 3.44 mm keeping the gauge length 50 mm. It has been found that the tensile strength is 16.9644 MPa which is almost 85% higher strength compared to single layer fabricated specimen.

Name	Thickness	Width	Gauge_Length
Unit	mm	mm	mm
S2	3.4400	39.5000	50.0000



Name Parameters Unit	YP(%YP)_Time 0.2 % sec	Max_Force Calc. at Entire Areas N	Max_Stress Calc. at Entire Areas N/mm2	Max_Disp. Calc. at Entire Areas mm
S2	-.-	2305.13	16.9644	0.83723
Average	-.-	2305.13	16.9644	0.83723

Figure 4.11 Stress-strain relationship of double layer using vacuum infusion method

The different fracture pattern and obtained tensile strength for different method are shown in Figure 4.12. It has been observed that most of the conditions the fracture occurs at the middle pan of the specimen. Specimen obtained from double layer using hand lay method has the highest Tensile strength of 34.61 MPa whereas specimen obtained from hand lay using small particle has the lowest tensile strength of 4.31 MPa.

Method	Fracture pattern	Tensile strength (Mpa)
Vacuum Infusion-single layer		9.17
Vacuum Infusion-Double layer		16.96
Hand lay –Big particle		9.24
Hand lay –Small particle		4.31
Hand lay –Single sheet		20.33
Hand lay –Double Sheet		34.61

Figure 4.12 Fracture pattern and obtained Tensile strength

4.2.4 Impact test analysis for different composite using epoxy casting process: The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition. It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. A disadvantage is that some results are only comparative. The standard flexure test specimen is a piece 10 mm by 55 mm notched (ASTM A370) as shown in Figure 4.13. The specimen which is loaded as a simple beam is placed between two anvils so that the knife strikes opposite the notch at the mid span. As the pendulum falls, a hammer block secured to the outstanding end of the specimen strikes against two extended anvils, the specimen being ruptured as the pendulum passes between the two anvils.

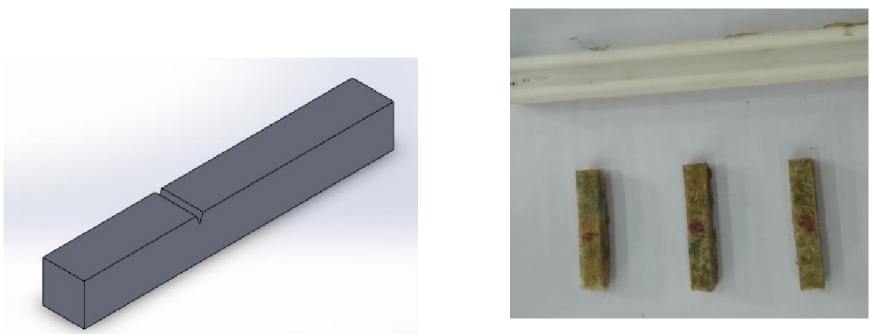


Figure 4.13: Standard flexure test specimen fabricated from natural fiber

It has been observed that most of the fabricated specimen ruptured at the middle location as shown in Figure 4.14.

Figure 4.14 Fabricated specimen ruptured behaviour

Three different fiber size of 0.75 mm, 1.8 mm and 3 mm has been taken for the fabrication of the impact test specimen. The fabrication procedure and testing method has been mentioned in article 3.3.5 in chapter 3. Figure 4.15 shows the effect of fiber size on impact laod of the casted green composite. It has been observed that medium fiber size 1.8 mm has the impact load compared to lower size or higher size fiber.

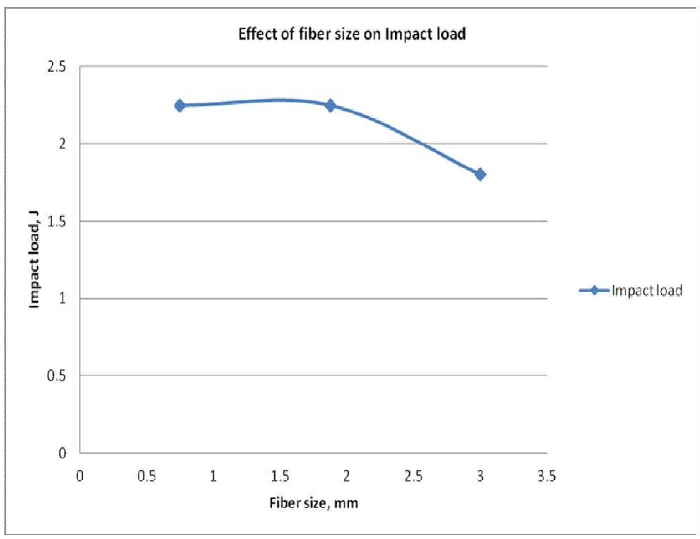


Figure 4.15 Effect of Fiber size on Impact load of the green composite

4.3 Investigation of the compressive load, developemnt of mathematiical model and FEM simulation.

4.3.1 Compressive load analysis for different cylidrical composite using epoxy casting proecess and coupling of the mathematical model with desirabilty analysis for optimizations.

4.3.2 Finite element simulation for flexure test analysis and comparison with the experimental results.

4.3.1 Compressive load analysis for different cylidrical composite using epoxy casting proecess and coupling of the mathematical model with desirabilty analysis for optimizations: In this section a detailed discussion has been made for the development of a mathematical model for the prediction of compressive load in terms of different fiber size variation along with weight ration of the grain weight and resin weight. Coupling of the mathematical model with desirability analysis for optimizations. Selection of the raw materials and process sequence and the mathematical model development sequence has been discussed in details and model was developed accordingly.

