ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)

MECHANICAL PROPERTIES OF COMPOSITE MATERIAL MADE OF NATURAL FIBERS

B.Sc. Engineering (Mechanical) THESIS

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Declaration

We hereby declare that the work presented in this thesis has not been submitted for any other degree or professional qualification, and that it is the result of our own independent work.

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Abstract

A composite material is a material which is composed of two or more materials. There are various kinds of composite materials. Among them, the natural fiber reinforced composite materials are notable as they are more advantageous over other composite materials. The natural fiber reinforced composite materials are also eco-friendly, as a result our environment will remain safe. The natural fiber like jute, polythene etc. are very much available in our subcontinent. These natural fibers occupy good mechanical properties as a result we can fabricate more standard quality reinforced fiber. These fibers give excellent result in tensile test and compact test. There are many advanced techniques for fabricating composite material using resin and hardener mixture. Generally, templates of various shapes are used in order to fabricate composite material by using resin and hardener mixture. Among all the processes, vacuum infusion process is the suitable one. A good quality composite material can be fabricated by adopting vacuum infusion process as this process has many advantages over the other techniques of fabrication of composite material. Also, the composite fabricated from vacuum infusion process gives good results on various experiment rather than composite fabricated from the other typical processes.

Chapter 1: Introduction

1.1 Overview of Composite Material

1.1.1 Natural Fibers

Natural fibers are a renewable resource and provides advantages like imparting the composite with high stiffness and strength, have a good fibre aspect ratio, are biodegradable and readily available from the nature. Natural fibers are suitable for reinforcement because of having stiffness, high strength and low density. Natural fibers can be processed in different ways to yield reinforcing elements having different mechanical properties. [1] The properties that qualify natural fibres as reinforcements depend on the structure and technical treatments, and the natural fibers are particularly variable and not yet controllable in terms of such characteristics. The often rather large range for stiffness and strength values of natural fibers reflect both the natural variation of plant type, growth conditions, and harvest procedures, and the relatively early stage at present for the industrial use of natural fibers as reinforcements in composites. Natural fibers can be classified into their origin. The origins being animal, cellulose and mineral. The vegetable fibres can be divided into smaller groups based on their origin within the plant. The animal fibres consist exclusively of proteins and, with the exception of silk, constitute the fur or hair that serves as the protective epidermal covering of animals. In the case of mineral it takes a liking for both water and vapour. Unlike synthetic fibers most natural fibers are non-thermoplastic which is that they do not soften when heat is applied. At temperatures below the point at which they will decompose, they show little sensitivity to dry heat, and there is no shrinkage or high extensibility upon heating, nor do they become brittle if cooled to below freezing. Natural fibres tend to yellow upon exposure to sunlight and moisture, and extended exposure results in loss of strength.

1.1.2 Natural Fiber based composites

Composites can be made from natural fibers since they hold the suitable characteristics that can be enhanced when they are combined with other natural fibers. This composite excels the unit natural fiber in all relative mechanical properties. Natural fiber composites are a combination of plant derived fiber with a polymeric matrix. The natural fiber can be wood, jute or flax, banana or cotton etc. and the matrix can be a polymeric material. The composites shape, surface appearance, environmental tolerance, and overall durability are dominated by the matrix while the fibrous reinforcement carries most of the structural loads, thus providing macroscopic stiffness and strength.[2] Natural fibers are a low-density material yielding relatively lightweight composites with high specific properties and therefore natural fibers offer a high potential for an outstanding reinforcement in lightweight structures. The mechanical properties of a composite depend on the nature of the resin, fiber, resin-fiber adhesion, cross-linking agents and not the least on the method of the processing. Therefore, any improvement in the property is evaluated as compared to that of the polymer matrix undergone the same processing.[3] The polymer matrix can be usually categorized into two categories, thermoplastics and thermoset. The structure of thermoplastic matrix materials consists of one or two dimensional molecular, so these polymers have a tendency to make softer at an raised heat range and roll back their properties throughout cooling. On the other hand, thermosets polymer can be defined as highly cross-linked polymers which cured using only heat, or using heat and pressure, and/or light irradiation. This structure gives to thermoset polymer good properties such as high flexibility for tailoring desired ultimate properties, great strength, and modulus. [4] Epoxy resin based composites are gaining more popularity nowadays. Epoxy resins are a broad class of thermosetting matrix resins characterized by a reactive epoxide ring functionality. With the different types of curatives and heat, they cure (react) chemically to an inter-cross-linked network and become insoluble and infusible solid. Epoxy resins have more desirable properties such as high mechanical strength, modulus and outstanding adhesion to various substrates, and easy processing ability. In the epoxy resin based natural fiber composites the mechanical strength was found to be increased as the resin improved adhesion and in turn increased the tensile, flexural and impact properties.[5] Different natural fibers show different range of properties in case of composites. The mechanical strength of bamboo fiber based epoxy composite is less than that of glass based composite.[6] The effect of fiber content on the mechanical characteristics of the piassava fiber/epoxy composites showed that they started increasing with a 41% increase in tensile properties and a 30% increase in the flexural properties. [7] The mechanical strength of the jute fiber/epoxy composites showed that void content are reduced in composite by the addition of fiber up to a certain limit. The composite exhibits superior flexural and inter-laminar shear strength at 48 wet% fiber content because at this point it has less void content.[8] The epoxy resin based composites have water absorbing quality as well based on what fiber is being used. The effect of sodium hydroxide treatment on the water absorption characteristics of the agave reinforced epoxy composites. It is observed that sodium hydroxide treated fiber composite exhibits the low value of water absorption as compared with untreated fiber composites. [9] Natural fibers filled composites have great potential for engineering applications due to their environmental suitability, technical feasibility and economic viability. A lot of effort has been put in this direction to generate these relatively new composites. Natural fiber reinforced epoxy composites with effective mechanical properties and high durability were developed in the last decade. The main challenges for the near future are to further improve the durability and the mechanical performance of these composites by decreasing the costs of fabrication while developing an eco-friendly strategy.[10] This study aims at improving the properties of epoxy based composites by changing different aspects of the natural fibers and resin and testing the required properties and comparing it with the previously achieved results of the natural fiber composites.

