A

MAJOR PROJECT REPORT

ON

INVESTIGATIONS OF MECHANICAL PROPERTIES OF NATURAL FIBER REINFORCED POLYMER COMPOSITION

A Project Report Submitted in partial fulfillment of the Degree Of

BACHELOR OF TECHNOLOGY IN MECHANICAL ENGINEERING

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2020-2024

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CERTIFICATE

This is to certify that the Project Report entitled **"INVESTIGATIONS OF MECHANICAL PROPERTIES OF NATURAL FIBER REINFORCED POLYMER COMPOSITES"**

is a bonafide work prepared and sudmitted

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partial fulfillment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING** during the period 2020-24 under our guidance and supervision.

Project Guide **Head of the Department** **Principal**

DECLARATION

I hereby declare that the work which is being presented in this sissertation entitled **'Investigation of mechanical properties of natural fiber reinforced polymer composites'** Submitted towards the partial fulfilment of the requirement for the award of degree of **Bachelor of technology in mechanical engineering to jayamukhi institute of technology and sciences ,**Narsampet is an authentic record of my own carried out under the supervission of **Dr. MAMIDALA JAWAHAR ,** Associate professor , Department of mechanical , JITS , Narsampet .

To the best of my knowleadge and belief , this project bears no resemblance with any report submitted to JITS or any other University for the award of any degree .

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ABSTRACT

Polymer composites are attracted by the industrialists, material scientists and investigators because of its applications in the fields like building industries, electronic industries, electrical industries, automobile sectors, marine, aviation and medical applications. Natural fiber reinforced polymer composites are majorly used owing to its low cost, environmental friendly, resistance to corrosion, resistance to electricity, high specific strength. Hybrid composite is a composite material fabricated by two or more fillers within the matrix.

In the present investigation, a hybrid composite was fabricated using neem and Indian almond fruit fiber by hand layup technique. Density measurement was carried out to confirm the rigidity of composite and the results showed that the prepared composites contained allowable percentage of voids. Mechanical /properties like tensile strength, flexural strength and impact energy absorption were tested. To understand the depreciation of the material, wear test was performed. Further, the neem fiber and Indian almond fruit fiber surface morphology was studied by scanning electron microscopy and the chemical composition of the fibers were investigated by the FTIR analysis.

The results showed that the composite prepared with neem fiber as skin displayed superior tensile and flexural strengths compared to that of the composite

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LIST OF SYMBOLS AND ABBREVIATIONS

Al2O3	-	Aluminum Oxide or Alumina
ASTM	-	American Society for Testing and Materials
BF	-	Basalt Fiber
CF	-	Carbon Fiber
CNT	-	Carbon Nanotube
ρ	-	Density, kg/m^3
DSC	-	Differential Scanning Calorimetry
DMA	-	Dynamic Mechanical Analysis
ε	-	Elongation
MgO	-	Magnesium oxide
MMT	-	Montmorillonite
MWCNT	-	Multi Walled Carbon Nanotube
PALF	-	Pineapple leaf fiber
PEI	-	Poly (ether imide)
PEN	-	Poly(ethylene 2,6-naphthalate)
PET	-	Poly(ethylene terephthalate)
PHA	-	Poly(hydroxybenzoic acid)
PMPA	-	Poly(methyl methacrylate-co-phenyl methacrylate)
PMMA	-	Poly(methylmethacrylate)
PTT	-	Poly(trimethylene terephthalate)
PA	-	Polyaniline
PC	-	Polycarbonate
PEO	-	Polyethylene oxide
PI	-	Polyimide
PNC	-	Polymer Nanocomposite
PP	-	Polypropylene
PS	-	Polystyrene
PU	-	Polyurethane
SEM	-	Scanning Electron Microscope

SWCNT	-	Single Walled Carbon Nanotube
T	-	Temperature, ° C
σ_t	-	Tensile strength, N/mm^2
TiO_2	-	Titanium Oxide or Titania
®	-	Trade Mark
XRD	-	X-Ray Diffraction
E	-	Young's modulus, N/mm^2

CHAPTER

INTRODUCTION

1.1 INTRODUCTION

Material is a substance composed of particles and formed into object. It is naturally available abundantly as raw material. Raw materials are further processed to form a new material and used in the specific applications depending on its physical and chemical properties. Ancient people used the raw material without any modifications. During Stone Age, human used the stone as weapon to protect him from the animals or used as a hunting weapon to catch pray. After civilization, materials were used as building blocks in construction and transport sectors. Army people focused on the most of the materials whatever available in the earth and used for the purpose of building shelters and making weapons for their use. Engineers involved in the materials research to fulfill the needs of army from supplying weapons to constructing ship and aircraft. Ancient army people used the readily available metal in the earth as ore to construct ship and aircraft. Steel placed a major role in construction industries. After the development of technology, engineers realized the need of new materials to reduce the expenses without compromising the strength of the material.

They focused on the naturally available composite materials like wood and bone. Composite materials are made up of combination of two or more materials of different physical and chemical properties. The advantages of composite materials are its high weight-to-strength ratio, low cost, environment friendly material and easily available. In the recent technological developments, composite materials are unavoidable materials that are used in

the fields of building construction, marine, aviation, electronic, electrical andIT industries.

1.2 OVERVIEW AND BACKGROUND

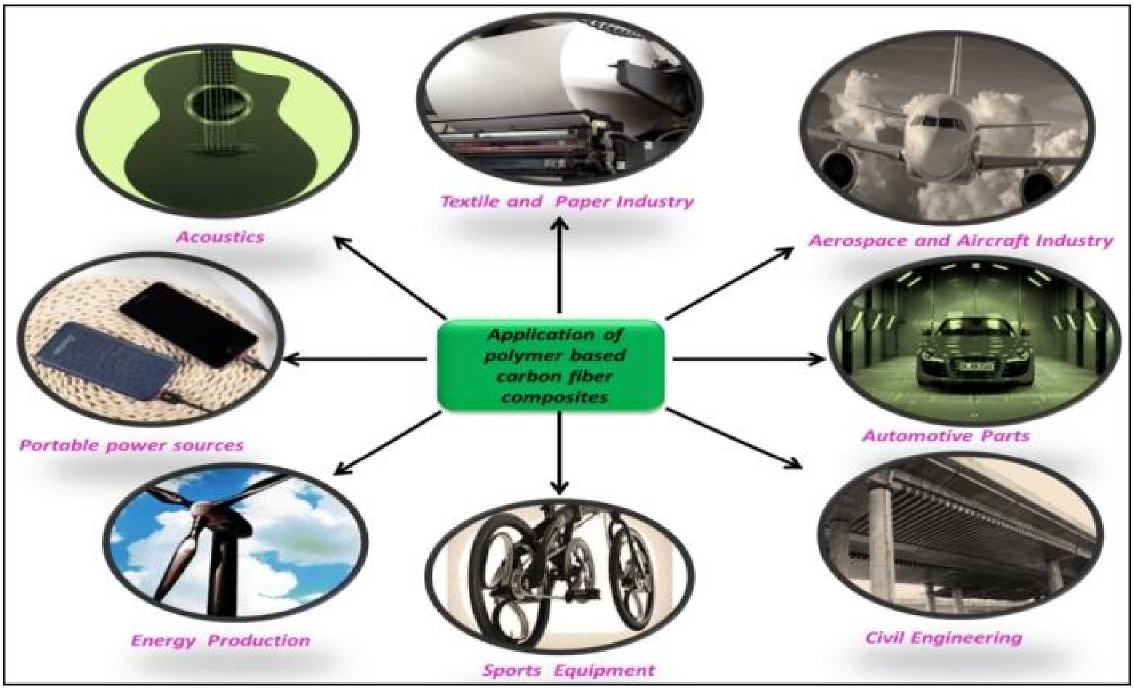
1.2.1 Polymer Composites

Composite material consists of matrix and reinforcement. Matrix isthe major portion of the composite that consume maximum volume of the material and reinforcements are filled in the space between the matrices. Generally used matrices are metals, ceramics and polymer. Depending on the type of matrix used the composites are classified as metal matrix composite, ceramic composite and polymer composite.

Polymer composite was prepared and used after the invention of plastics in early 1900s. In ancient days, the glues extracted from the plant and animals were used as binders in place of resins. In 1935, glass was introduced as fibers in the plastic that improved the strength of the plastic to a greater amount. Polypropylene, Polyvinyl chloride, Polyamide, Polystyrene and Polycarbonate are the plastics used in most of the polymer composites.

The strength of the polymer composite is depending on the fiber type, plastic type, the ratio of plastic and fiber in the composite and the orientation of the plastic and fiber in the composites. Further, the geometry of the fiber also influences the properties of the composite materials.

Polymer composites find applications in many fields from household applications to Aviation technology as listed in Figure 1.1.



(Source: Das *et al.* 2019)

Figure 1.1 Applications of polymer composites

1.3 MATRIX

1.3.1 Polymer

Polymer is a macromolecule that contains repeated subunits called polymer chains. Polymers are classified into natural polymer and synthetic polymer. Natural polymers are DNA and proteins. The synthetic polymers arepolystyrene, polycarbonate etc. Polymers formed into many structures like linear, branched, cross-linked and network. Generally, polymers are categorized into thermoplastics, thermosetting and rubber.

(Source: www.azom.com)

Figure 1.2 Polymers

Thermoplastic polymer melts while applying heat and regains its shape after the removal of heat. It finds many applications in the fields of construction industries to make many small components. Thermosetting polymer withstands heat and not melted or collapsed while applying heat. These polymers find applications in the areas where heat is to be withstood. Hence, thermal insulating materials are made from thermosetting polymers. Rubber is a homogeneous material that deforms while applying load and regain upon removing the load. It finds the applications where damping is required to arrest the vibrations.

1.3.2 Metal

Metals are used as matrix in composite materials that are called as metal matrix composites. Even though metals are stronger than the polymer, polymers are used in some places of metals without compromising the strength. The generally used metals are iron, aluminium, magnesium, beryllium, titanium, nickel, and cobalt etc. Metals are excavated from earth as ore and processed further for the specific applications. Scrap metal also used as the matrix in composite materials.

(Source: www.mechanicalthink.com)

Figure 1.3 Variety of metals

1.3.3 Ceramic

Ceramics are non-metallic materials that are used as tiles, bricks and toilet fittings. The structure of the ceramic materials is from highlycrystalline to semi-crystalline. Ceramic materials are harder than the metals. Ceramics are used as fire refracting bricks, water proof material and glasses. Ceramics are chemically inert, give resistance to electrical and thermal behavior, have high melting point and withstand forces.