4.3.1.1 **Compressive load model by response surface methodology**

Compressive load model for green composite fabrication in terms of the parameters can be expressed in general terms as:

$$F = S * A^{x} B^{y} \text{.................................}(4.1)$$

Where F is the Compressive load, A is the Fiber size (mm), B is the weight ratio grain and resin weight ratio. S*, x and y* are model parameters to be estimated using the experimental results. To determine the constants and exponents, this mathematical model can be linearized by employing a logarithmic transformation, and Equation (4.1) can be re-expressed as:

$$\ln F = \ln S + x \ln A + y \ln B \text{ ....}(4.2)$$

The linear model of Eq. 5.2 is:

$$F = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 \text{ ....}(4.3)$$

where F is the true response of compressive load on a logarithmic scale $x_0 = 1$ (dummy variable), x_1, x_2 are logarithmic transformations of fiber size and weight ratio, respectively, while *β_0, β_1, and β_2* are the parameters to be estimated. Eq (5.3) can be expressed as:

$$\hat{F} = F - \varepsilon = b_0x_0 + b_1x_1 + b_2x_2 \text{ ....(4.4)}$$

Where $\hat{F}$ is the estimated response and F the measured Compressive load on a logarithmic scale, ε the experimental error and the b values are estimates of the β parameters. The second-order model can be extended from the first-order model equation as:

$$\hat{F}_2 = F - \varepsilon = b_0x_0 + b_1x_1 + b_2x_2 + b_{11}x_1^2 + b_{22}x_2^2 + b_{12}x_1x_2 \text{..........................(4.5)}$$

Where, $\hat{F}_2$ is the estimated response based on the second order model. Analysis of variance is used to verify and validate the model.

4.3.3.2 Independent variables and Coding levels:

For this experiment the upper limit and lower limit of the process parameters as shown in Table 4.2 are considered as follows:

Table 4.2: Upper limit and lower limit of the process parameters

Process Variable	Upper Limit	Lower Limit
A, Fiber Size (mm)	0.28	3.47
B, Ratio of grain (A)and resin (B) wt in gm	A:B 20.86	A:B 49.14

The range of the independent variables was coded from initial experimentation and the raw materials size and weight ratio considerations. Levels of independent and coding identification are presented in Table 4.3 for experiment.

Table 4.3Coding Identification for individual variable for epoxy resin casting of Green composite.

Levels Coding	Lowest $-\sqrt{2}$	Low -1	Centre 0	High +1	Highest $+\sqrt{2}$
A, Fiber Size (mm)	0.28	0.75	1.88	3	3.47
B, Ratio of grain and resin wt	20.86	25	35	45	49.14

4.3.3.3 Experimental design and Model development

The design of the experiments has an effect on the number of experiments required. Therefore, it is important to have a well-designed experiment to minimize the number of experiments which often are carried out randomly. In the experiment, small central composite design was used to develop the compressive load model. The analysis of mathematical models is carried out using Design-expert 6.0.8 package. Process conditions in coded factors and the measured compressive load values obtained experimentation are presented in Table 5.3. Experimental design has been made based on central composite design for two variables with five level factorials having 3 central points with 8 non-center point. 11 Experiment has been designed with the different combinations of fiber size and ratio of the grain wt and resin wt. Experimental conditions in coded factors and the measured compressive load are presented in Table 4.4.

Table 4.4 Compressive load results and process conditions in coded factors

Std Order	Coding of Level		Compressive load (kN)
	A, Fiber Size (mm)	B, Ratio of grain and resin wt	
1	-1	-1	24
2	1	-1	28
3	-1	1	38
4	1	1	24
5	-1.414	0	19
6	1.414	0	18
7	0	-1.414	20
8	0	1.414	30
9	0	0	14
10	0	0	12
11	0	0	11

The analysis of mathematical models was carried out considering the Fit and summary test as shown in Table 4, indicate that the quadratic CCD models was more significant than other model and it also proved that quadratic model has a significant lack of fit (LOF) as shown in Table 4.5.

Table 4.5: Selection of the model based on (a) sequential model of sum of squares and (b) Lack of fits tests

(a)

Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	5149.45	1	5149.45			Suggested
Linear	89.14	2	44.57	0.61	0.5883	
2FI	81.00	1	81.00	1.12	0.3251	
Quadratic	399.25	2	199.63	9.32	0.0206	Suggested
Cubic	11.36	2	5.68	0.18	0.8453	Aliased
Residual	95.79	3	31.93			
Total	5826.00	11	529.64			

(b)

Lack of Fit Tests

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Linear	582.74	6	97.12	41.62	0.0236	
2FI	501.74	5	100.35	43.01	0.0229	
Quadratic	102.48	3	34.16	14.64	0.0646	Suggested
Cubic	91.13	1	91.13	39.05	0.0247	Aliased
Pure Error	4.67	2	2.33			

Therefore, based on the analysis made by fit summary, the quadratic model was chosen in order to develop the CCD model. The second order compressive load model is given as:

$$\text{Compressive Force} = +89.40663 - 1.40405 * A - 4.56281 * B + 3.76955 * A^2 + 0.080208 * B^2 - 0.40 * A * B$$