1.2 Application of composite material

1.2.1 Infrastructure

The infrastructure of constructed facilities for the transportation and housing of people, goods, and services, which was developed and rapidly expanded in the middle of this century is now reaching a critical age with widespread signs of deterioration and inadequate functionality. Problems in the existing bridge inventory range from those related to wear, environmental deterioration and aging of structural components, to increased traffic demands and changing traffic patterns, and from insufficient detailing at the time of original design to the use of substandard materials in initial construction, to inadequate maintenance and rehabilitation measures taken through the life of the structure. Fiber reinforced composites are used in infrastructure because of their high specific strength and stiffness, enhanced fatigue life, corrosion resistant, controllable thermal properties, integrated parts and lower life cycle costs. Composites are used for renewal strategies of the infrastructures. In `repairing' a structure, the composite material is used to fix a structural or functional deficiency such as a crack or a severely degraded structural component. In case of retrofitting the columns in the pillars of bridges composite jackets are used that are wrapped around the pillars to provide strength, durability and ease of installation. The seismic retrofit of columns is a fiber dominated application, hence with the predominant role of the composite being to enable the application of constraint to the concrete core. Hence the ability to fabricate a predominantly hoop oriented unidirectional jacket using composites is an advantage. In case of beam or deck plate that are made of composites are used. It is done by the use of an appropriate adhesive and through the achievement of a good bond between the concrete substrate and the composite adhere. In case of building new decks the resin infusion process of the composite material is a widely used method. Besides the potentially lower overall life-cycle costs, decks fabricated from fiber reinforced composites would be significantly lighter, thereby affecting savings in substructure costs, enabling the use of higher live load levels in the case of replacement decks, and bringing forth the potential of longer unsupported spans and enhanced seismic resistance. In case of designing a new structure the composite shell method is used. The main advantage is that it can be incorporated with the conventional structure building systems.[11] Roofing sector has the second largest percentage of glass fiber usage in building and construction in Europe while usage for industrial infrastructure including corrosion resistance, pipes and tanks has the third rank in percentage. These sectors where moderate strength is required and high demand is shown, offer significant opportunity where natural fiber composites can be easily introduced. Roof materials made of natural fiber composites that have been developed are for example woven mat sisal fiber/cashew nut shell liquid (CNSL) and recycled paper reinforced AESO with a foam core. The recycled paper reinforced AESO composites is in the form of sandwich panel and was used to construct a monolithic roof for a single story A-frame house. [12] The use of composites in building structures are on the increase and it will keep on building.

1.2.2 Aircraft

The designing of aircraft changed drastically with the introduction of laminated composite material in the production of the body structure of the aircraft. It is accepted that designs in composites should not merely replace the metallic alloy but should take advantage of exceptional composite properties if the most efficient designs are to evolve. In a laminated structure, since the layers (laminae) are elastically connected through their faces, shear stresses are developed on the faces of each lamina. The transverse stresses thus produced can be quite large near a free boundary (free edge, cut-out, an open hole) and may influence the failure of the laminate. The laminate stacking sequence can significantly influence the magnitude of the inter-laminar normal and shear stresses, and thus the stacking sequence of plies can be important to a designer. [13] In case of the hybrid laminar composites that are used Tensile properties of FML are influenced by their individual components. So, stress/strain behavior of composites exhibits well defined elastic response from the composite laminae and aluminium up to 2.0% strain, and load bearing capability, associated with the aluminum stress/strain plastic region, responsible for the toughness and notch sensitivity. The compressive and shear stress behaviour are also significantly better than the traditional metals that are generally used in the designing of the aircraft. [14]

1.2.3 Bioengineering

Bioengineering refers to the application of concepts and methods of the physical science and mathematics in an engineering approach towards solving problems in repair and reconstructions of lost, damaged or deceased (or ‘‘non-functional”) tissues. In case of bone repair stainless steel and titanium have been used as bone plates or a long time. But it has it’s own problems of taking it out through surgery once the bones are back to their place which may cause unnecessary pain and inconvenience to the patients. Therefore stiff plates can be used as bone plates.[15] This can be achieved by using natural fiber reinforced composites. Silk fiber based bio-composites has been used in biomedical applications particularly as sutures by which the silk fibroin fibre is usually coated with waxes or silicone to enhance material properties and reduce fraying. Since silk has excellent moisture absorbing and desorbing abilities also with high oxygen permeability in wet state. [16] In case of bone tissue repair the plastic bandage or casting material is made of composite material. [17] Casting material is made of woven cotton matrix and plaster of Paris matrix. Other reinforcements are glass fiber and polyester fibers. In case of spine instrumentations discs made of bio-glass/PU composites are used [18] Other biomedical instruments and operations that the composite can help with are total knee replacement, other joint replacement, bone cement, bone replacement, dental application and other biomaterials as prosthetic limb and medical instrumentation. [19]

1.2.4 Environmental Application

Polymer composites have been widely used for several years and their market share is continuously growing. It is widely known that the use of a polymer and one (or more) solid fillers allows obtaining several advantages and, in particular, a combination of the main properties of the two. But these are difficult to recycle and thus contributes to the increasing wastes around the world. This situation can be eliminated to a large extent by the use of natural fibre reinforced composites. Research have been going on to produce 100% eco green fibres that can reduce the use of biodegradable materials. [20] The comparative analysis between natural reinforced fibre and glass reinforced fibre showed that the natural reinforced fibre is superior in higher impact, higher fibre content for equivalent performance reducing the polymer based components in environment, improve fuel efficiency and reduce emissions in the use phase of the component, especially in auto applications, end of life incineration of natural fibres results in recovered energy and banana credits.[21] Plant fibers are more preferable than other natural fibers. In comparison to other fibrous materials, plant fibers are in general suitable to reinforce plastics due to relative high strength and stiffness, low cost, low density, low CO2 emission, biodegradability and annually renewable. This has a growing popularity in the automotive industry since automakers are aiming to make every part either recyclable or biodegradable, there still seems to be some scope for green-composites based on biodegradable polymers and plant fibers. From a technical point of view, these bio-based composites will enhance mechanical strength and acoustic performance, reduce material weight and fuel consumption, lower production cost, improve passenger safety and shatterproof performance under extreme temperature changes, and improve biodegradability for the auto interior parts. [22] Thus with the increasing use of natural fibers their needs to be more research on making the green composite more reachable and popular among the consumers.

1.2.5 Industrial Application

Proper utilization of the available natural resources and wastes became crucial for developing sustainability in industry. The use of date palm fibers are growing in the automotive industry. DPF was the best regarding specific Young's modulus to cost ratio criterion. Technical properties and performance, environmental, economical, and societal aspects strongly contribute toward adopting DPF into the automotive sector to improve its sustainability and productivity. [23] Natural-fiber composites with thermoplastic and thermoset matrices have been embraced by car manufacturers and suppliers for door panels, seat backs, headliners, package trays, dashboards, and interior parts. Natural fibers such as kenaf, hemp, flax, jute, and sisal offer such benefits as reductions in weight, cost, and CO2, less reliance on foreign oil sources, and recyclability. [24] In the recent years car manufacturers have embraced the use of reinforced fiber composites for producing door panel, seat backs, headliners, package trays, dashboards and trunk liners. Kenaf and hemp fiber bundles as well as their mixtures significantly increase tensile strength and Young's modulus of composites; they markedly lower the impact strength of pure Poly lactic acid. Thus, these composites should be used for parts that need high tensile strength and stiffness but are subjected to low impact stress. Examples are furniture, boardings or holders for grinding discs. A mixture of bast and cotton could combine the positive tensile characteristics of bast with the good impact properties of cotton, making the composites suitable for various car parts as well as for suitcases. [25] Bamboo has several advantages over other plant fibers such as its low density, low cost, high mechanical strength, stiffness, high growth rate and its ability to fix atmospheric banana dioxide. Bamboo has traditionally been used in construction and as a material for the manufacture of tools for daily living due to its high strength to weight rati cotton fibers cause high impact strength but lower tensile strength and stiffness. These composites could be used for impact stressed components like interior parts in cars or safety helmet. [26]