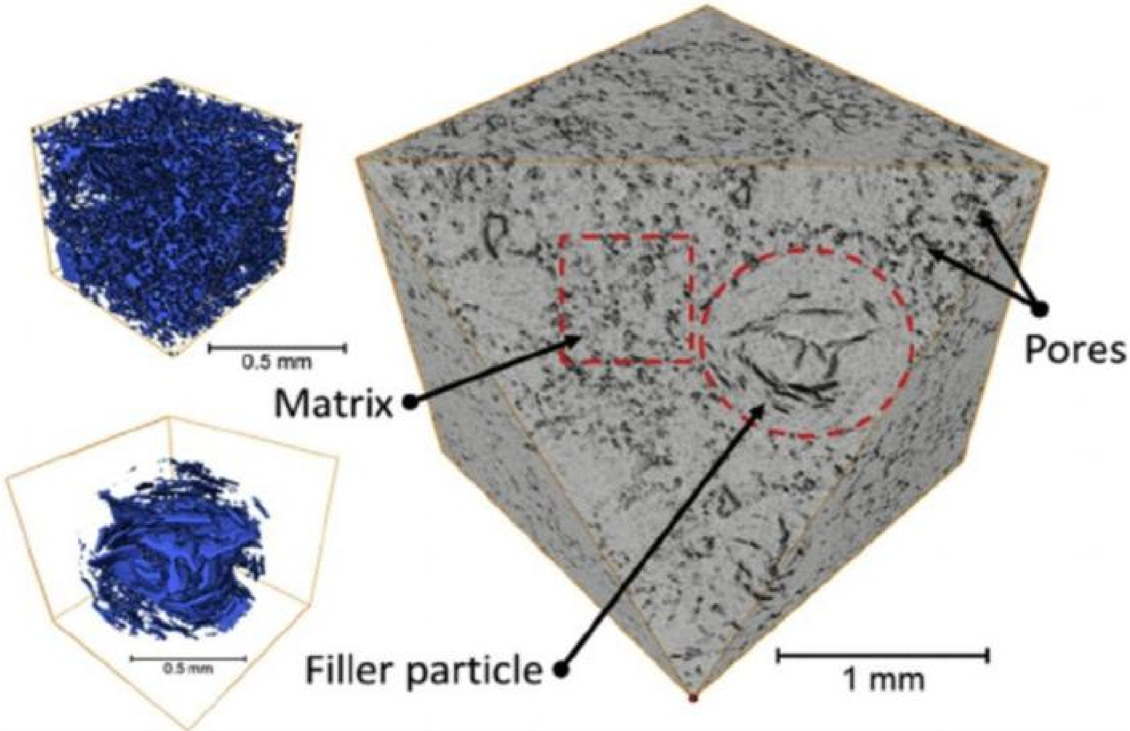
(Source: www.ceramicartnetwork.org)

Figure 1.4 Ceramic material

1.4 FILLERS

1.4.1 Particles

Particle fillers are metal particles or carbon particles milled to micro or nanometer size. Metal oxide nano fillers are widely used along with the polymers. Single walled and multi walled carbon nanotubes are attracted by the many investigators because of their superior properties. Montmorillonite and nanoclays are used mostly in polymer composites. Particle improves the physical property of the composites and the physical properties are depending on the physical and chemical properties of the particle fillers used. The inorganic metal particles such as silicon oxide, aluminium oxide, titanium oxide, zirconium oxide, cerium oxide and magnesium oxide etc. are the mostly used particles in the polymer composite materials.



(Source: Morrison *et al.* 2016)

Figure 1.5 Particle fillers

1.4.2 Fibers

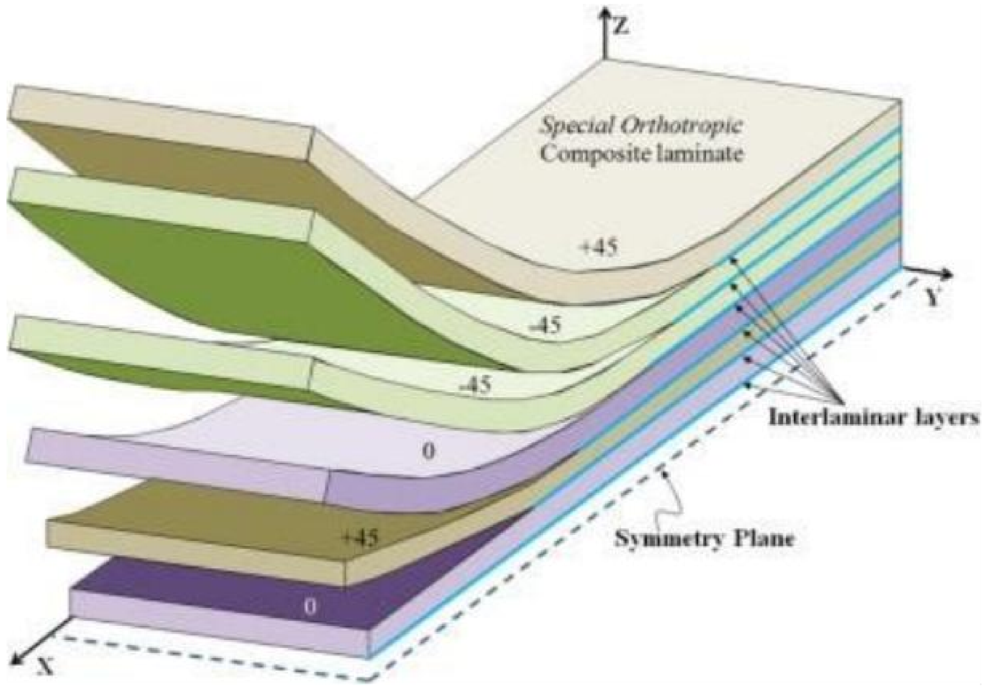
Fiber is a substance which is longer than wide. Fibers are available naturally and extracted from plants. Synthetic fibers are also made form animals that are cheap and stronger than the natural fibers. Fibers are mostly used in the manufacturing sectors to make other materials. Vegetable fibers and wood fibers are natural fibers. Cellulose is the major content of the natural fibers. The strength of the natural fiber is depending on the cellulose content of the fibers. Silk and wool are the animal fibers that contain proteins. Mineral fiber such as asbestos and man-made synthetic fiber like glass fibers are the other types of fibers used in the field of manufacturing sectors.

(Source: www.rdmag.com)

Figure 1.6 Natural fiber

1.4.3 Laminates

Laminates are composites that contain different layers of varieties of fibers added together one above one and bonded together by adhesive glue or resin to give greater strengths. The individual layer is made with high modulus and high strength fibers. The mostly used fibers are graphite, cellulose, boron and silicon. The each layers of laminates are orthographic,
i.e. the property of the material changes with perpendicular directions.

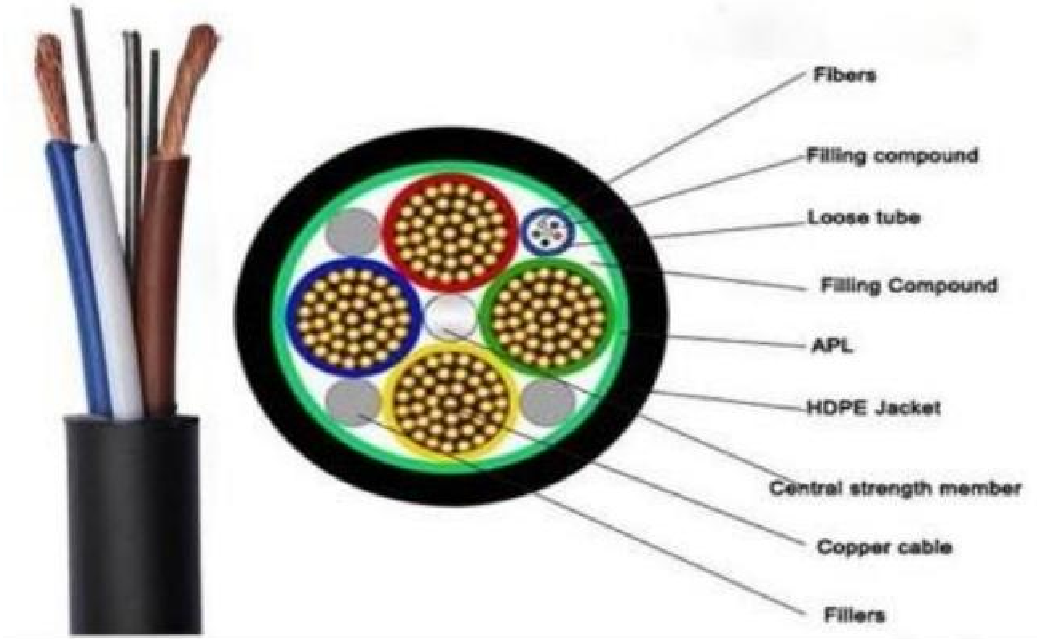


(Source: www.sciencedirect.com)

Figure 1.7 Laminates

1.4.4 Hybrid Fillers

Hybrid fillers are made up of two or more fillers of different physical and chemical properties. The properties of different fillers are combined together to form new strength to the materials. Synergistic effect is the effect created due to the combination fillers that leads to the better improvement of the final property of the composite material. Hybrid filler overcomes the limitations of natural fillers. The selection of the fillers to make hybrid fillers is based on the need of the specific property of thematerial for specific applications.



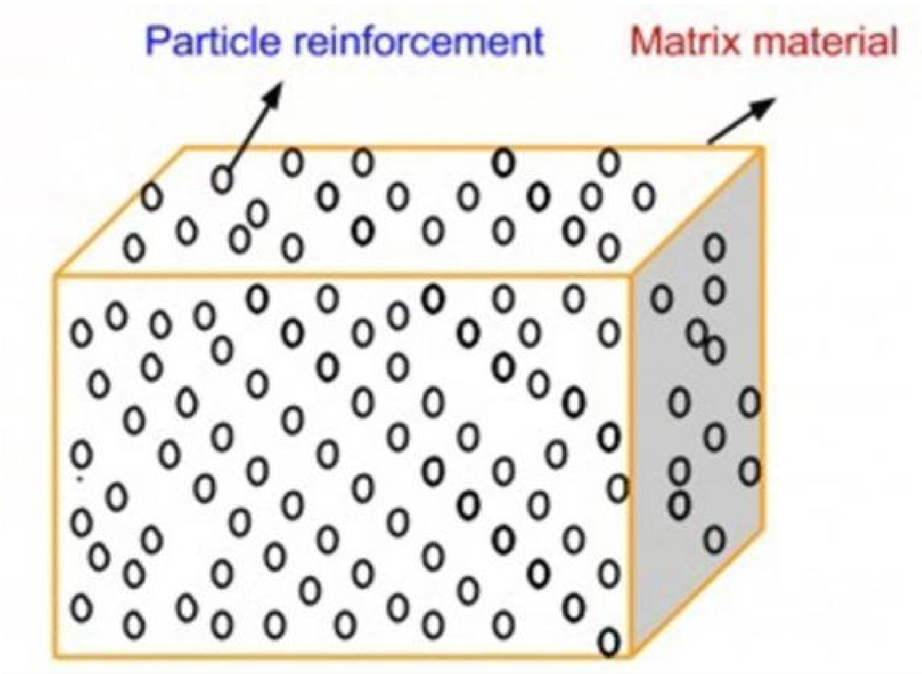
(Source: www.awcwire.com)

Figure 1.8 Hybrid fiber cable

1.5 POLYMER COMPOSITES

1.5.1 Particles Reinforced Polymer Composites

In particle reinforced polymer composites, particles are mixed withpolymers by melt blending method or casting method to make the composites. Particle reinforced composites improve the wear resistance of the material. Gravels are added with tar to lay road for transport vehicles to increase the wear resistance. Strength, stiffness and toughness of the material are increasing while adding particle fillers to the polymer. However, particle reinforced composite is less effective compared to fiber reinforced composites. Particle reinforced composite are classified into large particle composite, cermet, concrete and reinforced concrete.

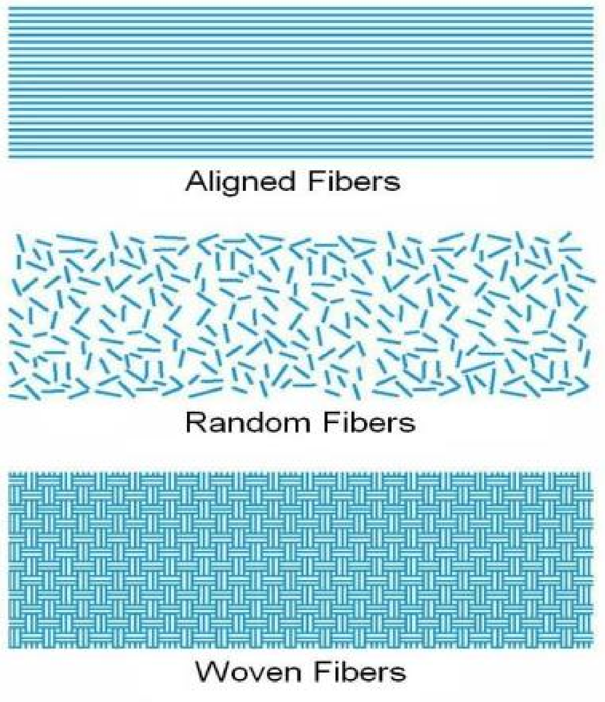


(Source: www.iesgeneralstudies.com)

Figure 1.9 Particle reinforced composite

1.5.2 Fibers Reinforced Polymer Composites

In case of fibers reinforced composites, the fibers are embedded in the matrix. Fiber reinforced composites give high specific strength and high specific modulus to the composite. The strength of the material is depending on the adhesion between the fiber and matrix. Good adhesion means better stress transfer is the results. Further, the strength of the material depends on the orientation of the fiber. Three types of fiber orientation is practiced viz. aligned, random and woven.