Table 4.6: Analysis of variance (ANOVA) of quadratic CCD model

ANOVA for Response Surface Quadratic Model
Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	569.39	5	113.88	5.31	0.0453	significant
A	*16.29*	*1*	*16.29*	*0.76*	*0.4232*	
B	*72.86*	*1*	*72.86*	*3.40*	*0.1245*	
A^2	*128.53*	*1*	*128.53*	*6.00*	*0.0580*	
B^2	*363.30*	*1*	*363.30*	*16.95*	*0.0092*	
AB	*81.00*	*1*	*81.00*	*3.78*	*0.1095*	
Residual	*107.15*	*5*	*21.43*			
Lack of Fit	*102.48*	*3*	*34.16*	*14.64*	*0.0646*	*not significant*
Pure Error	*4.67*	*2*	*2.33*			
Cor Total	*676.55*	*10*				

The analysis of variance (ANOVA) as shown in Table 4.6 was used to check the adequacy of the developed model. As per the ANOVA test the calculated "F value" of the second-order model is 5.31 which indicates that there is only a 4.53% chance that a "Model F-value" this large could occur due to noise. The corresponding "Prob > F" for 95% confidence is less than 0.00500 as obtained from statistical tables.

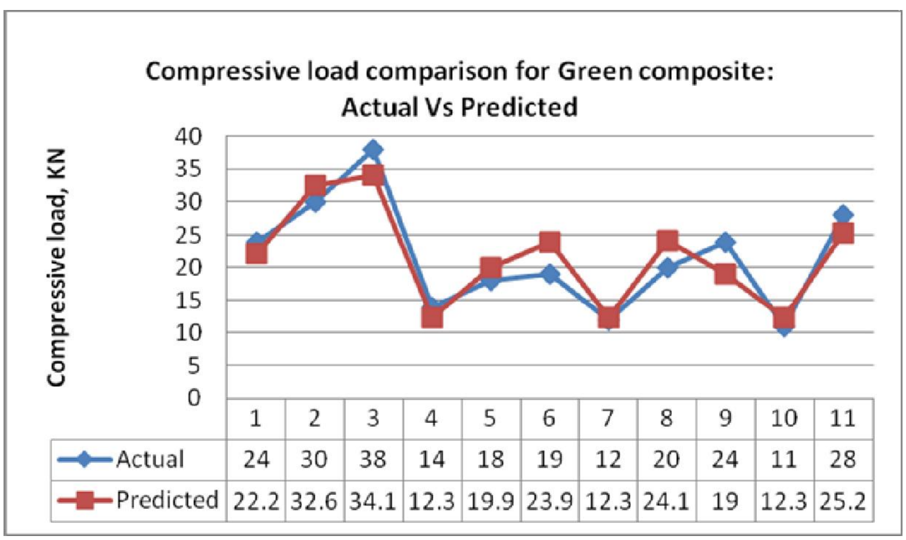
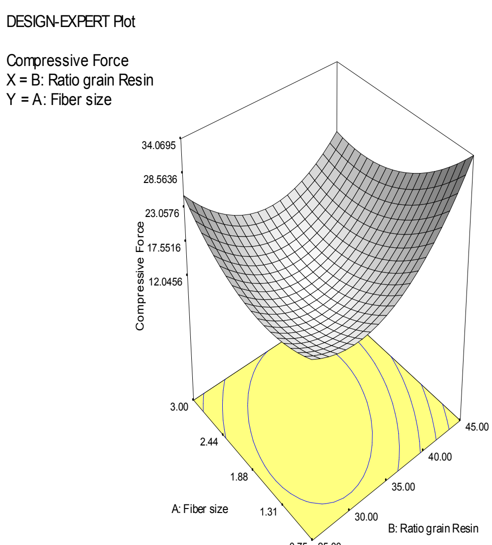


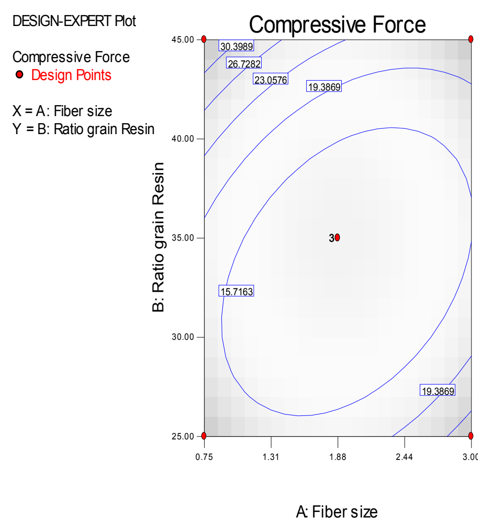
Figure 4.16: Compressive load comparison of experimental and quadratic CCD predicted values

Figure 4.16 shows the contours of actual results and the predicted values of quadratic CCD model. The graphs indicate that the quadratic model leads to closer results to the actual values. Figure 4.17 (a) shows the 3D-response surface of quadratic CCD model, Figure 4.17 (b) shows the 2D compressive load contour profile based on the effect of Fiber size and weight ratio of the fiber and resin with hardener on fabricated green composite compressive load and Figure 4.16 (c) shows the fracture patter of the compressed green composite. Most of the fracture pattern it appears that buckling occurs in the middle part of the composite cylinder.