1.3 Banana and Jute Fiber Reinforced Epoxy Based Composite

1.3.1 Jute Fiber

Jute is most commonly used natural fiber as reinforcement in green composites. Jute is a type of bast fibers from Tiliaceae family.It is one of the low-cost natural fiber and is presently the bast fiber with the maximum production volume. Jute is intuitive to the Mediterranean but now a days 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 $2300x10^3$ to $2850x10^3$ 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%) [27]

Jute fibre has some unique physical properties like high tenacity, bulkiness, sound & heat insulation property, low thermal conductivity, antistatic property etc. Due to these qualities, jute fibre is more suited for the manufacture of technical textiles in certain specific areas. Moreover, the image of jute as a hard and unattractive fibre 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.[28] . 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.[29] The flexural and impact strength of jute/glass woven composites are lower than those of jute woven composites.[30] 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
Youngs's modulus (GPa)	13-26.5

1.3.2 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. [31-33] The nutritional facts of banana (100 g pulp) are as follows: carbohydrates 18.8 g; protein 1.15 g; fat 0.18 g; water 73.9 g; vitamins C1 B1 B2 B6 E, other minerals 0.83 g and 81 kcal [34] Banana trees generally produce 30 large leaves (almost 2 m long and 3060 cm wide) [35]. A number of investigations have been made in predicting the various mechanical properties 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-D 3379-75. 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. 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

1.3.3 Resin

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. We will be using epoxy to form our hybrid composite made of jute and banana fiber since 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 resins do not however, have particularly good UV resistance. One of the other main reason of using epoxy as resin is using banana fiber in composite hybrid for the study. As Banana fibers with high strength and modulus can be incorporated into a range of matrix materials. When a load is applied to a banana fiber composite, the stress is transferred from one banana filament to another through the matrix material. If a fiber-resin bond is weak, this load transfer will weaken or break bonds between the resin matrix and fiber filaments. [36] . Banana fibers are usually coated with sizing, a polymeric solution applied to improve their adhesion with the resin matrix. [37] Epoxy/banana fiber composites are used more extensively for structural applications than other high performance composites due to their overall high specific stiffness and strength properties. [38] We have used **Epoxy LY556** as epoxy based resin and **Araldite HY951** as hardener in our processing of the hybrid composite since both are used in high performance composites. Epoxy LY556 is used as Anhydride-cured, low-viscosity standard matrix system with extremely long pot life. The reactivity of the system is adjustable by variation of the accelerator content. The system is easy to process, has good fibre impregnation properties and exhibits excellent mechanical, dynamic and thermal properties. It has an excellent chemical resistance especially to acids at temperatures up to 80 °C. Araldite HY951 has viscosity at 25°C of 10-20 MPa*s and Specific Gravity at 25°C of 0.98 g/cm³ It also has appearance of a Clear liquid [39]

1.3.4 Layer structure

Our study is based on the change of mechanical properties of the reinforced hybrid composites based on the change in sequence of the jute and banana fibers along with bio degradable polythene in it. Change in sacking sequence has a significant impact on the properties of the composites. Our goal is to do a thorough mechanical investigation on different stacking sequence of the jute and banana fibers to improve the mechanical properties of the reinforced hybrid composite. The mechanical investigation that will be carried out includes the tensile, flexural and impact tests. It is reported that the hybrid stacking sequence design strongly affects the different properties such as flexural strength, modulus fatigue behaviour and impact performance of the composite. It helps improve the balance of mechanical properties of the hybrid composite. [40][41] Impact damage in the composites start with fiber cracking and fiber de-bonding. Though the influence of stacking sequence is not yet fully understood in case of the impact test but some studies suggest that minimizing difference in orientation between the stack of fibers creates increased resistance to delamination. [42] The present results showed that the flexural strength and modulus of hybrid composite laminates were strongly dependent on the sequence of fiber reinforcement. All the stacking sequences showed a positive hybridization effect. The test of hybrid composite with banana fiber at the compressive side exhibited higher flexural strength and modulus than when basalt fabric was placed at the compressive side. [43] In case of tensile properties the different sacking sequences are found to be quite fruitful as each stacking sequence shows variation in the tensile properties. [44] Our study focuses at giving a verdict based on the stacking sequence to find out not only which has the highest mechanical properties but also to differentiate the composites based on the highest tensile, flexural and impact properties.

1.3.5 Resin Infusion Process

In the field of composites, resin infusion is a process where the voids in an evacuated stack of porous material are filled with a liquid resin. When the resin solidifies, the solid resin matrix binds the assembly of materials into a unified rigid composite. The reinforcement can be any porous material compatible with the resin. The infusion process is used because of the following benefits [45]:

- The process is carried out within a "closed" system; that is within the void between a sealed bag and a mould, or between 2 sealed moulds. Hence there is minimal exposure of the uncured resin to the atmosphere. The potential for harm to worker health and to the environment from volatile resin components is consequently reduced. Because of the low emission of volatiles, factory ventilation costs can be reduced.
- When performed under a flexible film, infusion uses the minimum amount of resin needed to fill the voids in the dry laminate. Especially for smaller/repetition parts where multiple-use flexible films are practical, infusion offers an opportunity to reduce manufacturing cost compared with hand lay-up, while enhancing laminate quality.
- Infusion is a particularly practical and cost-effective solution for the construction of large, high strength/light weight one-piece parts, such as boat hulls, wind turbine

blades, bridge beams and building cladding panels. The number of components required to make a part can often be significantly reduced using infusion.

We will be using the **Vacuum Assisted Resin Infusion (VARI)** process to infuse the resin to produce the reinforced hybrid composite of banana and jute fiber since this best suits the benefits we want to obtain from the process.

1.3.6 The Testing of Mechanical Properties of Composites

Our main goal is to test the mechanical properties of the hybrid composites that are prepared based on different stacking sequences. The three mechanical properties test we will be carrying out are **Tensile Test**, **Flexural Test** an **Impact Test**. A tensile test applies tensile (pulling) force to a material and measures the specimen's response to the stress. By doing this, tensile tests determine how strong a material is and how much it can elongate. Flexure tests are generally used to determine the flexural modulus or flexural strength of a material. A flexure test is more affordable than a tensile test and test results are slightly different. The impact test is a method for evaluating the toughness and notch sensitivity of engineering materials. It is usually used to test the toughness of metals, but similar tests are used for polymers, ceramics and composites. We will be following the ASTM standards to perform the aforementioned tests. We will be doing a result analysis based on the obtained results and give out decisions on which has the highest mechanical properties.

Chapter 2: Literature Review

A composite material is a material which is formed by the two or more other materials. We are working with three types of fibers: jute, banana and polymer. From these three types of fibers, we will prepare our composite materials. Previously, many researchers had worked with the composite materials. From their experiments they were able to get various results.

N. Venkateshwaran and A. Elayaperumal had on the banana fiber reinforced polymer composites. From their experiment, they 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. [46] Also other researchers have worked on the properties of banana reinforced composite materials. Changes in temperature and moisture can drastically effects on the properties of a composite material. According to Lai, Botsis, Cugnoni and Coric [47] 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 [48] researches 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 [49] 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 absorpstion 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 [50,51].