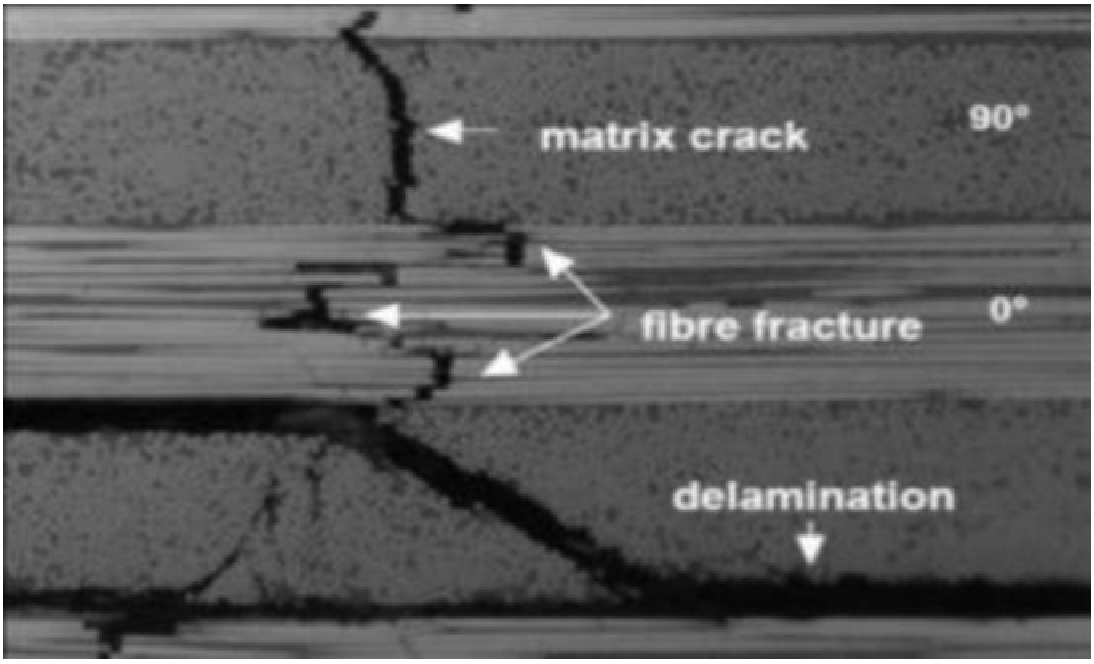


(Source: www. fog.ccsf.edu.com)

Figure 1.10 Fiber orientation

1.5.3 Laminates Reinforced Polymer Composites

Laminates reinforced polymer composites composed of fibers bonded together layer by layer to improve the strength in both longitudinal and lateral directions. The strength is depending on the number of layers inthe materials. When load is applied, matrix fails first and micro crack forms. The cracks propagate layer by layer and withstand the load for certain time period. The laminate materials and number of layers are chosen based on the specific application of the material to satisfy the engineering requirements.



(Source: Kreculj *et al.* 2018)

Figure 1.11 Crack formations in laminates

1.5.4 Hybrid Fillers Reinforced Polymer Composites

Hybrid composite material is a combination of more than twofillers embedded in the matrix or combination of both synthetic and natural fillers bonded with the matrix. Hybrid composite exhibit distinct physical properties compared to the traditional composites. The presence of natural filler highlights the hybrid composites in economical point of view. Further, the different diameters of fillers improve the stress transfer between the matrix to filler and filler to filler. Hybrid composites have greater fatigue strength and corrosion resistance. Hybrid composites are used in marine, aviation, electronic and commercial purpose.

(Source: www.ptonline.com)

Figure 1.12 Injection molded hybrid composite

1.6 OBJECTIVES OF THE PROPOSED WORK

Polymer composites are attracted by material scientist because of their superior properties and used the material scientists in the fields such as automobile, marine, aerospace, construction, electrical, electronics and medicine. Polymer composites are reinforced with carbon nano tubes, graphite, montmorillonite, naoclays, metal oxides and fibers. The final properties of the composite depend on the physical properties of the reinforcement added with the matrix. Fibers are available from two sources viz. natural and synthetic. Natural fibers are extracted from plants and synthetic fibers are extracted from the animals. The advantages of natural fibers like no harm to environment, low cost, easily available and resistance tocorrosion attracted this investigation. In the current investigation, natural fiberreinforced polymer composite is to be prepared and the mechanical properties of the prepared composite is to be studied. The objectives of the present studyare described below.

- To prepare a hybrid composite based on natural fibre
- To characterize the mechanical properties [Tensile, Impact,Flexural] of prepared hybrid composites
- To study the morphological Structure using Scanning ElectronMicroscope.
- To analyse bonding strengthof composite using FT-IR spectroscopy
- To compare the new Hybrid fibre composite with the existing fibrecomposite

1.7 STRUCTURE OF THE THESIS

The main features covered in this thesis are:

- Composites and their applications
- Background of polymer composites
- Previous studies on natural composites
- Preparation of natural composites
- Experimental investigation of natural composites
- Mechanical, chemical and morphological characterization ofnatural composite

The contents of doctoral thesis presented is briefly described below

Chapter 1 describes the introduction to the composites, background work of composite material, introduction to the polymer composite and its applications. Further, it deals with the different types of matrix and fillers, combination of different kinds of polymer composites and objectives of the present work.

Chapter 2 deals with the literature survey of the natural fibers, natural fiber reinforced polymer composites, research gap and research methodology to perform the investigation.

Chapter 3 details about the materials collected for the investigation, methods of composite preparation, and characterization techniques such as mechanical, chemical and morphological of composites.

Chapter 4 describes the results and discussions of various studies carried out. It explains detail about the tensile, flexural, impact, wear and damping characterization. Further, it gives the analysis about morphological and chemical point of view. Additionally, the prepared material have been analyzed using FEA and the discussion are described.

Chapter 5 concludes the various results obtained from the studies and describes the scope for future work to continue this present investigation.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

The concern on environmental condition is increasing recently. The harmful effect of non-degradable waste is a major issue in the present situation. Hence, the best practice of material scientists is to reduce the waste, recycle the waste and avoiding the usage of non-degradable materials. One of the best choices is using of naturally available material. Natural fiber is an environment friendly, low cost and easily available material. Many investigators are concentrating on the natural fibers to make new materials. Natural fibers are extracted from the plant source.

The commonly know natural fibers are cotton, coir, hemp, flax and jute. Natural fiber reinforced polymer composites are focused by the manufacturers because of its low cost, low weight and no damage to the processing equipment. Further, the properties such as tensile, flexural, impact and damping are superior compared to the other materials. Natural fiber reinforced polymer composites are used by the automobile industry, construction industry, electronics industry, marine and aerospace industries.

2.2 NATURAL FIBERS

Natural fibers are fibers extracted from the natural sources, biodegradable, have superior specific strength and stiffness, and have better aspect ratio. Natural fibers come from sources like plants, animals and minerals. Plant sources give the natural fibers like coir, flax, hemp and bamboo. Animal sources give the natural fibers like wool and silk. Mineral sources give the natural fibers like asbestos, ceramic and metal fibers. In economic point of view and environmental considerations, natural fiber was used by many automobile, textile and plastic industries. Further, many investigators have focused on the natural fiber for the benefit of manufacturers and peoples. In this section, the previous investigations about the natural fibers are discussed.

Chan *et al.* (1988) reported about the forgotten natural dietary fiber psyllium mucilloid and described its chemical compositions, properties and food products to which the fiber could be included.

Bledzki *et al.* (1996) studied the structure and properties of vegetable natural fibers and reported that the poor wettability and water absorption of vegetable fiber led to the debonding of fiber with matrix. Hence, they pointed out the importance of surface modification technique like plasma treatment of the fibers.

Herrera-Franco *et al.* (1997) fabricated HDPE/sand and short henequen fiber composites and studied its properties. The results showed that the tensile strength did not improved for varying the processing temperature and varied remarkably for 15wt% of fiber and the flexural strength reached a maximum value for the fiber content of 30wt%.

Dahlke *et al.* (1998) prepared natural fiber based foam from renewable sources for automobile interior applications and found that the mechanical properties of the prepared composites exhibited better strength. Additionally, they concluded that the developed composite was economically great, environmentally free and recyclable.

Rowell *et al.* (1998) investigated the agro waste residue for the use of composite reinforcement by applying the chemical surface modification methods and concluded that the agro residue could be used in composite preparation as low cost, bio-degradable and environmental free material.

Valadez-Gonzalez *et al.* (1999) studied the effect of surface treatment of fiber on the bonding strength of the fiber-matrix interface and reported that alkali treatment improved the wetting of the matrix fiber and chemical modification of surface improved the physicochemical interactions.

Bledzki *et al.* (1999) studied the impact behavior of natural fiber reinforced epoxy composites and reported that woven flax fiber displayed superior impact behavior compared to woven jute fiber. Further, they pointed out that the damping index and loss energy was linearly related with the void content and impact energy. Additionally, they reported that the damping index was decreased with the increase of fiber content under controlled test conditions and void contents.

Turk *et al.* (1999) invented an interfacial blending agent for the natural fiber composites and prepared the composites using melt blending method in screw extruder.

Sanadi *et al.* (2000) fabricated a kenaf-polypropylene composite and used maleated polypropylene (MAPP) as coupling agent to promote the stress transfer between the fiber and matrix. They reported that the glassy- rubber transformation was more in coupled composites compared to uncoupled composites.

Gassan *et al.* (2000) proved the possibilities to improve the surface structure of jute and prepared a jute-polypropylene composite. They found that the strong interaction was depended on the following factors: (1) dynamic modulus; (2) stiffness; (3) load cycle and (4) maximum stress.

George *et al.* (2001) presented a review report about interfacial modification and characterization of natural fiber reinforced composites and described detailed methods of physical and chemical treatment methods to achieve superior bonding between the fiber surface and polymer surface.

Dansiri *et al.* (2002) prepared a composite reinforced with kenaf fiber in polybenzoxazine (PBZX) matrix using resin transfer molding technique. They reported that the flexural strength of the composite increased while increasing the fiber content whereas the impact strength increased slightly compared to the matrix.

Pervaiz *et al.* (2003) prepared polyolefin natural fiber composites for automobile applications. They pointed out that hemp/thermoplastic composite exhibited better tensile strength compared to flax/thermoplastic composites.

O'donnell *et al.* (2004) prepared a plant-oil based resin natural composite contained flax, pulp, cellulose and hemp and resulted that the 50wt% natural fiber increased the flexural strength to 6 GPa.

Joshi *et al.* (2004) studied and compared about the environmental issue of natural fiber and glass fiber. They concluded that natural fiber was superior to glass fiber for the following reasons described: (1) the impact on environment by natural fiber was lower compared to that of glass fiber; (2) For the same performance, natural fiber occupied more space and reduced the volume fraction of polymer; (3) In case of automobile industry, the low weight natural fiber reduced the fuel consumption and better control on emission was achieved; (4) Waste heat energy recovery could be possible in case of natural fibers.

Rouison *et al.* (2004) prepared a hemp/kenaf natural fiber based composites using resin transfer molding and cure simulation study was conducted. They concluded that keeping constant mold temperature improved the tensile and flexural properties and the same was reflected on the simulation studies.

Burgueño *et al.* (2004) investigated the load bearing capacity of the composites reinforced with natural fibers. They used hemp and flax fibers and polyester resin to make cellular beams and planes and concluded that the prepared material could be a competent material for the conventional composites.

Shanks *et al.* (2004) prepared bio-composites using flax and poly(3-hydroxylbutyrate) bipolyesters (PHB) and reported that the adhesion between the fiber and matrix was better compared to that of polypropylene and natural fibers. Further, they reported that the bending modulus and storage modulus improved significantly.

Haverhals *et al.* (2010) demonstrated the natural fiber welding and they meant that natural fiber welding was the creation of congealed fiber using IL solvent to transform the loose fiber into rigid. They reported that the outer skin fiber experienced the welding effect; however, the inner core was not affected by the welding and was remained as native state.