(a)



(b)



(c)

Figure 4.17 - (a) 3D Response surface of the quadratic CCD model for green composite fabrication (b) 2D contour profile of compressive load with the variation of Fiber size and weight ratio of the fiber and resin with hardener. (c) Fracture behaviour of the compressed green composite

For the analysis of the developed quadratic model for compressive load prediction of green composite made from jute, banana and jute-bio-degradable plastic-a perturbation analysis has been done to assess the process parameter effcts on compressive load. Figure 4.18 shows the trace or perturbation plot with in the deign space at different process values. The intersaction of the lines is at the reference point and the actual conditions for the factors at the said point are as indicated in the Figure. It has been appeared that process paramer A & B has the similar trend that it move from left to right with a decresaing tendency upto a certain limit and then it strated to incresae.

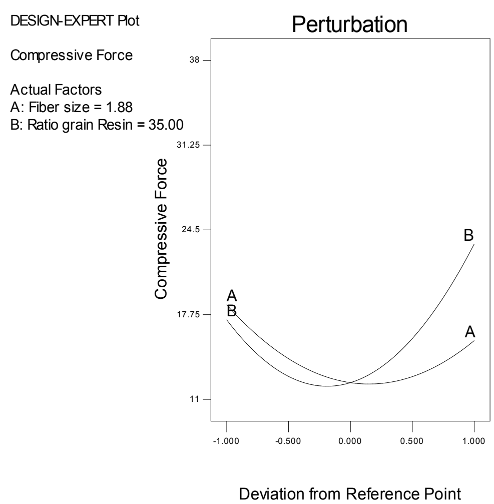


Figure 4.18: Effect of process parameters on compressive load by perturbation analysis for green composite fabrication. .

4.3.3.4 Result of Desirability Test:

Desirability function approach has been adopted to find out the maximum compressive load with the combination of the process parameters within the designed space limit considering the developed quadratic model as fitness function. If the desirability value is greater than 0.9 the values of process parameters was considered to be the optimum for giving maximum compressive load. Following table 4.7 shows the parameters and results of desirability function-

Table 4.7: Desirability test for optimum process parameters

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A	is in range	-1.414	1.414	1	1	3
B	is in range	-1.414	1.414	1	1	3

Optimum process parameters derived from desirability test				
	Fiber size (A)	Ratio grain Resin+hardner (B)	Compressive Force (kN)	Desirability
	1.10	48.50	39.4143	1.000

4.3.2 Finite element simulation for flexure test analysis and comparison with the experimental results: It is required to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are acceptable. The model of the green composite is made considering the layer arrangment and analyzed by finite element simulation using ANSYS software to extract the theoretical behavior of the green composite in case of bending test only. The dynamic behavior of the green composite beam is simulated using an ANSYS finite element model. The green composite layer arrangemnet used in the simulation, model matrix flexural, FEM ANSYS model and calculated distortion of the element mesh for a centre load at the middle are shown in Figure 4.19. The mechanical properties of the materials has been used from the experimental findings and literature review.

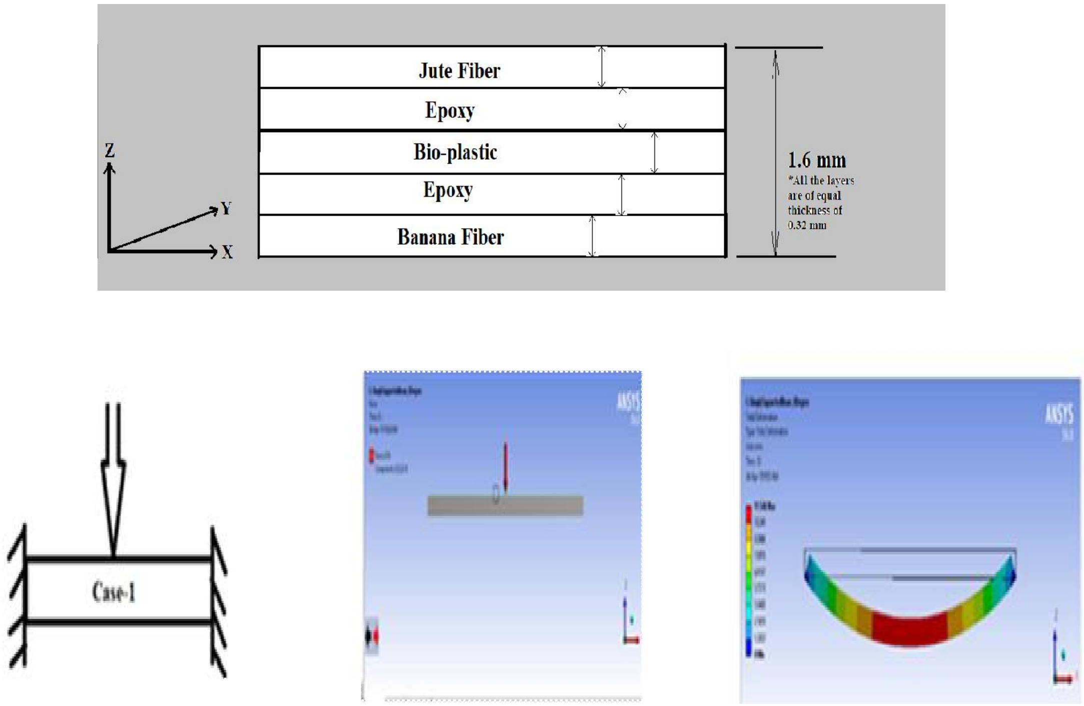


Figure: 4.19 model matrix flexural, FEM ANSYS model and calculated distortion of the element mesh for a centre load at the middle

Flexural strength was measured under a three-point bending approach using a bending test apparatus. The distance between the spans was 100 mm. Initially six different loads are applied in the centre point of the beam and the maximum deflection of the middle of the beam was recorded. Figure 4.20 shows the experimental set-up and load vs deflection curve of the green fabricated composite materials. It has been observed that with the increase of load the deflection in the middle span of the beam increases. Linear regression was made to predict the nature of the bending pattern with R-square value 0.9728.