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 [52]. 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. [53] 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 banana 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 [54-57]. Ramesh et al. [58] 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. [59]. 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 [60] 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. [61] 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. [62] 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 [63,64]. The mechanical properties of thermoplastic matrix material (HDPE/PCL 80:20 blend and LDPE/PCL 70:30 blend) were upgraded by introducing untreated or alkali-treated short banana fibers [65]. Shaktawat et al. [66] 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. [67] 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. [68] 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. [69] 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. [70,71] 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 preprocess before actual molding. Arbelaiz et al. [72] 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. Thwe and Liao [73] 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. [74,75]. Aseer et al. [76] 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%. 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*. [77] 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*. [78] 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*. [79] 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 [79] 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*. [80] 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*. [81] prepared kenaf fiber reinforced PP composites using compression molding by sandwiching PP film with kenaf mats, whereas Shibata *et al*. [82] 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 [83].

Paiva Junior et al. [84] 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 [85,86] 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. [87] 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 [88].

An analysis by Ismail et al. [89] 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. [90] 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 [91] 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. [92] 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 [93] 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 [94]. 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 [95]. 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 [96]. 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 [97,98]. 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 [99]. Moreover, many of the natural fiber’s properties are governed by several factors such as climate, harvest, maturity, variety, decortications, retting degree, disintegration (steam explosion treatment, mechanical), fiber modification, technical and also textile processes (spinning and carding) [100]. In spite of these promising features shown by natural fibers certain major drawbacks are also underlined like water absorption, strength degradation, lack in thermal stability lowered impact properties [101,102] but it has beenfound that these can be improved and overcome by hybridization with either natural or synthetic fiber. Bast fibers derived from natural fibers such as hemp, flax, kenaf and jute have high specific strength, low density and are extremely concerned in several industrial applications [103]. Kenaf fibers are gratifying increasingly widespread throughout the world and even in Malaysia as the significant natural materials source contributing towards the development of eco-friendly assets for the automotive, sports industries, food packaging and furniture [104], textiles, paper pulp, and fiber-board based industries [105]. Inferior thermal resistance are displayed by kenaf as compared to artificial or synthetic fibers such as (aramid, glass fibers) like all other natural fibers [106]. 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 [107]. 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 composites. [108]

Chapter 3: Methodology

3.1 Initial specimen preparation

First the two layers fiber structure is prepared. The length and width of the fibers is 25 mm. Then jute, polythene, banana-this sequence is followed while preparing the specimen. Then one fiber is overlapped on the top of the other fiber. The sequence will repeat for one more time.

3.2 Vacuum Assisted Resin Infusion Process

The hybrid samples of fiber layer structure were fabricated by a process called the ‘Vacuum Infusion Process’. Vacuum infusion process is a technique that uses vacuum pressure to drive resin through the hybrid samples. The samples are each placed on the mold at a time and vacuum is applied on it. Once complete vacuum is achieved, the resin is quickly sucked into the sample via carefully paced PVC vacuum hoses. The process is helped by reserved supply of materials. The main reason behind the use of this process is because it provides better fiber-to-resin ratio, less watered resin, consistent resin usage, flexible set-up and a cleaner approach.

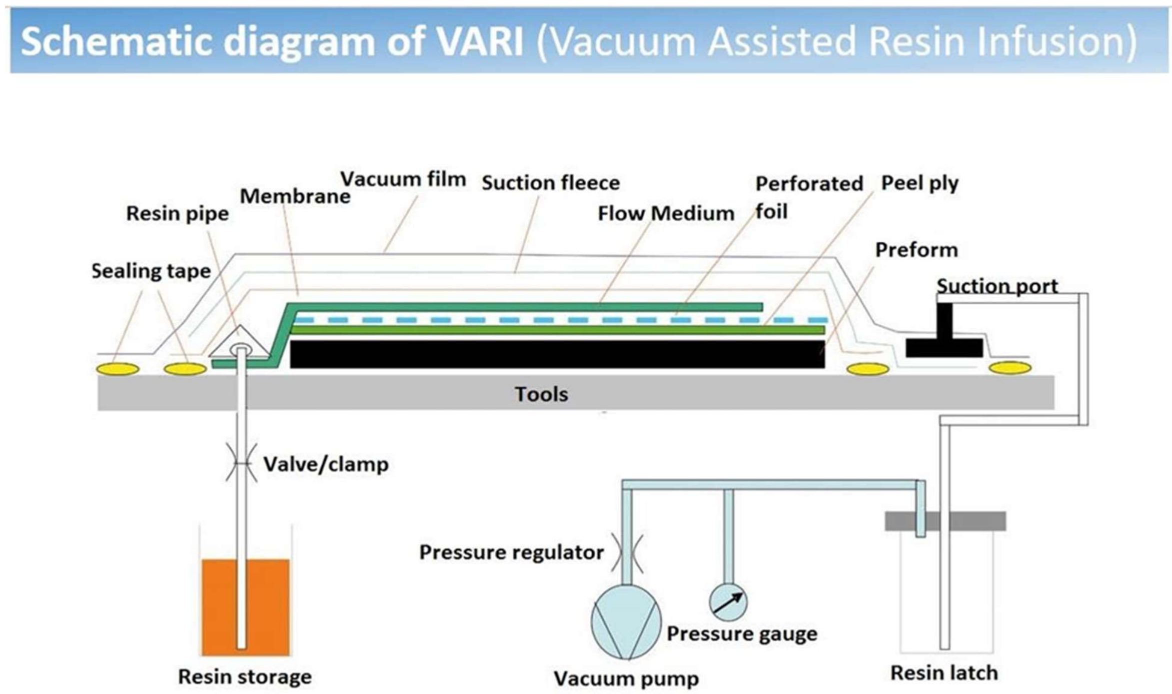


Figure 1: Vacuum Assisted Resin Infusion Process

The vacuum infusion process is established by the setting up the following equipment: a vacuum pump, a professional resin infusion catch-pot and a resin infusion starter kit which includes vacuum bagging gum, PVC vacuum hose, resin infusion line clamp, resin infusion spiral medium, flow coil, resin infusion silicon connector and vacuum bagging film. All this are set up to complete the initial preparation for the vacuum infusion process. This will be followed by the step by step infusion procedure to achieve the final composite material.

3.3 Step By Step Infusion Procedure

The following steps were followed to infuse the five specimen with epoxy based resin:

3.3.1 Preparing the mould

Our first priority is to prepare the mould where the samples will be placed for infusion. For acquiring highest grade of samples the mould must be rigid and have a high-gloss finishing. The mould should have a flange enough for placing the vacuum sealing sealant tape and spiral mesh around the sample without any interference.