Milanese *et al.* (2011) studied the mechanical behavior of natural fiber composites and used polyurethane-sisal for the study. They tried to replace the conventional glass fiber with sisal fiber and found that the developed composite showed a higher tensile strength.

Ku *et al.* (2011) reported a review on tensile properties of natural fiber reinforced composites and concluded that the tensile properties depended on the adhesion between the natural fiber and matrix

Rokbi *et al.* (2011) studied the effect of chemical treatment on flexural property of the Alfa natural fiber reinforced composites and reported that the 10% NaOH treated Alfa natural fiber exhibited the flexural strength of 57 MPa from 23 MPa.

Senthamaraikannan *et al.* (2018) characterized the raw and alkali treated fiber extracted from the Coccinia grandis.L *and* reported that after alkali treatment the cellulose content increased, and the hemicelluloses, wax and lignin content were decreased. The activation energy was improved from 67 kJ/mol to 73 kJ/mol and the thermal stability was enhanced from 213 °C to 220 °C owing to the alkali treatment.

Manimaran *et al.* (2019) characterized the cellulose fiber extracted from the red banana peduncle and reinforced with matrix for the industrial applications. They reported that the extracted fiber showed the high specific strength and good bonding strength due to its high cellulose content and low weight. The diameter and density of the fiber was found to be 15-250 μm and 0.896 gm/cm^3 and the fiber withstood the temperature up to 230 °C.

2.3 NATURAL FIBERS/POLYMER COMPOSITES

Materials because of their high specific strength, modulus and impact energies. Composites are fabComposites materials are attractive materials in place of metals and other conventional ricated with matrix and fillers. Matrix is continuous phase and filler is discontinuous phase. The space between the matrix and filler is interface. Polymer composites are composite materials made from polymer matrix and the filler material could be natural or synthetic. Natural filler reinforced composites are attracted by the industrialists and materials scientists because of their light weight, low cost, environmental free and high specific strength. Natural fibers like coir, sisal, hemp, kenaf, fine apple leaf fiber etc. have been used in many industrial applications and automobile industries. Many investigators have examined the natural fibers and characterized their properties to identify their applicability to make natural fiber based polymer composite polyamide 6 (PA6) were used as matrix and banana fiber was used as reinforcement. Twin screw extrusion method was used to prepare composites. The results were concluded that the ABS/PA6-banana composite showed the improved mechanical, thermal and morphological properties.

Potluri *et al.* (2019) prepared a silicon carbide particle included pine apple leaf fiber composites and studied its physical properties. Finite Element Analysis was used to study the performance of epoxy/silicon carbide. They reported that the shear properties of the composited improved upon inclusion of the silicon carbide particles in the composites.

Reddy *et al.* (2018) fabricated a bio-composite based on jute, pine apple leaf and glass fiber and polymer resin and studied the tensile and flexural properties. The varied the volume content of fiber from 0.18 to 0.42 volume percentage and concluded that the tensile and flexural behavior of the composite enhanced while increasing the volume concentration of fiber in the matrix.

Vieira *et al.* (2018) fabricated the sisal and silica nanoparticles based hybrid composite and studied its performance. They reported that the composite made with 2wt% silica nanoparticles and unidirectional untreated fiber exhibited better impact strength. Further, highest strength and stiffness values were obtained while reinforcing the composite with 2wt% silica nanoparticles and treated sisal fibers.

Barczewski *et al.* (2018) determined the thermo-mechanical properties of the sun flower husk waste filler reinforced low density polyethylene composites. Chemical modification was implemented to achieve better results. They concluded that the chemical modification and filler loading improved the mechanical and thermal properties of the prepared composites.

Patel *et al.* (2018) prepared sour-weed/polyester composites using hand layup technique and concluded that the sour-weed fiber of 15 mm length and 6wt% loading improved the physical properties and displayed the tensile strength of 34 MPa, impact strength of 10 Joules and hardness of 12 HV.

Dayo *et al.* (2018) prepared the hemp fiber by alkali treatment, shredded process, ball milling and sieved by 20, 40 and 80 mesh. The prepared fiber was reinforced with polybenzoxazine matrix. The effect of fiber loading and fiber diameter on the tensile, impact, flexural and water absorption properties were studied. They reported that while adding 30% volume fiber of 20 mesh fibers improved the tensile, flexural, impact, tensile modulus and flexural modulus by 91%, 43%, 168%, 137% and 73% respectively. Further, they pointed out that the reduction of fiber diameter improved the mechanical properties.

Yu *et al.* (2018) prepared short ramie fiber reinforced poly lactic acid composite by extrusion and injection molding process. The water absorption and hydrothermal aging processing was analyzed. The results showed that higher volume of ramie fiber absorbed more water as ramie fiber was hydrophilic in nature. Thermal aging test showed that the tensile and flexural strength decreased after adding the ramie fiber with composite.

Otto *et al.* (2017) prepared hybrid composite using polyurethane and natural fibers like sugarcane bagasse, sisal and rice husk and studied the mechanical properties. The fibers were pre-treated with sodium hydroxide and hydrogen peroxide before processing

Khalili *et al.* (2017) compounded the epoxy/hardener based natural composite using flame retardants by resin infusion technique and studied the effects of ammonium polyphosphate (APP), alumina trihydrate (ATH) and natural fiber (NF) on the thermal and mechanical behavior of the APP/ATH composites. The results showed that the incorporation of NF in the composite shifted the degradation temperature to higher value and inclusion of APP reduced the flame time and zero drip. The addition of 10 wt% of ATH and 2 wt% of APP in composite improved the flame retardancy and increased the amount of char residue. Further, the authors pointed out that the increases of ATH reduced the tensile strength and tensile modulus and the increases of APP enhanced the flexural strength.

Devireddy *et al.* (2017) fabricated jute/banana hybrid composites and studied their physical behavior. The results showed that while adding 30 wt% fiber contents of both jute and banana with epoxy composites, the mechanical properties were improved compared to the composites that were reinforced with the individual fibers.

Neves Monteiro *et al.* (2017) prepared curaua/aramid fiber based polyester composites and found that the addition of 30 wt% of curaua fiber displayed lower strength and stiffness compared to that of aramid fiber based composites. The energy absorption study revealed that the curaus fiber absorbed more energy compared to the aramid fiber. The authors concluded that the curaua fiber reinforced composite could be a suitable material in ballistic protection applications compared to aramid fibers considering the economic and environmental factors.

Latha *et al.* (2016) investigated the effect of stacking sequence on the tribological and mechanical properties of the bamboo and glass fiber reinforced polymer composites. The composite was fabricated using hand layup technique and cured under light pressure at room temperature. The composites were made as laminates; each laminates contained four plies of glass fibers. The position of glass fiber and number of plies formed the different sequences of the composites. The results displayed that the inclusion of glass fiber improved the mechanical and tribological behavior of the bamboo fiber and the stacking sequence affected the performance of the composites.

Essabir *et al.* (2016) fabricated the polypropylene hybrid composite using coir fiber and coir shell particles. The influence of hybridization and coupling agent on the structural, morphology, thermal and mechanical properties were investigated. The morphology test revealed that the coupling agent improved the interface strength of fiber and matrix. Thermal study reported that the thermal degradation of coir shell particles shifted to lower temperature compared to that of coir fiber. The coir fiber and the coir shell particle improved the young‟s modulus value.

Kumar *et al.* (2016) hybridized the banana fiber and coconut sheath with polyester using compression molding. Both banana and coconut sheath were involved into alkali treatment to improve the interfacial interaction. The results showed that the mechanical performance of the composite improved while adding banana fiber to the polyester compared to that of coir sheath. Further, the alkali treatment exhibited the positive effect on the mechanical performance. Additionally, the composite made with the order of pattern of coconut-banana-coconut displayed the enhanced damping propertie

Tan *et al.* (2016) prepared the coir fiber based polymer and cementitious composites. The authors pointed out that the alkali treatment of the fiber made the clean and rough surface of the fiber. Treated fiber increased the tensile and flexural property of the composite by 18% and 17% respectively compared to untreated fiber. However, the alkali treatment reduced the damping property of the composite. Additionally, the compressive strength, flexural and impact strength of the coir fiber composite was observed as high compared to that of plain cement. SEM image clearly displayed that the composite failure was due to the breakage of fiber, fiber pullout and debonding of fiber with matrix.

2.4 IDENTIFICATION OF RESEARCH GAP AND INDUSTRY PROBLEM

Previous investigations showed that there has been enormous amount work had been done on the natural fiber reinforced composites. Natural fibers improved the physical properties of the polymer composites slightly; however, surface treatment of the natural fiber displayed the reasonably improved strength to the composites. Even though, more investigations had been done in natural fiber reinforced composites, still there are some research gaps to identify and conduct research. The identified research gaps are described below in detail.

- There are very few research work has been done on the natural fibers occurring in India. Hence, there is a possibility to focus on the natural fibers growing in India.
- Very limited work has been done on Neem fiber and Indian almond fruit fiber. Hence, there is a scope to prepare hybrid composite based on Neem/Indian almond fruit fiber.
- Hybrid composite is fabricated by laminates of fiber mats. Hence, hybrid composite could be made using two or three laminates of fiber mats
- There is a scope to analyze the fracture morphology of the hybrid composite to investigate the fiber pullout, fiber breakage and fiber- matrix interfacial strength.
- The chemical compositions of the fibers could lead to analyze the bonding strength and mechanical properties of the composites.

2.5 RESEARCH METHODOLOGY AND FLOW CHART

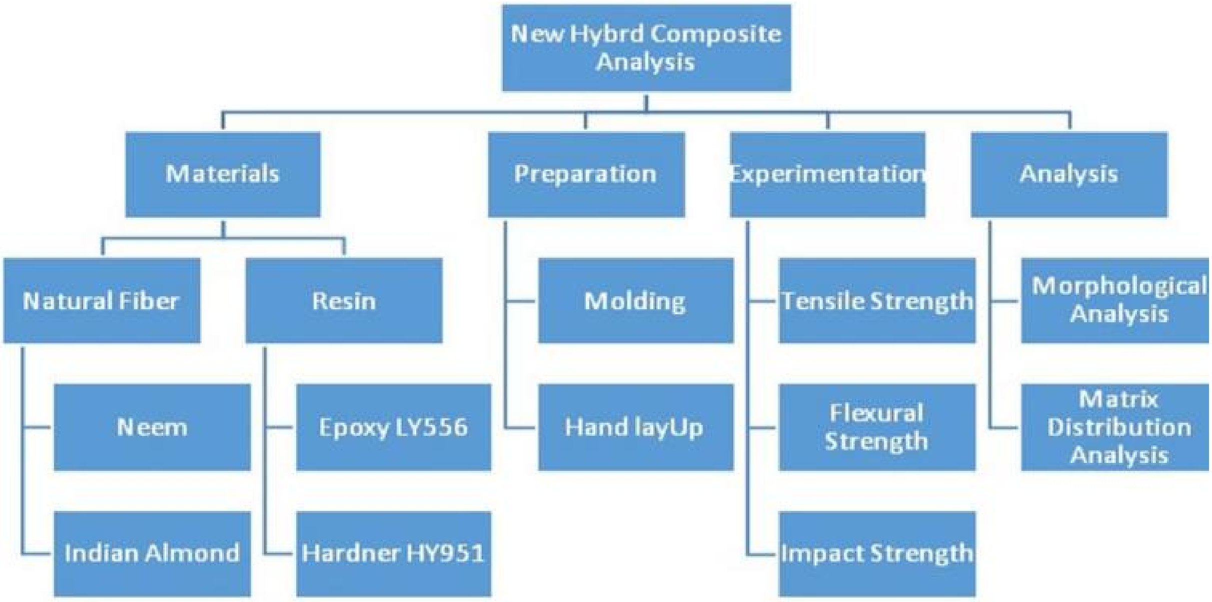


Figure 2.1 Hybrid composite materials research methodology

2.6 SUMMARY

Several investigations showed that natural fibers have the ability to enhance the physical properties of the composites. Many investigators have studied the effect of hybridization of the fibers and found the successful results. In this investigation, the hybridization is considered and hybrid composite consisting of two natural fibers namely neem and Indian almond fruit fibers is to be prepared. The hybridization effect and the stacking sequence of the fiber in the composite are to be studied. The morphological study of fractured sample and the chemical composition analysis of the fibers are to be investigated to analyze the strength of the fiber.