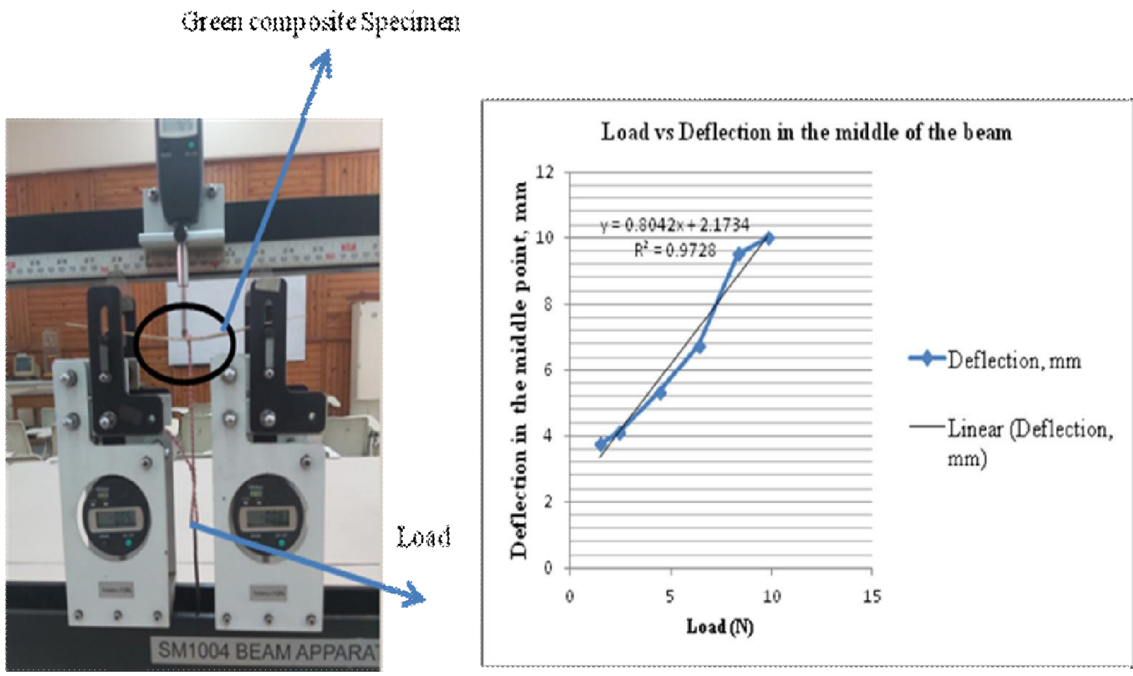


Figure 4.20 shows the experimental set-up and load vs deflection curve of the green fabricated composite materials.

The deformation pattern of the fabricated green composite beam along with the application of point load 10 N at the middle has been compared with simulated results and experimental one. Figure 4.21 shows the comparison between the calculated and experimental deflection pattern of the composite beam along the length wise. It has been observed that the calculated results showed good match with the experimental results.

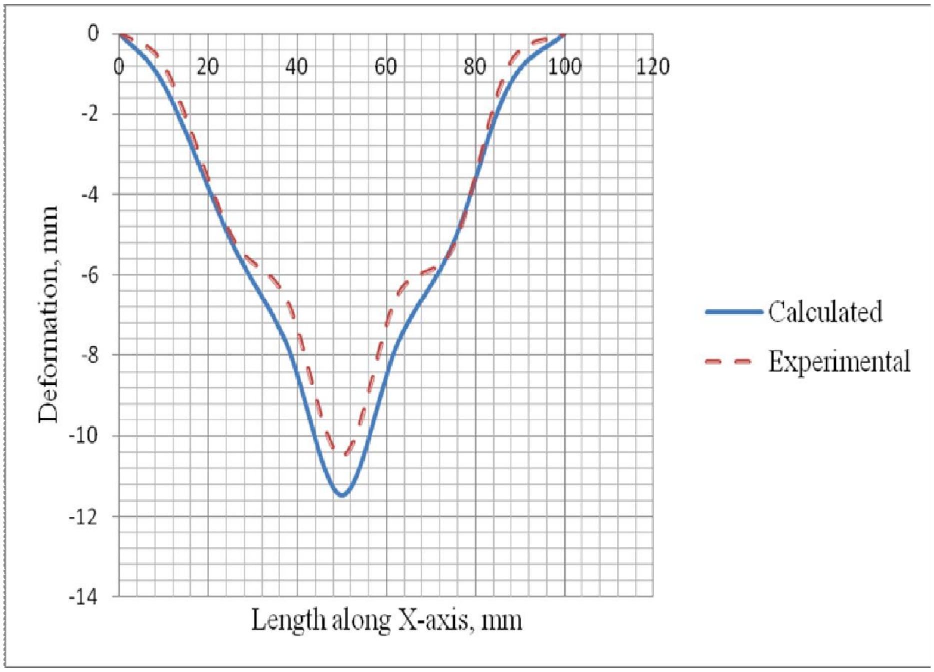


Figure 4.21: Comparison between the calculated and experimental deflection pattern of the composite beam along the length wise.