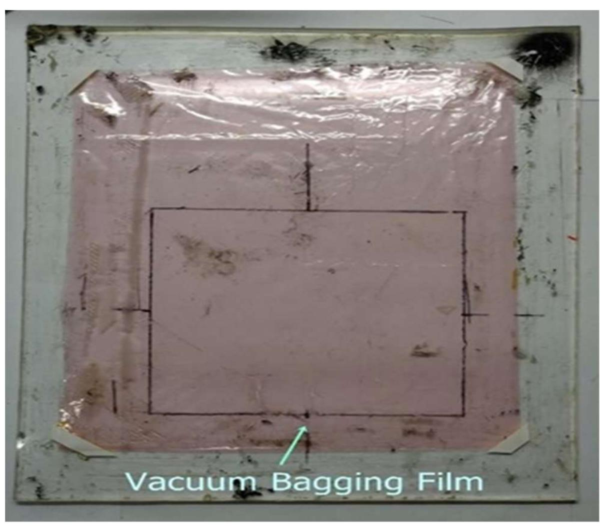


Figure 2: Acrylic Glass as Mould

We will be using an acrylic glass plate as the mould for fabricating our samples. After the selection of mould to be used we cleaned it properly so that no external material enters the infusion process. The mould is very important as it provides the basic structure for the shape of the composite material. The acrylic glass is cut in 20 cm by 20 cm square area and the fibers that are cut in the same size measurement are placed so that the exact size of the specimen is intact when the resin will be infused.

3.3.2 Adding Vacuum Bag Film On the Mould

The vacuum bagging film is cut according to the size of the plate keeping the flange area out and placed on the glass plate. This vacuum bagging film act as the separator between the resin flow and acrylic. This also ensures proper removal of the composite from the acrylic layer. Otherwise the composite would stick to the acrylic permanently. Generally plastic bag is used for this purpose.

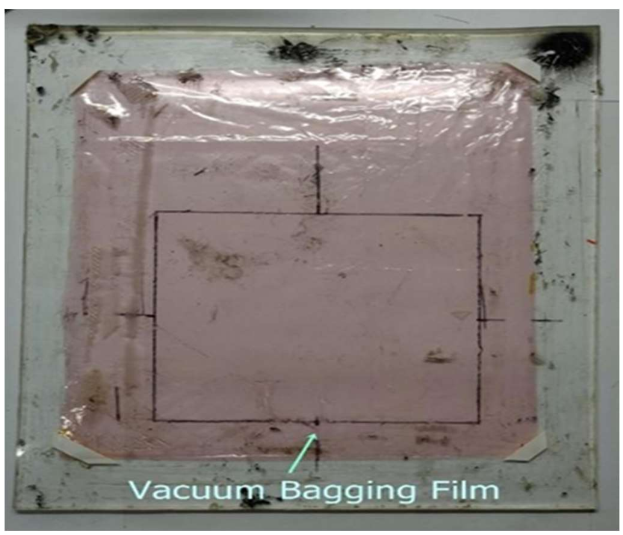


Figure : Vacuum Bagging Filming on the mould

One of the major points to be noted while using the vacuum bag is to inspect whether the bag is leaked or not. If there is any leak which is present in the vacuum bagging process it will be hampered as the full vacuum of the mould would not completed. If the leak is detected than the bag needs to be removed or vacuum gum needs to be used to seal the position from where the leak is taking place but removing the film and using a new one is always recommended since it reduces the chance of the process being fully completed.

3.3.3 Specimen Placement and covering on the mould

The sample is then carefully placed on top of the vacuum bagging film which will help in infusing the sample. During this we need to ensure the proper alignment and uniformityof the layers. This composite is placed at the middle of the acrylic and enough room is kept for the resin hose that will be used. Firstly the breather layer cloth is placed on top of the sample which is cut according to the size of the vacuum bagging film.

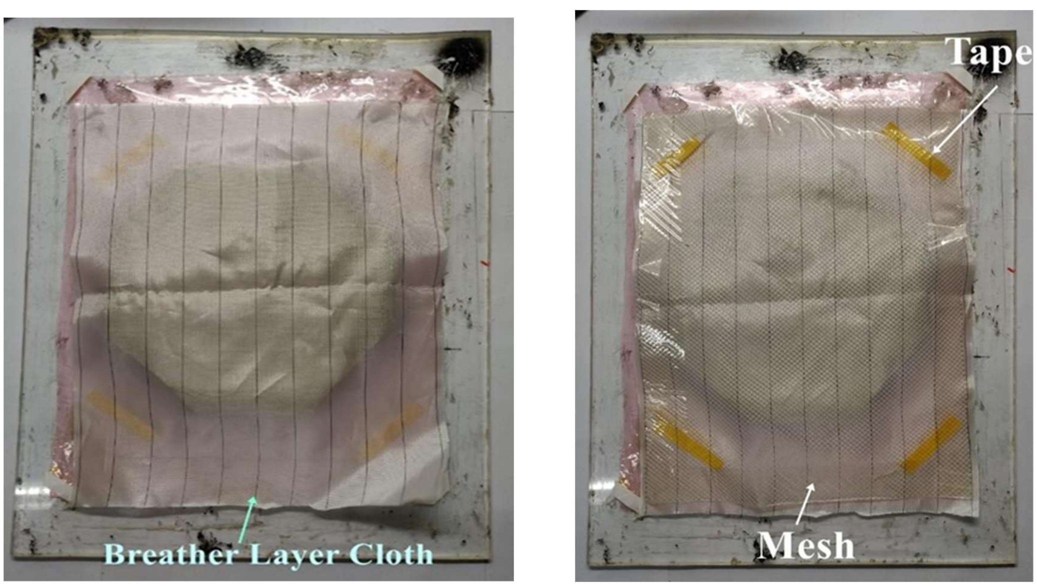


Figure : Attaching the Breather Layer Cloth and the Mesh

We used tape to attach the vacuum film to the plate and the breather layer to the vacuum film. Then the mesh is cut in same size as the breather layer cloth and placed it on top of it. All the sides of the mesh were wrapped by duct tape to cover the sharp edges that might create a leak in the vacuum bag. The mesh is also tapped to the breather layer same as the previous ones.

The mesh and the breather layer were provided so that he resin might easily flow through the whole composite witout being disrupted at any point of the flow.

3.3.4 Installing the Infusion Spiral Tubes and Vacuum Hose Pipe

selecting and installing the vacuum lines through which the resin will pass. We will use spiral resin infusion flow tubes which is a coil that is coiled into a tube shape. Due to its construction criteria resin can enter and leave through the wall of entire length of the tube. This property is ideal for the in-bag vacuuming feed lines. When we use a feed lie resin can quickly pass through the tube but also simultaneously seep out along the way. This helps acquire a quick infusion of the entire area inside the vacuum bag.