CHAPTER 3

MATERIALS AND METHOD

3.1 MATERIALS

3.1.1 Resin

Resins are highly viscous substance available in nature or synthetic. It is insoluble in water and used for adhesive purposes. While preparing polymer composites resins are used to bind the fillers in addition to acting as matrix.

3.1.1.1 Epoxy resin

Epoxy resin was used in this investigation as matrix and binding material. Epoxy resin finds general applications in fiber reinforced composites. Epoxy LY556, hardener HY951 and silica release gel was purchased from Roto polymers and chemicals, Tamilnadu, India. The manufacturer‟s data are given in Table 3.1.

Table 3.1 Manufacturer's data of Epoxy LY556

Properties	Details
Aspect (visual)	Clear, pale yellow liquid
Viscosity at 25 °C	10000 – 12000 mPa.S
Density at 25 °C	1.15 – 1.20 g/cm^3
Flash point	> 200 °C
Storage temperature	2 – 40 °C

(Source: www.indiamart.com)

Figure 3.1 Epoxy resin LY559 and Hardener HY951

3.1.1.2 Hardener

Hardener is a resin used along with the epoxy resin to promote the chemical reaction and convert the liquid form of epoxy into solid to make firm adhesive. In this investigation HY951 hardener was used along with Epoxy LY559 resin. The manufacturer‟s data of hardener HY951 is shown in Table 3.2.

Table 3.2 Manufacturer’s data of hardener HY951

Properties	Details
Aspect (visual)	Clear liquid
Viscosity at 25 °C	50 – 100 mPa.S
Density at 25 °C	1.20 – 1.25 g/cm^3
Flash point	> 195 °C
Storage temperature	2 – 40 °C

3.1.1.3 Silica release gel

Silica release gel is another form of silica consisting of tridimensional alternate layers of silicon and oxygen atoms. Generally, silicon release gel is used while composite preparation to avoid the sticking of the epoxy resin in the mould cavity. It is applied inside the mould gently with hand brush before the preparation of composites.

(Source: www.indiamart.com)

Figure 3.2 Silica release gel

3.1.1.4 NaOH solution

NaOH solution was used for the purpose of alkali treatment of fibers in this investigation. It was purchased from the RV Enviro chemicals, Madurai, Tamilnadu, India.

(Source: www.fishersci.com)

Figure 3.3 NaOH solution

3.1.2 Natural Fibers

Natural fibers are the fibers extracted from the plants that are used in polymer composites to reduce the weight as density of natural fibers are low compared to other materials. Natural fibers are attracted due to environment friendly, abundantly available, low cost and biodegradable.

Neem tree (Azadirachta indica) is a common and fast growing tree in Asia, can grow up to 15-20 m height and used as herbal in medical field. The fiber of Neem tree has the high potential to apply as reinforcing agent in the polymer composites as the ultimate tensile strength of Neem fiber reinforced polymer composite is 1.35 times higher than the pure polymer.

Indian almond tree (Terminalia catappa) is large tropical trees grow in Asia, Africa and Australia. The fruits of Terminalia catappa are edible fruits eaten by birds, animals and humans. The fruit contain inner nut surrounded with fiber and flesh.

In this investigation, Neem fiber and Indian almond fruit fiber were used to prepare the composites. Neem fiber was obtained commercially from the Gogreen products, Chennai and Indian almond fruit fiber was prepared manually.

3.1.2.1 Preparation of Indian almond fruit fiber

The Indian almond fruit contains inner nut surrounded with fiber and flush. The Indian almond fruits were collected from the local agricultural field and soaked in water for three days to loosen the flush from nut. After three days, the loosened flush was removed by cleaning in the high force running water. The nut surrounded with fibers was dried in sun for one hour and the fibers were removed from the nut by manually. The collected fibers were again dried in sun for one day to completely remove the moisture.

Figure 3.5 Neem stem

Figure 3.4 Neem tree

Figure 3.6 Neem fiber

Figure 3.7 Indian almond tree

Figure 3.8 Indian almond fruit

Figure 3.9 Indian almond fruit fiber

3.1.2.2 Alkali treatment of fibers

Alkali treatment is a chemical process of cleaning the natural fibers. Generally, natural fiber surface would be covered with dirt and sand. It should be cleaned by chemicals and followed by water to obtain clean surface. Further, the alkali treatment improves the roughness of the fiber surface that would lead to better bonding between the fibers and resin.

The fibers were treated with 5% NaOH solution for 30 minutes to remove the dirt from the fiber to get better reinforcement between fiber and matrix. After treating, it was thoroughly cleaned with distilled water to neutralize the NaOH solution deposited on the fiber surface and dried in room temperature for 24 hours.

3.2 PREPARATION COMPOSITE

3.2.1 Natural Fiber Composite Preparation

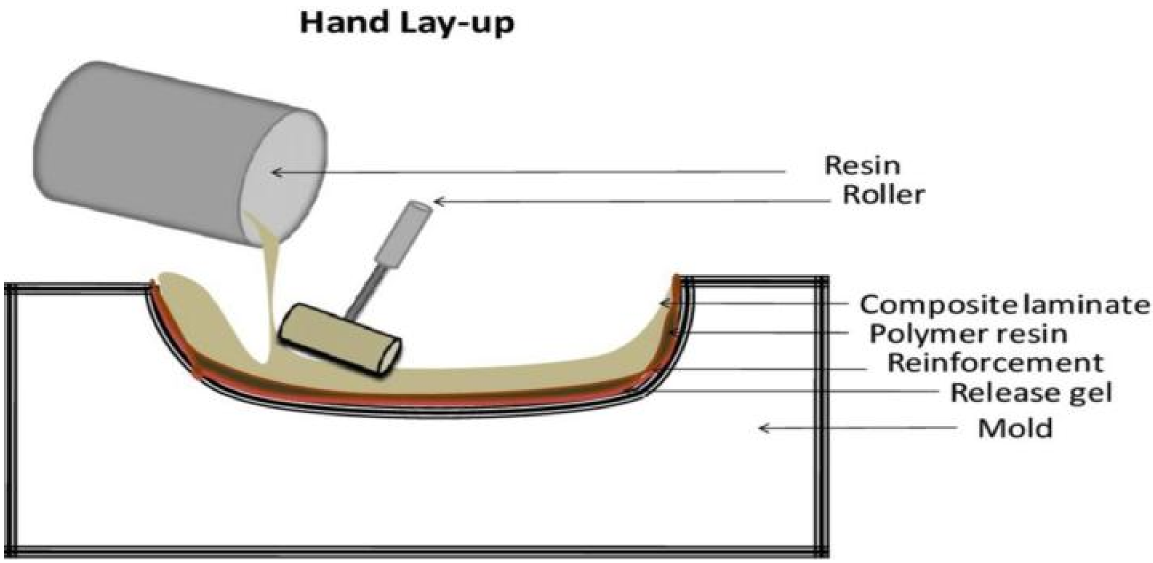
Natural composite are composites that are reinforced with naturally available fibers. Composite might contain one or more than one fibers depending on the strength and need. There are various methods available to fabricate the natural composites as given below.

- Hand lay-up method
- Vacuum bag molding
- Pressure bag molding
- Autoclave molding
- Resin transfer molding
- Finishing methods
- Tooling

In this investigation, Hand lay-up method was used to prepare the composites.

3.2.2 Hand Lay-up Method

Hand lay-up method is one of the inexpensive and beat methods to prepare natural composites in open molding from small size to large. The composite preparation using hand lay-up method is described below.



(Source: www.nptel.ac.in)

Figure 3.10 Hand lay-up methods

The alkali treated fibers were made into fiber mat by manually before the composite preparation. Neem fiber and Indian almond fruit fiber were reinforced in epoxy resin to prepare the composite. The composite was prepared using hand layup technique as detailed in Table 3.3. Initially, the epoxy resin LY556 was mixed with hardener HY951 by 10:1 weight ratio and stirred manually to get even distribution of resin in the hardener. Each layer of Neem and Indian almond fruit fibers was 200 mm x 200 mm in size. A stainless steel mould of size 210 mm x 210 mm x 40 mm was used. Firstly, a silica release gel was applied on the mould to avoid the sticking of resin. The epoxy resin LY556 was applied on the mould surface by using hand brush and then fiber mat was placed over the resin. This process was repeated till the 70:30 weight percentage of resin and fiber was achieved. After putting every fiber mat, a metallic roller was rolled above the surface of fiber mat to remove the gases and bubbles trapped in the layers. After laying up process, the mould was closed tight and cured for 24 hours under a load of about 25 kg. Then this composite was taken from the mould and post cured at room temperature for another 24 hour and sliced into required dimensions for testing.

Table 3.3 Formulation of composites

Composites	Epoxy (wt %)	Neem (wt %)	Indian almond (wt %)
Pure Neem	70	30	0
Pure Indian almond	70	0	30
Neem/Indian almond/Neem	70	20	10
Indian almond/Neem/Indian almond	70	10	20

Figure 3.11 Fiber mat

Figure 3.12 Prepared composites

3.2.3 Density Calculations

Density of the composite is determined to analyze and confirm the appropriateness of the material for the required applicability. The material is processed further after confirming the nullification or minimum amount of voids in the prepared composites. The actual density of the composite was measured by water immersion method based on Archimedes principle and the theoretical density was calculated using the following equation (Agarwal *et al.* 2017).

$$\frac{1}{\rho_T} = \frac{W_R}{\rho_R} + \frac{W_M}{\rho_M} \qquad (3.1)$$

where, ρ_T is theoretical density, W_R is weight fraction of reinforcement, ρ_R is density of reinforcement, W_M is weight fraction of matrix and ρ_M is density of matrix. The percentage change in density was calculated using the following equation.

% change in density = [(Theoretical density – Actual density)/Theoretical density] x 100 (2)

3.2.4 Tensile Strength Analysis

Tensile test was conducted to calculate the tensile strength and tensile modulus or young‟s modulus of the materials.

The tensile test was performed according to the standard ASTM D3039 with the test speed of 5 mm/min. The test speed was maintained from
1.3 mm/min to 1.5 mm/min. The test was conducted using Instron 3369 universal testing machine. Five specimens were tested and average value was considered for discussion.

Figure 3.13 Universal testing machine

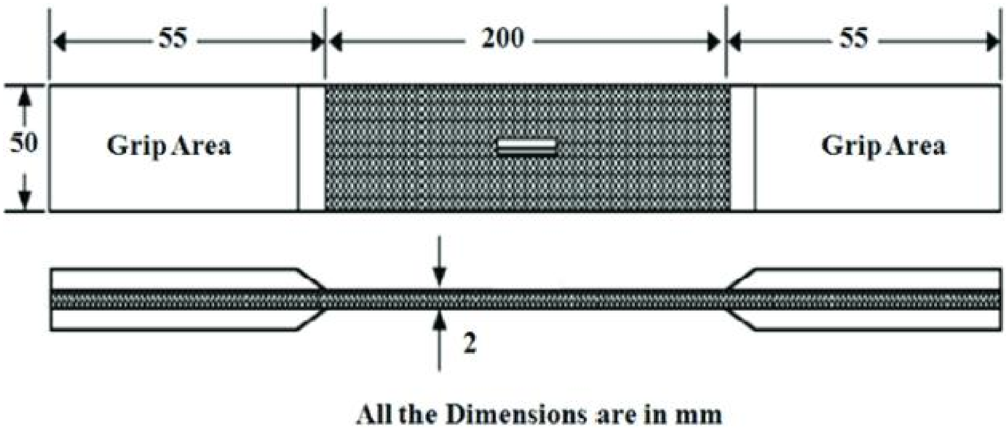


Figure 3.14 Tensile test specimen

3.2.5 Flexural Strength Analysis

Flexural strength and flexural modulus was calculated using the Universal testing machine. The flexural test was conducted as per standard ASTM D7264. The test speed was maintained from 1.3 mm/min to 1.5 mm/min. five specimens were tested and average value was considered for discussion.