4.3.3 Strut test analysis of the fabricated composite: Strut analysis was made to find out the critical axial load of the fabricated composite. A strut apparatus has been used with digital load cell for the application of the applied load and digital micro-meter has been used to find out the maximum deflection at the middle span of the composite strut. It has been observed that initially the load was 10 N with minimum deflection and if the load applied gradually the strut withstand the maximum load up to 20 N and then the load is decreased and reached up to 13 to 14 N even with the increase of deflection. Up-to 10 mm deflection the load lies between 13 N to 14 N. Figure 4.22 shows the experimental details and load vs deflection curve of the fabricated composite materials.

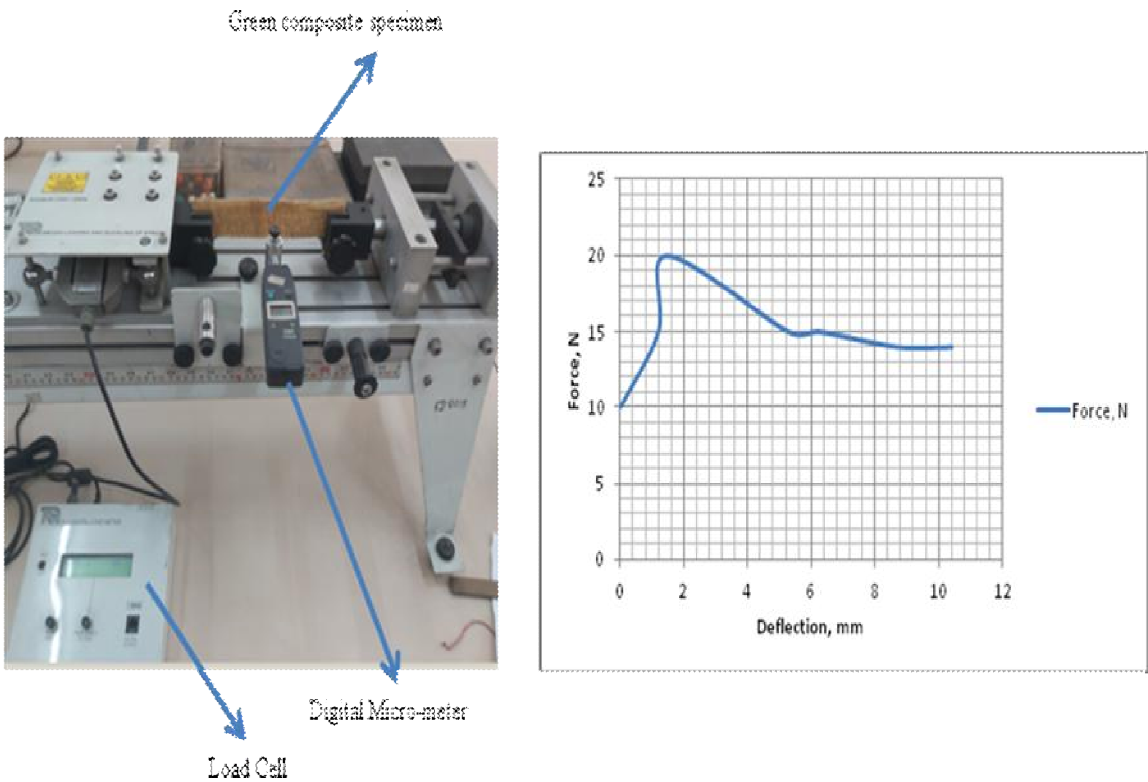


Figure 4.22: Strut Analysis and critical load determination of the green composite.

4.4 Fabrication of natural fiber composite tiles and investigate its applicability: An attempt was made to fbaricate the natural fiber tiles using the long fibers of three materials and fabrication was made by hand-lay method using epoxy casting processes. The fabricated tiles was prepared and drilling was made using 6 different types of drill bytes of diamter 1 mm, 2 mm, 3 mm, 4 mm, 5 mm and 6 mm respcetively.

Figure 4.23 Fabrication of natural fiber composite tiles

Figure 4.23 shows the tile fabrication process and drill operation made on the fabricated tiles using six different types drill byes. It has been observed that with small diameter drilling like 1 to 3 mm the delamination is fully controlled but with the increase of drill diameter the drilling induced delamination shows very significant. The circularity factor has been calculated using the formula as shown in equation 4.6.

CM= 4*pi*area/perimeter^2 ……………………………… (4.6)

The circularity factor has been calculated for all the drilled holes using different diameter drill bits are shown in Figure 4.24. It has been observed that with the increase of drill bit diameter the circularity factor changes. The CM factor is close to one for small diameter drill but it becomes less for higher diameter drill. Even at higher diameter drill the delamination observed by visual inspection compared to small diameter drilling.