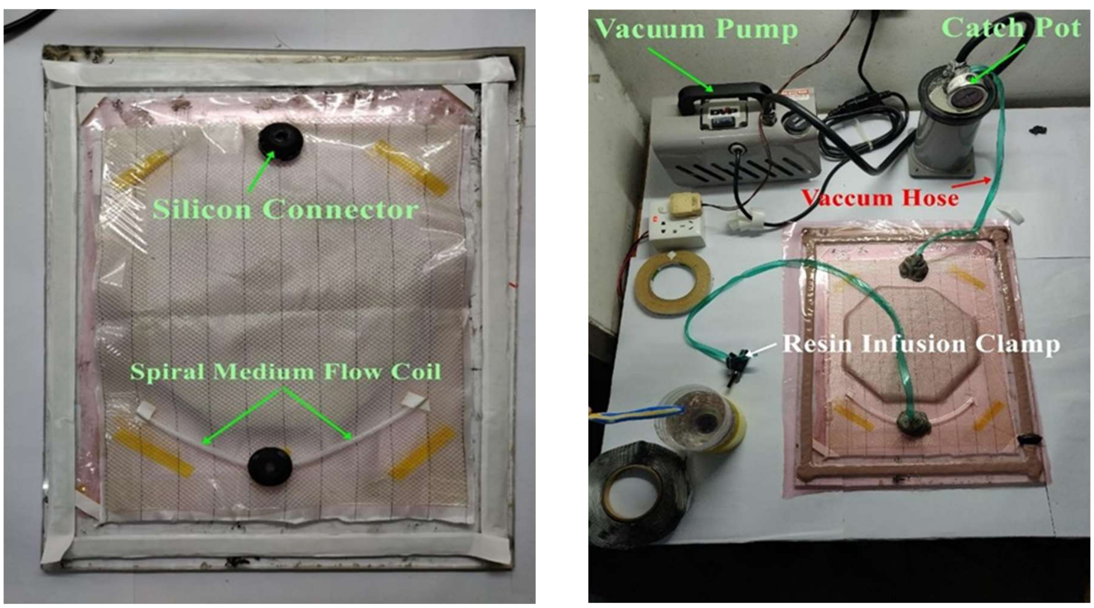


Figure : Installation of Spiral Medium Flow Coil and Vacuum Hose Pipe

. We attach the spiral flow coils to the resin infusion silicon connector and place it at one end of the prepared bed. The spiral tubes have a tendency of straightening up when the stretch is released so we used duct tape to attach both ends to the breather layer. In the silicon connector there is a 4-way channel that forms a good flow of resin into the spiral tubes. This connector can accept a PVC vacuum ID hose of 6 mm for transferring the resin to the tubes underneath. The other silicon connector is placed on the other side of the bed so that it can suck in the additional resin that is present inside the vacuum bag. It can also use a vacuum hose of the previously mentioned diameter

3.3.5 Vacuum Tight Seal Using Vacuum Bagging Gum

Now that all the dry materials are in place we will advance to creating the vacuum bag. The bag should be tight but still have enough room for all the materials and also the vacuum lines since shortage of space can result in improper infusion.

Figure : Vacuum Sealing the specimen using Gum

The vacuum film is used to create the vacuum bag. First the sealant tape is attached around the flange area so that it has all the dry material in the middle. The vacuum film which is cut a tad large in measurement than the glass plate is then carefully attached with the sealant tape serially completing all the sides. The bagging should be done very carefully so that there is no leak in the film.

3.3.6 Vacuum Bagging Procedure

First a PVC vacuum hose is attached to the resin infusion catch-pot. The catch-pot ensures that any additional resin does not draw down the vacuum line into the vacuum pump. It has a barb-type fitting for easy connection of the vacuum line as well as an easy to tighten resin infusion line. The vacuum hose is entered through the tight infusion line also called the gland nut so that the additional resin can fall into the buckets placed inside the catch-pot. The other side of the vacuum hose is entered into the resin infusion silicon connector placed for collecting the additional resin. Both ends are sealed with sealant tapes to avoid any kind of leakage from inside the vacuum bag. Another vacuum hose is entered into the silicon connector that holds the spiral tubes for flowing resin and it is also sealed in the previous way with sealant tape.

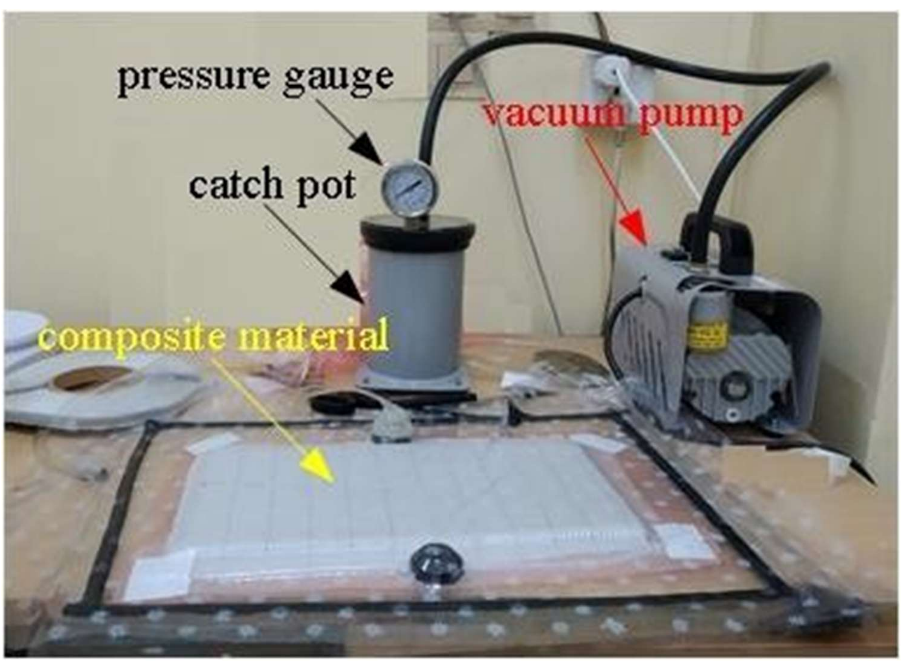


Figure : Total Vacuum Bagging Procedure

Lastly we are ready for the pumping process that will create the vacuum pressure inside the bag. Before the pump is switched on the resin line is clamped using the resin infusion line clamp because the hose will act as a temporary leak that must be closed. Now the pump is turned on. Right after turning it the air is sucked out of the vacuum bag. We then turn off the pump and wait for 30 minutes to check whether any leak is present in the vacuum bag because in any vacuum bagging, leak poses the biggest threat. Even a small leak can greatly hinder the infusion process or maybe ruin the whole process. After we have confirmed that the vacuum bag is officially leak proof we move on to the next step. The next step involves the selection of resin and hardener. The most important aspect while selecting a resin is viscosity. Since lower viscosity aids the infusion we have chosen Epoxy LY556 as the resin to be used in the fabrication of our sample material. Choosing the hardener is also equally important. While selecting hardener we have to keep in mind the time it takes to harden the resin-hardener mixture. At one stage the mixture will get immensely dense and the flow through the hose into the vacuum bag will eventually stop which will hinder the infusion process. So in accordance with the resin we have chosen Araldite HY951 as the hardener. The ratio of resin to hardener we have used for our infusion process is 10:1. This ratio gives us enough time to infuse the whole hybrid sample before the mixture tends to harden. We attach the hose to the resin bucket and double check so that the hose does not leave the bucket. Once everything is satisfactory we open the clamp. The machine is again turned on and now the resin starts to flow through the hose into the silicon connector and the spiral tube placed underneath to the bed prepared with dry materials. Since the bag is covered with vacuum pressure it quickly sucks in the resin and transfers it through-out the whole reinforcement infusing the sample in the process. Once it has infused the whole reinforcement the additional resin starts to climb through the hose that is connected to the catch pot. We remove the clamp attached to the hose and the resin starts to fall into the bucket place inside the catch-pot. Once the whole reinforcement is infused with resin there is no need for resin to enter further. We also were careful that the bucket was not sucked dry so the destructive air bubbles could enter and to prevent this we clamped of the hose line carrying the resin in the same way it was previously accomplished. After the completion of the infusion process we have got specimens of double layer structure.