(Source: www.wyomingtestfixures.com)

Figure 3.15 Flexural test

3.2.6 Impact Strength Analysis

Impact test was conducted to analyze the materials capability to absorb the energy while applying sudden loads. In the current investigation, the izod impact test was conducted as per ASTM D 256 standard using impact tester. In impact test, five specimens were tested and average value was considered for discussion.

Figure 3.16 Izod impact tester

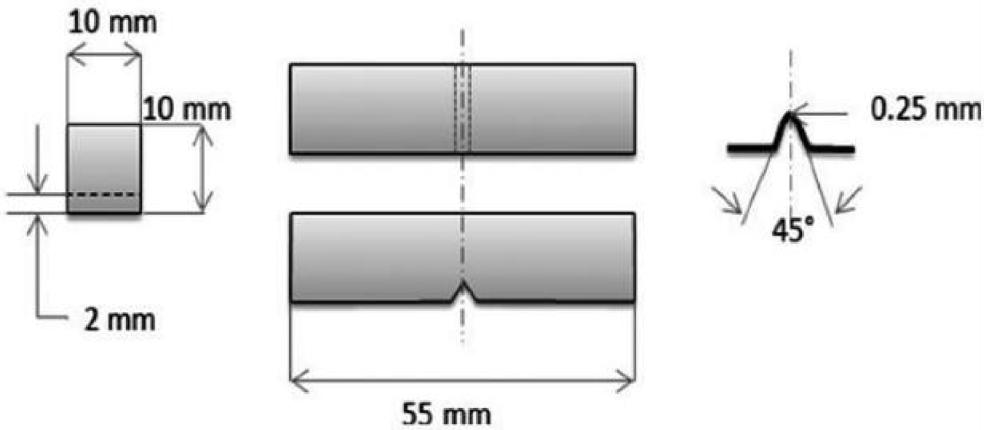


Figure 3.17 Izod impact test specimen

3.2.7 Wear Analysis

Wear analysis was done to know the lifetime of material that would be helpful to change the damaged material at right time before failure occur. Wear test was conducted in pin-on-disc wear testing machine as per ASTM G99-95 standard. A spherical pin was pressed against the rotating disc where the material to be tested was fixed. The test could be conducted in dry and wet conditions. In this investigation, the test was performed in dry conditions without using any lubricants. The wear test parameters were selected as: applied load 20 – 80 N, Sliding velocity – 150 mm/s & Sliding distance – 1000 m.

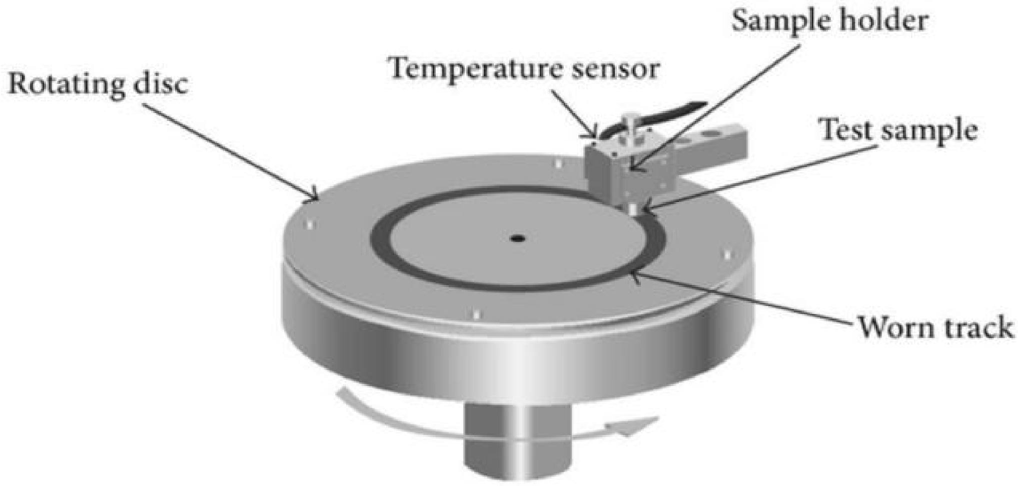


Figure 3.18 Pin-on-disc

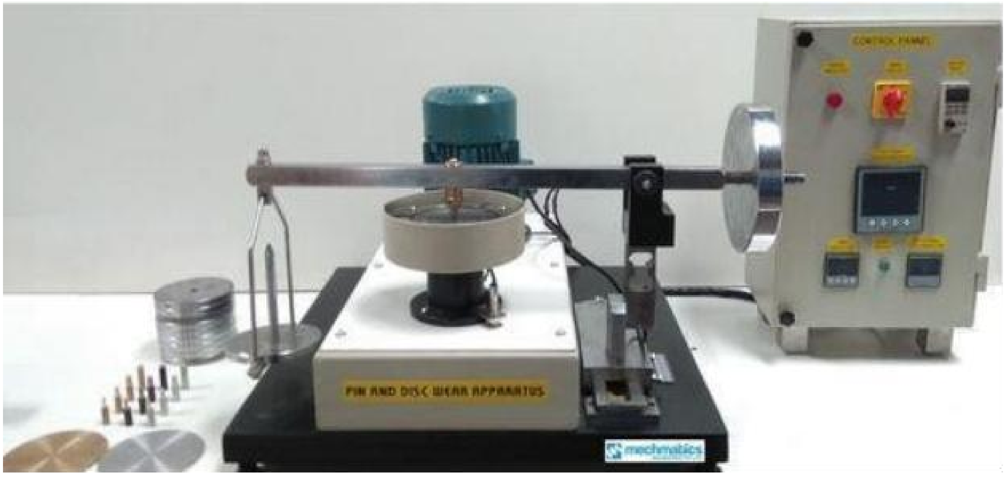


Figure 3.19 Pin-on-disc wear test equipment

3.3 CHEMICAL CHARACTERIZATION

3.3.1 FTIR Analysis

Fourier Transform Infrared Spectroscopy (FTIR) is used to identify the organic, inorganic and polymeric material that uses infrared light to identify the chemical composition of the test samples. In this investigation, both the fibers were involved into experiment using SHIMADZU FTIR analyzer.

Figure 3.20 FTIR analyzer

3.4 MORPHOLOGICAL STUDY

Morphological study was carried out using Scanning Electron Microscopy (ZEISS) to analyze the adhesion between the resin and fibers, fracture morphology of the mechanically tested specimens. Gold coating was applied on the fracture surface to increase the conductivity since the specimens were polymeric materials. The accelerated voltage of 20 kV was used while carrying out the experiment.

(Source: www.biocompare.com)

Figure 3.21 Scanning electron microscopy

CHAPTER 4

RESULTS AND DISCUSSION

4.1 MECHANICAL STRENGTH ANALYSIS

Mechanical strength is the ability of the material to withstandexternal force and this is the most desirable factor in the engineering field. Performance and suitability of the material is assessed by the mechanical strength of the material. Mechanical strength includes the tensile, compressive, shear, flexural and so on. In this section, the strengths like tensile, flexural, impact and wear behavior of the materials are discussed.

4.1.1 Density Calculation

Natural fiber Composite was prepared by hand lay-up method.Generally, while preparing the composite, there is a chance to entrap the air inside the composite and this would create voids inside it and finally lead to poor strength of the composites. To avoid this, a hand roller was used while composite manufacturing and rolled over it to release the entrapped air. It is a good practice to confirm the eradication of voids or presence of minimum amount of voids in the composite. Composite density is the identification of voids. Hence, density measurement was done both experimentally and theoretically and the values are tabulated in Table 4.1. As the results showed minimum percentage of voids content, it is confirmed that the composite manufacturing was better executed and finally the prepared composite was processed further for the mechanical characterization

Table 4.1 Theoretical and experimental density

Material	Experimental density (g/cm^3)	Theoretical density (g/cm^3)	% change in density (% void content)
Pure Neem	1.09	1.15	5.22
Pure Indian almond	0.96	1.03	6.80
Neem/Indian almond/Neem	1.02	1.09	6.42
Indian almond/Neem/Indian almond	1.10	1.18	6.78

4.1.2 Tensile Study

In tensile study, tensile strength and tensile modulus or young‟s modulus of the material is characterized. Tensile strength is the ability of the material to withstand an external load exerted along the longitudinal axis of the material. Young‟s modulus measures the stiffness of the material.

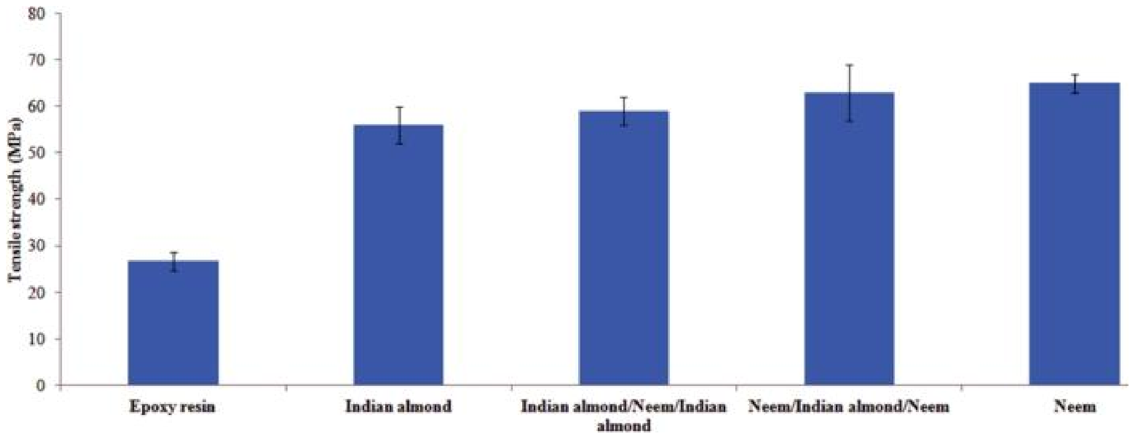


Figure 4.1 Tensile strength of composites

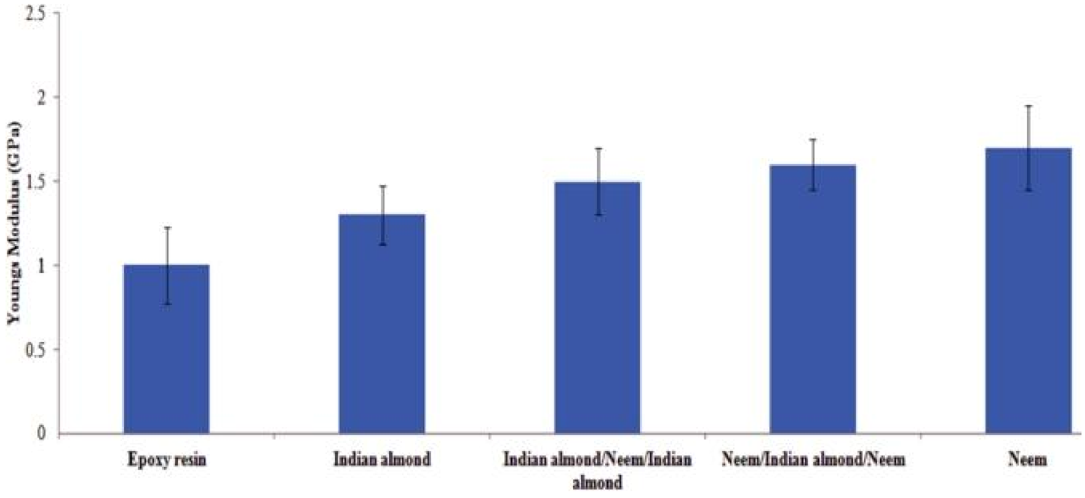


Figure 4.2 Young's modulus of composites

The tensile strength and young‟s modulus of Indian almond/Neem/Indian almond (IA/N/IA) and Neem/Indian almond/Neem (N/IA/N) composites are shown in Figure 4.1 and 4.2.