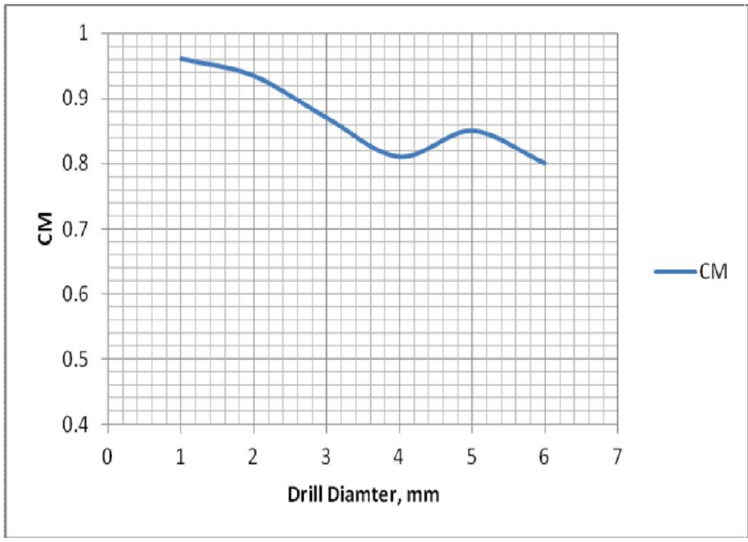


Figure 4.24: Variation of CM at different drill bit in the green composite tiles.

The circularity factor is close to 1 for a small diameter drill hole which indicates a perfect circular shape and whereas with the increase of drill diameter the circularity factor is less than which indicates non circular shape.

4.5 Applicability analysis of the fabricated composite: The applicability of the fabricated composite has been tested using absorption test, bio-degradable test and flammability test. The green composite made by hand lay method and vacuum infusion method was tested to investigate the water absorption, bio-degradable condition and flammability. The water absorption percentage (w) has been calculated using the following equation 4.7.

$$W = \frac{M_2 - M_1}{M_1} x100 \qquad (4.7)$$

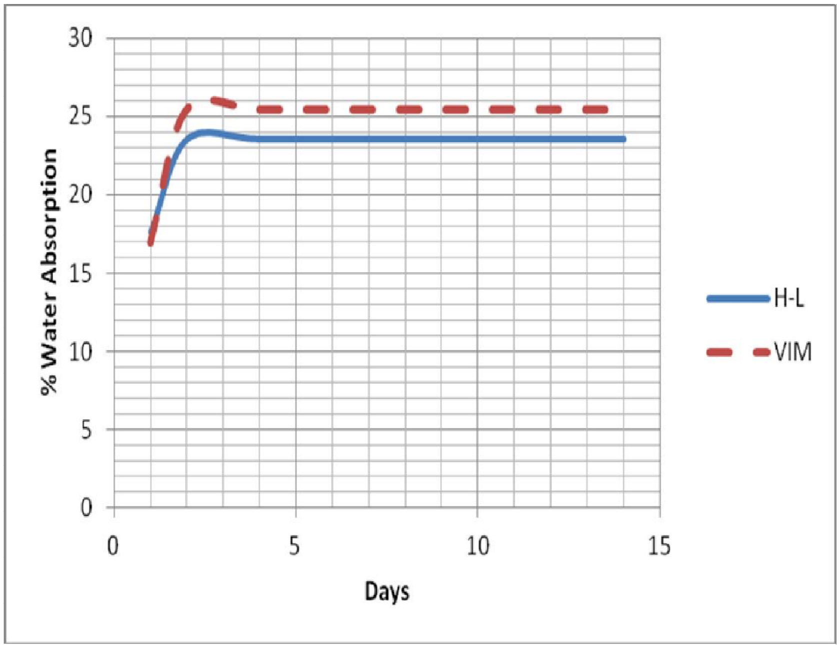


Figure 4.25: Percentage of water absorption of the green composite using two different methods

Figure 4.25 shows the variation of percentage of water absorption for hand-lay and vacuum infusion method. It has been observed that in first two days increases up to 24% to 25% and after that up to 14 days the water absorption percentage for both the fabricated composite shows no significant changes and the strength visually seems good.

Investigation has been made to find out the bio-degradable nature of the composite by placing the specimens inside the soil and it has been observed that after 14 days both the specimen degraded but the degradation seems slow. Figure 4.26 shows the specimen both made by hand-lay and vacuum infusion before and after 14 days of investigation. By visual inspection, it has been observed that the specimen stated to degrade.