Figure : Infused Hybrid Composites with Double Layer Structure.

3.4 Preparing Specimen for Mechanical Property Test

We have used American Society for Testing and Materials (ASTM) standard for the production and testing of our specimens**. ASTM D039** is used for Tensile test. We have followed **ASTM D790** for Flexural test and for impact test we have used **ASTM D6110** standards. The composite material forms are limited to continuous fiber or discontinuous fiber-reinforced composites in which the laminate is balanced and symmetric with respect to the test direction.

3.4.1 Tensile Test Specimen Dimension

We have used ASTM D3039 standard for this study. This standard is the test method for tensile properties of polymer matrix composite materials. The size of the specimen used is 250mm*25mm. [63] A thin flat strip of material having a constant rectangular cross section is mounted in the grips of a mechanical testing machine and monotonically loaded in tension while recording load. The ultimate strength of the material can be determined from the maximum load carried before failure. If the coupon strain is monitored with strain or displacement transducers then the stress-strain response of the material can be determined, from which the ultimate tensile strain, tensile modulus of elasticity, Poisson's ratio, and transition strain can be derived.

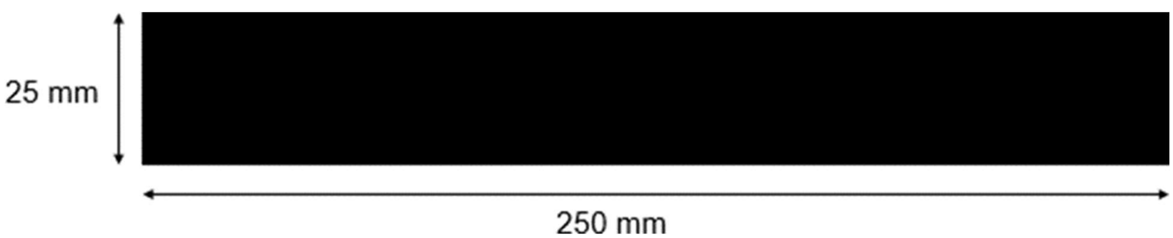


Figure : Specimaen Dimension for Tensile Test

The shape of the specimen is a thin rectangular slab. Using this we can easily use a universal testing machine for determining the tensile strength of the specimen. Tensile strength of a material is the maximum amount of tensile stress that it can take before failure, breaking. We will find out the tensile strength in the axial direction in our case along the length of the specimen. This rectangular shape ensures uniform distribution of load and a better gripping surface in the UTM.

3.5 Performing the Tests on UTM

After all the specimen were cut according to the ASTM standards for the flexural, tensile and impact test, the tensile and flexural tests were performed on the UTM machine. The UTM machine produced stress vs strain graph with an excel file containing all the data concerning applied force and displacement due to the force with respect to time. The graphs and the concerning data will be analysed in the following result and discussion section to conclude which composite specimen has the highest mechanical properties.

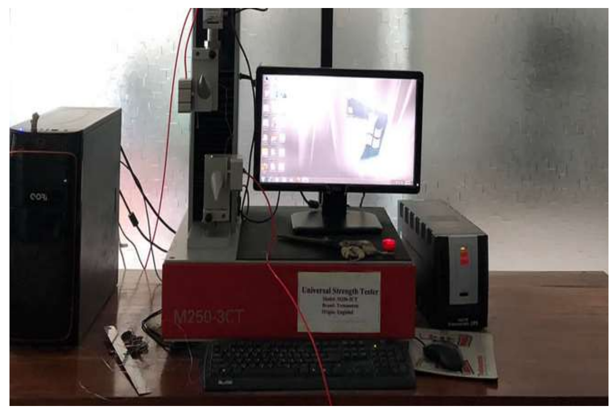


Figure: Universal Testing Machine

Chapter 4: Results and Discussion

4.1 Introduction

The UTM machine provided the stress vs strain graph along with excels files with the data that includes the force applied by the load being put on the specimen and the displacement due to this with respect to time. The specimens have been observed and a conclusion has been reached from the observation. The tensile stress vs strain graphs have also been analysed which has enabled us to provide some corollaries based on the behaviour and damage pattern of the composite specimens.

The tensile, flexural and impact test were carried out by ASTM standard sizes for each test specimen respectively. The tests are performed to check the mechanical properties to observe if any change occurs based on the change in stacking sequence. The observation will focus on the fracture and cracks on the composite post testing and the strain vs stress curves will discuss about the characteristics and properties of a composite based on the values attained from the tests.

The following sections will discuss in details about the aforementioned parameters and observations.

4.2 Specimen Observation

4.2.1 Tensile Test Specimen

The tensile test was performed on all double layer structure and observation is performed on the post testing condition of each of the composites.

If we analyse the fractures and breaking points in the specimens we can see that in case of the jute layers the breaking is uniform. Which is an indication that the jute layers break uniformly when load is applied on it. The resin could not hold the jute fibers in the matrix strong enough to provide resistance to the strain applied. If we see the fracture pattern closely we can see that the jute fibers starts to crack from one position one after the other. As the first layer is cracked a cracking sequence is initiated which moves from one layer to the other until all the jute fiber is fractured. In case of the banana fibers being placed on the side where load is applied there is no uniform breaking point or fracture on the composite surface. The banana fibers are held more rigidly in the matrix and does not fracture until it totally disengages from one another to the last fiber laminae. The banana fiber laminae are seen in the figure to be edged out from the fracture point which tends to point that it takes more stress to cause damage to a composite specimen having a sequence where banana fiber is placed on the top and bottom side of the composite thus more tensile strength.

4.2.2 Flexural Test Specimen

The flexural test was performed on all double layer structure and an observation is performed on the post testing condition of each of the composites

It can be observed that there is fiber buckling, fracture and delamination on the specimens after the three-point bending test. Due to bending we can see that there is compressive force developed on the top layer and tensile force is created at the bottom of the sample. If the jute layer is placed on the top or bottom side of the composite specimen the fracture occurs quickly due to the load being applied on the tensile and compressive sides which quickly initiates the cracking and buckling on the jute fiber layers and there. The de-laminations are a major phenomenon in the flexural test as the strength of the matrix is lower in the junction of the jute and banana composite. The jute fibers or the banana fibers that are infused together after one another in a sequence are generally not delaminated. In case of the banana fibers being placed on the tensile and compressive side of the composite specimen the matrix strength is more than that of the jute fiber and the fracture is not uniform rather laminates are detached from one another slowly which result in more flexural strength.