It can be seen from the Figure 4.1 that the tensile strength of Neem fiber displayed a greater tensile strength (65 MPa) compared to the Indian almond fiber (56 MPa) and could be concluded that the Neem fiber is strongerand stiffer than the Indian almond fruit fiber. The high tensile strength of Neem fiber is due to the better bonding between the Neem fiber and epoxy resin and the lower tensile strength of Indian almond fruit fiber is due to the presence of surface cracks on the outer surface of the fiber. Moreover, the tensile strength of N/IA/N hybrid composite is superior compared to thetensile strength of IA/N/IA hybrid composites because of high tensile strengthNeem fiber is used as skin and low tensile strength Indian almond fruit fiber is used as core in hybrid composite. The young‟s modulus of hybrid composites and fibers exhibited a similar trend of variationof tensile strength as the young‟s modulus depends on fiber structure, fiber property and reinforcements (de Medeiros *et al.* 2005)

4.1.3 Flexural Study

Flexural study reveals about the flexural strength and flexural modulus. Flexural strength comprises both tensile and compressive strength of material when subjected to bending. While bending a beam or rod, the upper layer experiences tensile as well as lower layer experiences compressive force. Flexural strength measures the stress in a material before yielding occurs and flexural modulus indicates the bending resistance of the material.

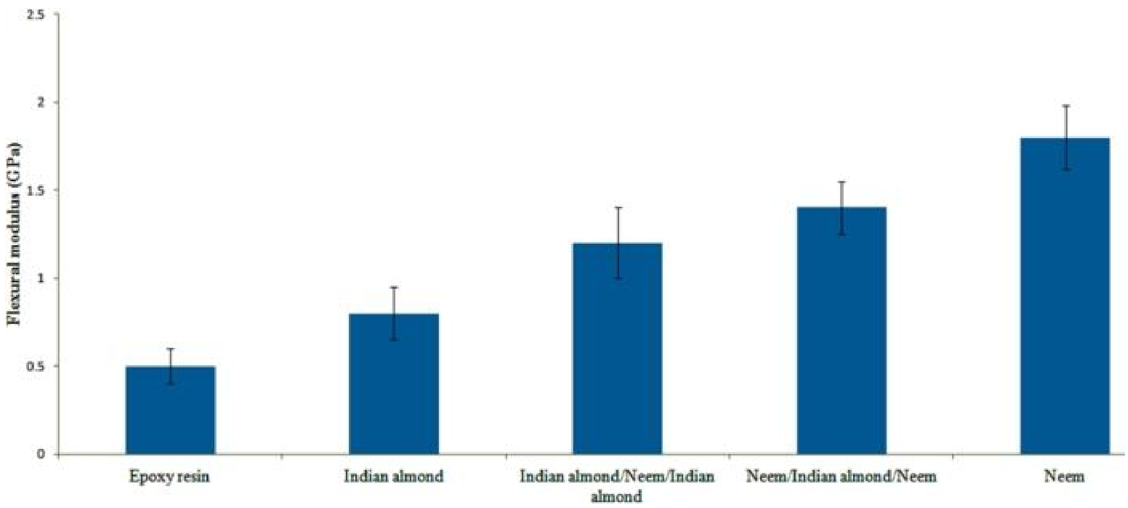


Figure 4.4 Flexural modulus of composites

The flexural properties showed similar trend of variation as the tensile properties. The flexural properties of hybrid composite made with highflexural strength (65 MPa) Neem fiber as skin exhibited the superior flexural properties compared to that of hybrid composite made with low flexuralstrength (51 MPa) Indian almond fruit fiber. Hence, in this investigation, it is concluded that the strength of the extreme fiber of hybrid composite determines the strength of the hybrid composite and this is well in accordance with the previous study reported by Gowda *et al.* (1999).

4.1.4 Impact Study

Impact study deals with the ability of the material while applying sudden loads. The energy absorbed by the material while applying suddenload is measured in impact study and this investigation is used to understand the performance of the material in the field of damping or vibration environment.

The impact strength of IA/N/IA and N/IA/N composites is shownin Figure 4.5. The impact strengths of N/IA/N and IA/N/IA composites are
4.5 kJ/m^2 and 5.1 kJ/m^2 respectively. It is obviously seen that the impact

strength of IA/N/IA composite is greater than the impact strength of N/IA/N owing to the presence of high impact strength Indian almond fruit fiber at the outermost layer of the composite. The surface architecture and the presence ofsmall cracks on the extreme surface of the Indian almond fruit fiber helped to absorb more energy as the cracks hinder the stress transfer and increased the impact strength to 5.6 kJ/m^2 (Rizal *et al.* 2018). The epoxy showed the low impact value (4 kJ/m^2) compared to fiber reinforced hybrid composites which indicates that the fiber play a major role in impact strength.

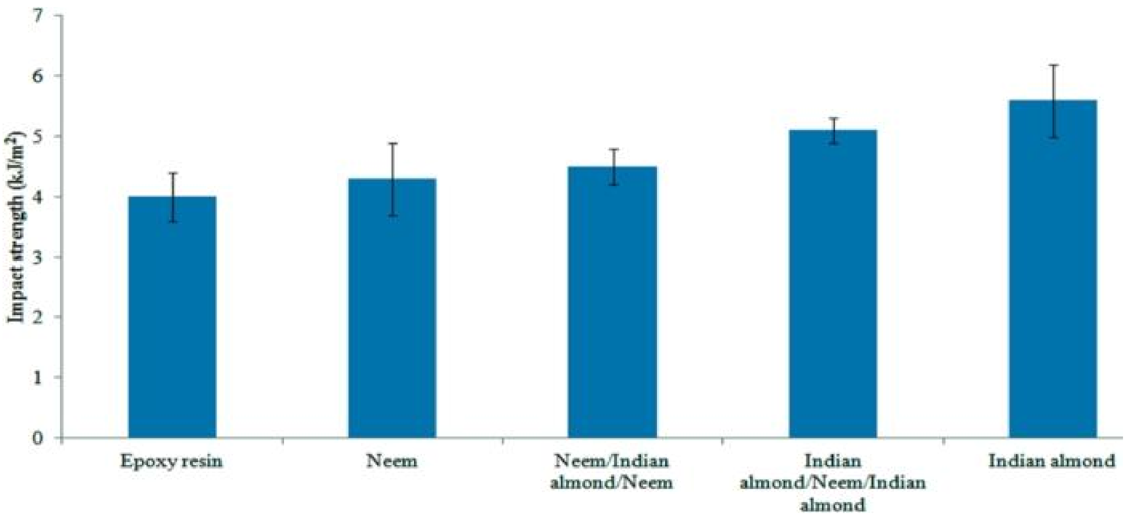


Figure 4.5 Impact strength of composites

4.1.5 Wear Study

Wear is the removal of material from the surface of the composite and it reduces the strength and life of the material. Wear resistance or wear strength is a measurable factor of the material to identify the suitability of material in a particular application.

The plot of wear test is shown in Figure 4.6. As obviously seen from the Figure 4.6, it is concluded that the wear rate of the composites increases as load increasing. This could be due to the fact that while increasing the load, the composite involved into deep grooving and large amounts of material is removed from the composite. Further, compared to N/IA/N composite, the IA/N/IA composites showed more wear rate because of the low strength Indian almond fruit fiber used as skin. Moreover, the wear rate of the composite is depending on the various dominant factors such as tensile and flexural strengths.

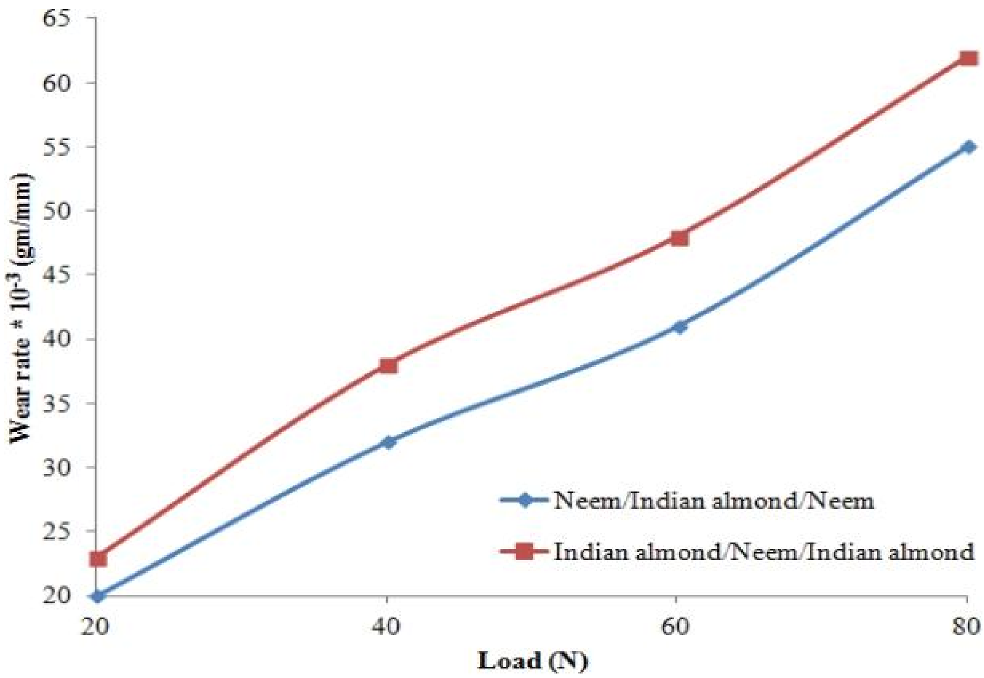


Figure 4.6 Wear rate of composites

4.2 CHEMICAL CHARACTERIZATION

Chemical analyses of the fibers are used to investigate the chemical bonding present in the fibers. The chemical bonding is linked with the physical properties of the materials. Fourier Infrared Transform Analysis (FTIR) is an analytical method used to investigate the compositions of the materials or impurities present in the materials.

4.2.1 FTIR Analysis

The FTIR spectrum of the Neem fiber and Indian almond fruitfiber is shown in Figure 4.7 & 4.8. Both the fibers showed a strong peak around 3406 cm^{-1} that is the indication of O-H stretching vibration of strong hydrogen bonding (Wang *et al.* 2017). The peak at 2924 cm^{-1} and 2922 cm^{-1} of Indian almond fruit fiber and Neem fiber respectively attributed to the absorption peak of C-H methylene group (Salem *et al.* 2017). The ester group corresponding to the spectrum at 1740 cm^{-1} is appeared in Neem fiber and not appeared in Indian almond fruit fiber. The C-O strong amide functional group corresponding to the peak at 1649 cm^{-1} exhibited in both the fibers. Further, the Neem fiber and Indian almond fruit fiber showed the spectrum at 1506 cm^{-1} and 1319 cm^{-1} respectively is the indication of NO_2 strong stretch bonding. Hence, the Neem fiber is stronger than Indian almond fruit fiber and this result is well accordance with the mechanical properties of the composites.