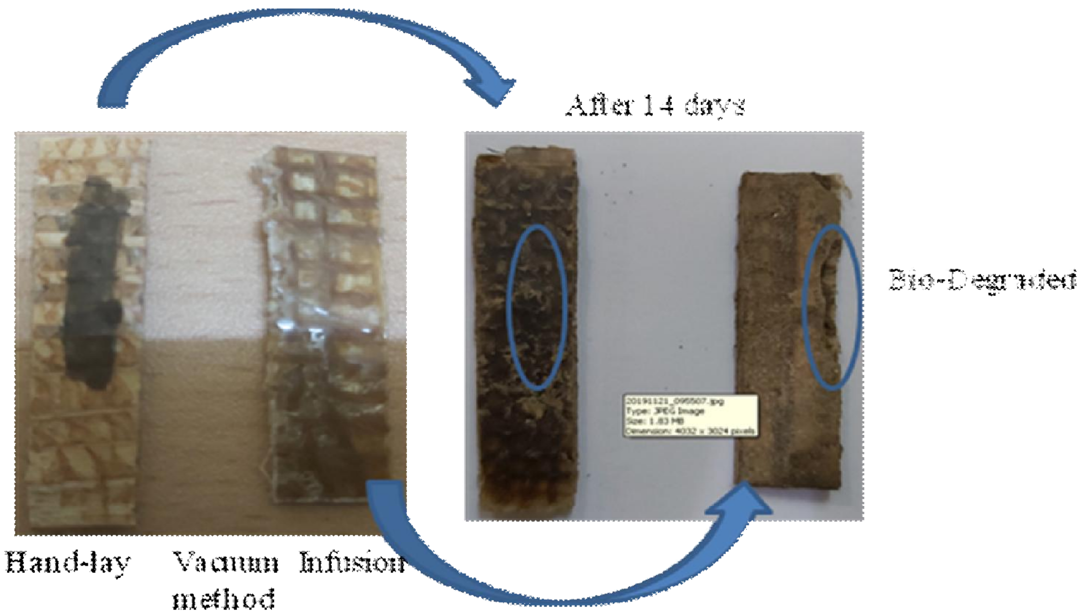


Figure 4.26: Specimen by hand-lay and vacuum infusion after 14 days

Small portion of the fabricated green composite was burnt and it appears that the materials ignite very quickly burn completely. The purpose of this review is to examine important aspects of the flammability of natural fiber-reinforced composites and to outline some of the findings. Burning was done by vertical test method and after the burning it has been observed that burned composite becomes charred black. Figure 4.27 shows the burnt composite of charred black. Initially the specimen weight was 0.57 gm but after burning the weight become 0.12 gm.

Figure 4.27: Burnt composite of charred black.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This thesis investigated the performance of three natural fibers for the fabrication of composite materials under different conditions by adopting different methods. Different parameters which affect the mechanical properties were studied by experimental investigations and mathematical modeling. From all these investigations and analysis, the following conclusions have been made and further studies may be done accordingly.

5.2 Conclusions:

1.0 A mathematical model has been developed for prediction and optimization of compressive load of newly fabricated composite materials from natural fiber in terms of fiber size and weight ratio in between fiber and resin and hardener combination. The developed model was considered as fitness function and coupled it together with desirability function approach to predict the optimum process parameters within the mentioned range. From the optimized data predicted from desirability analysis, it has been observed fiber size of 1.10 mm of equal length and weight for three different materials having the resin and fiber wt ratio 48 results the maximum compressive load of 39 KN.

2.0 It has been observed that both the process parameters have signification effects on compressive load. For constant weight ratio of resin and fiber at 35, it has been found that with the increase of fiber size from 0.28 mm to 1.88 mm the compressive load varied with a decreasing tendency from 19 KN to 14 KN but after that limit with the increase of fiber size from 1.88 mm to 3.47mm the compressive load reaches from 14 KN to 18 KN load with an increasing tendency. For constant fiber size at 1.88, it has also been found that with the increase of weight ratio from 20 to 35 compressive load varied with a decreasing tendency from 20 KN to 14 KN but after that limit with the increase of weight ratio from 35 to 49 the compressive load reaches from 14 KN to 30KN load with an increasing tendency. The general tendency of the developed model shows that up-to a certain limit with the combination of process parameters the compressive load goes down but at a certain point the compressive load is going to increase.

3.0 Mechanical Properties of Composites: Tensile test has been made for different specimen using different techniques and classified fiber. It has been observed that most of the conditions the fracture occurs at the middle pan of the specimen and maximum tensile strength of 34.61 MPa obtained from the specimen using double layer hand lay method whereas specimen obtained from hand lay using small particle has the lowest tensile strength of 4.31 MPa.

4.0 Different fiber size fiber of 0.75 mm, 1.8 mm and 3 mm has different impact load. Medium fiber size 1.8 mm has the impact load compared to lower size or higher size fiber.

5.0 The deformation pattern of the fabricated green composite beam along with the application of point load 10 N at the middle showed good agreement between simulated results and experimental one.

6.0 It has been observed that initially the load was 10 N with minimum deflection and if the load applied gradually the strut withstand the maximum load up to 20 N and then the load is decreased and reached up to 13 to 14 N even with the increase of deflection. Up-to 10 mm deflection the load lies between 13 N to 14 N because of delta pressure effect.

7.0 Variation of percentage of water absorption: It has been observed that developed composite materials absorbability up-to the saturation limit of maximum to 24% to 25% and become stable.

8.0 Developed composite has the bio-degradable, flammability nature. After 14 days, the specimen degraded but the degradation seems slow.

5.3 Recommendations

Recommendations for future studies may be made based on the conclusion of the current research.

_ A study on performance of improvement may be done by adopting processed fiber for the fabrication of the composite and comparison may be done for the analysis of improvement.

_ Study the effects of water absorption for the green composite considering the variation of the fabrication procedure with the different composition of the fibers.

_ Different grades of fiber types as reinforced will be studied to find out the optimum performance of natural fiber reinforced composite for different applications.

_ Study the behavior of long natural fiber as a filler materials at different angles reinforced composites.

_ In case of any materials specially engineering materials, the key issues are the long-term properties. The different long term properties like flexure, creep behavior at different process condition may be studied in future.

PAPER PUBLISHED

Anayet U Patwari, S. Alam Bhuiyan, Qumrul Ahsan, Iftakhar H. Khan, Nihon Rabbani [2019], Prediction and Optimization of Compressive Load of a Green Composite Material from Natural Fiber Using Statistical Approach, International Journal of Integrated Engineering, 11(7), 83-89, https://publisher.uthm.edu.my/ojs/index.php/ijie/article/view/5042.

PAPER TO BE SUBMITTED:

Evalutaion Of Newly Developed Green Natural Composite Fabrics Using Hand-Lay Casting Process

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