4.3 Result Analysis

4.3.1 Elongation Test

With the help of UTM (Universal Testing Machine) machine, the elongation test has been done. First the fiber is hanged bottom of the UTM machine. Then force is given to the fiber. At a certain pressure, the fiber will detach from the machine and it will break down. From the elongation test, we can get the value of that maximum force. This force can be determined from the graph. The test has been done for both jute and banana fibers. For both cases, the highest force of elongation is 6 KN.

Test Speed : 300.000 mm/min
Pretension : 0.010 N
Sample Length : 250.000 mm
Linear Density : 26.000 Nec

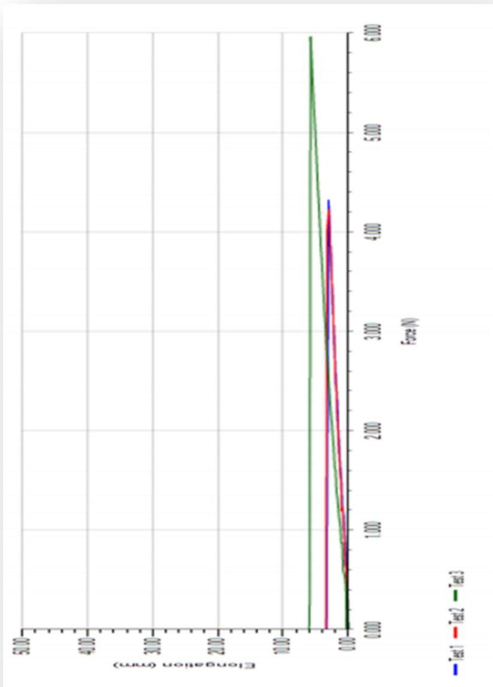


Fig: Elongation Test of Banana fiber

Test Speed : 300.000 mm/min
Pretension : 0.010 N
Sample Length : 250.000 mm
Linear Density : 26.000 Nec

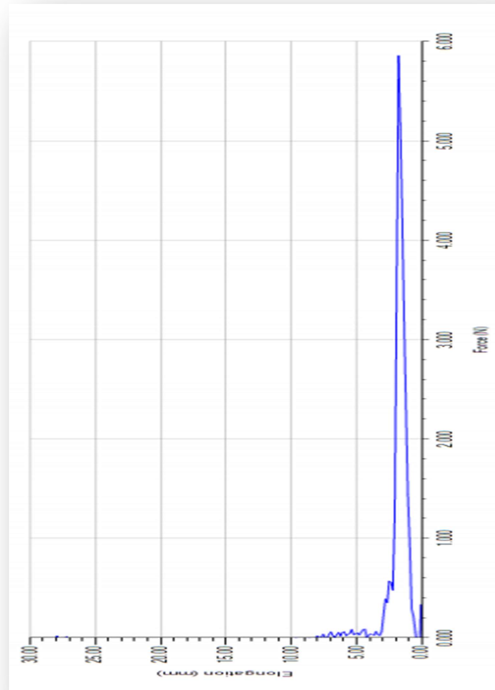


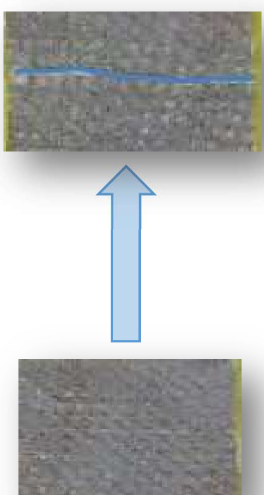
Figure: Elongation Test of Jute Fiber

4.3.2 Vacuum Infusion Test

From this test, maximum force for fracture angle of the specimen can be determined. During the vacuum infusion process, there will create a crack in the specimen. Due to this crack, a fracture angle is created. This crack is created for the stress given during the infusion process. From the graph, it is seen that the highest stress for the fracture angle is 17 N/mm².

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



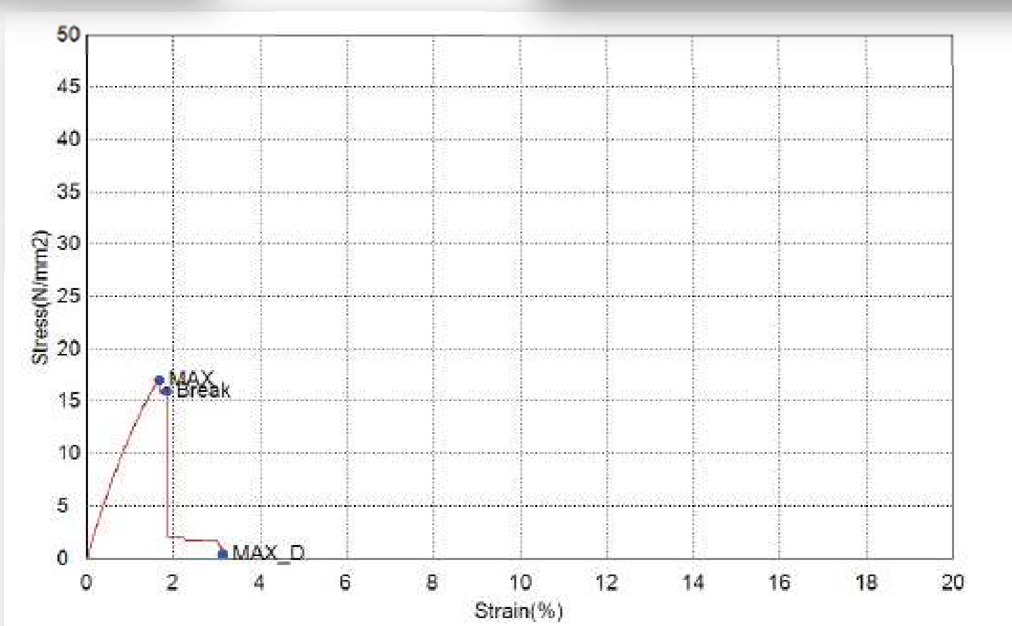


Figure: Vacuum Infusion

Chapter 5: Conclusion

5.1 Introduction

Lignocellulose based natural fibers are available in our subcontinent. Also they are ecofriendly, renewable source of energy for that they are highly used for manufacturing composite materials. Also natural fibers have the reputation for manufacturing better and stronger composite materials. As fiber reinforced composite material has many advantages, the application of it is increasing in various sectors day by day. A composite material offers high durability, high tensile strength, greater flexibility, low cost which make it more popular in the present time. There are many processes for manufacturing composites materials from natural fibers. Among them Vacuum infusion process is the most effective process for manufacturing composite material. Vacuum infusion offers higher quality, low cost, better consistency higher tensile strength and stiffness. Other conventional processes cannot offer these advantages. So a well quality composite material can be manufactured by adopting vacuum infusion process.

5.2 Outcomes

In this research banana and jute fibers were used as reinforcements. Banana fiber has its own physical and chemical characteristics and many other properties that make it a fine quality fiber. Jute fibers have good mechanical properties and are biodegradable. Both the fibers are also frequently cultivated in Indian subcontinent making them easily available.

The present review explores the potentiality of jute & banana fiber composites, emphasizes both mechanical and physical properties and their chemical composition. The utilization and application of the cheaper goods in high performance appliance is possible with the help of this composite technology.

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