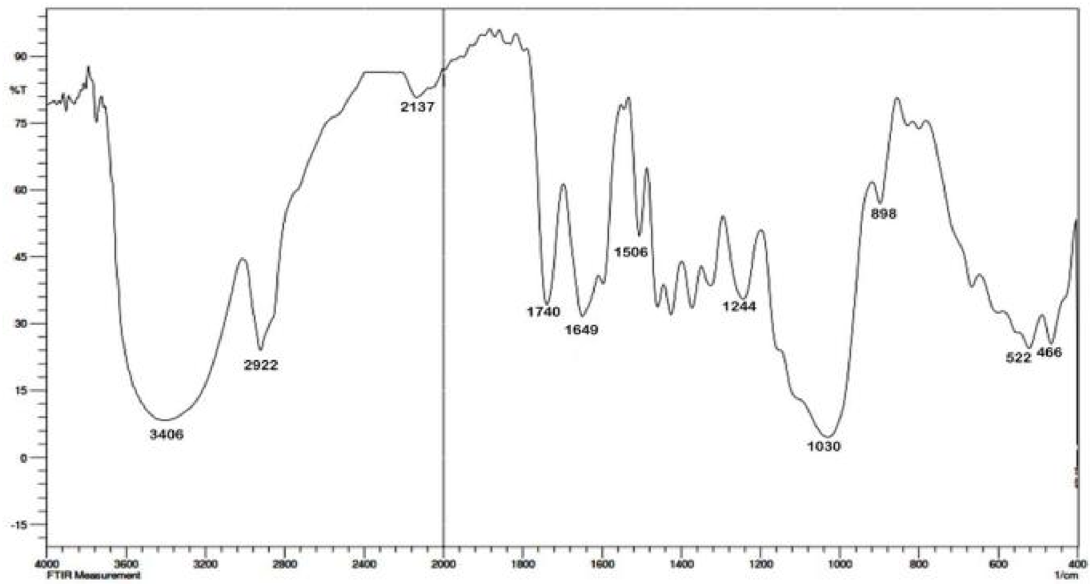
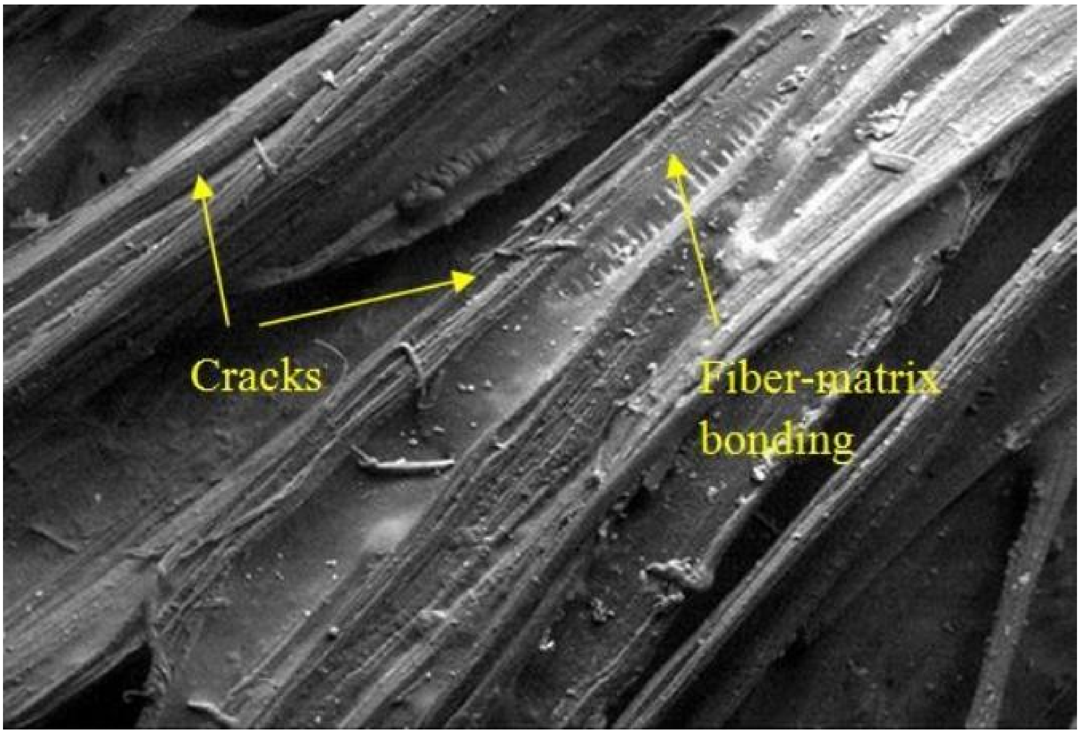


Figure 4.7 FTIR spectrum of neem fiber

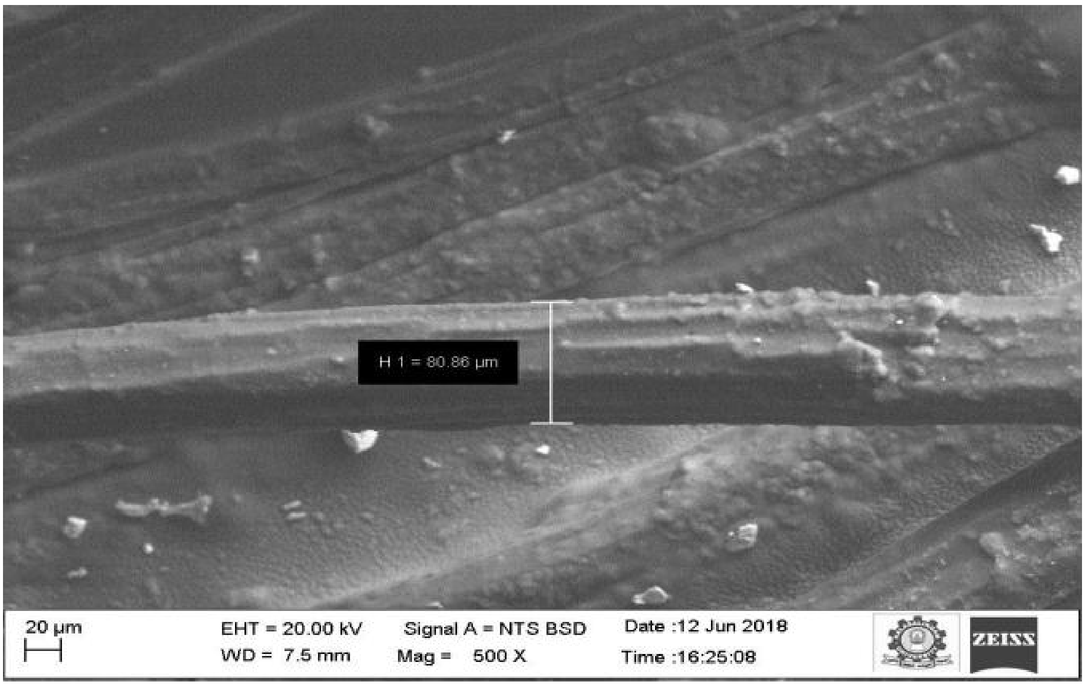
4.3 MORPHOLOGICAL ANALYSIS

Morphological studies are carried out to analyze the composite samples in microscopic level to know the bonding of the matrix and fillers. The bonding determines the mechanical properties of the materials.

SEM image depicts the matrix and fiber reinforcements. The reinforcement is determined by the bonding between the matrix and fiber, fiber surface morphology and voids. The SEM images of surface morphology of hybrid composites are shown in Figure 4.9 & 4.10. The Neem fiber reinforced composite showed good bonding between the fiber and matrix due to the dry, clean and rough surface of the fiber and the Indian almond fruit fiber reinforced composite showed cracks on the fiber surface and voids in the composite which decreased the tensile and flexural strength compared to composite reinforced with Neem fiber. Figure 4.9 represents the morphological analysis of the layered composite structure of Indian almond/Neem/Indian almond.



(a)



(b)

Figure 4.9 (a and b) Surface morphology of Indian almond/Neem/Indian almond Composit

The chemical treatment reduces the wax content and the foreign impurities in the fiber which is clearly visible from the analysis. Which increases the fiber matric interaction also visible from the Figure 4.9 (a). Figure 4.9 (b) is the morphological analysis of the composite the fiber pulled out from the matrix in the fractured section. The fiber diameter reduces in thefractured region reassures that the fracture is ductile in nature of the prepared composite. These ductile fractures are responsible for the increase in thestrength of the composite.

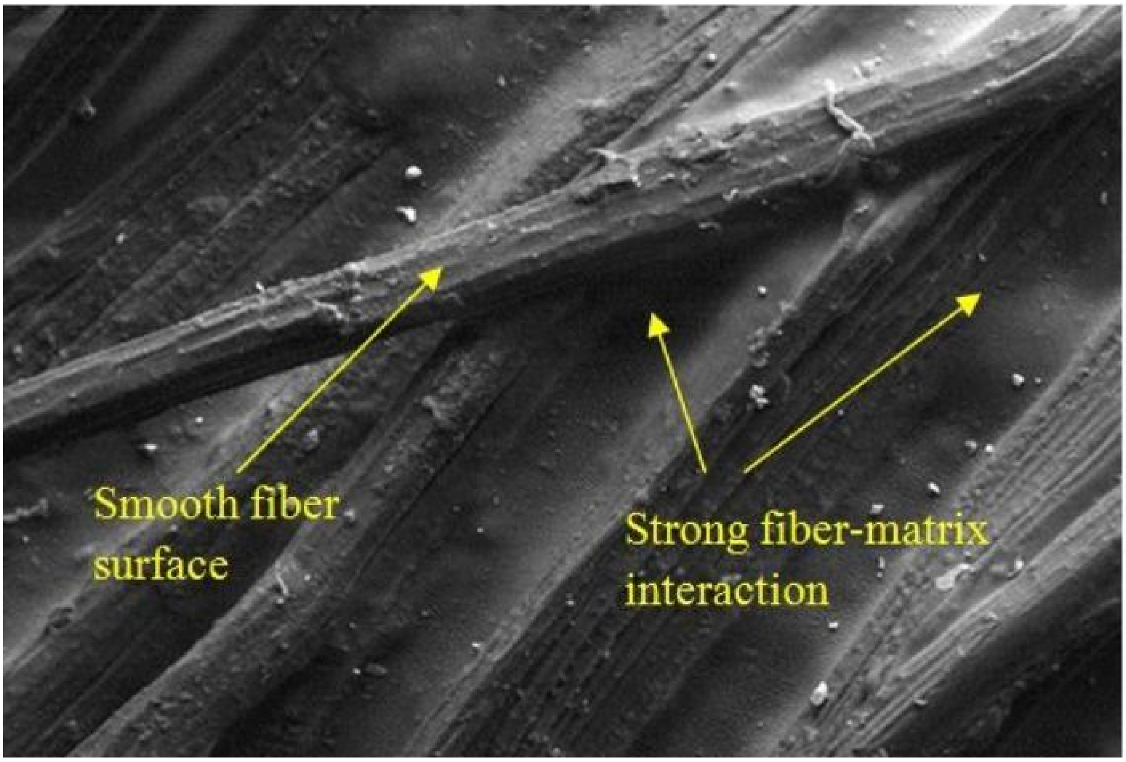
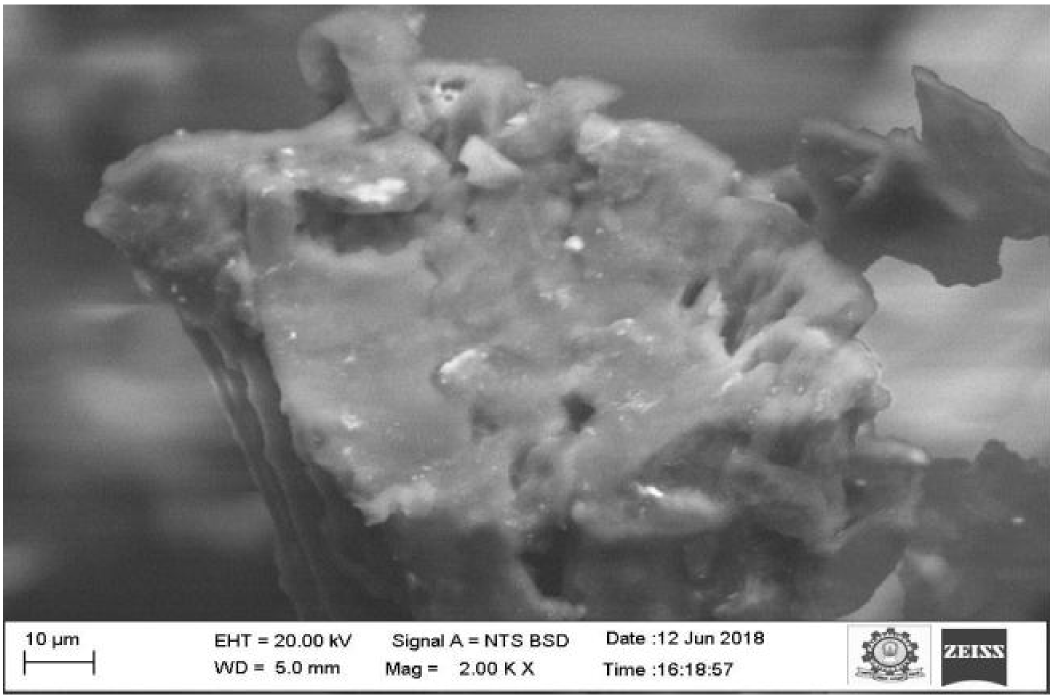
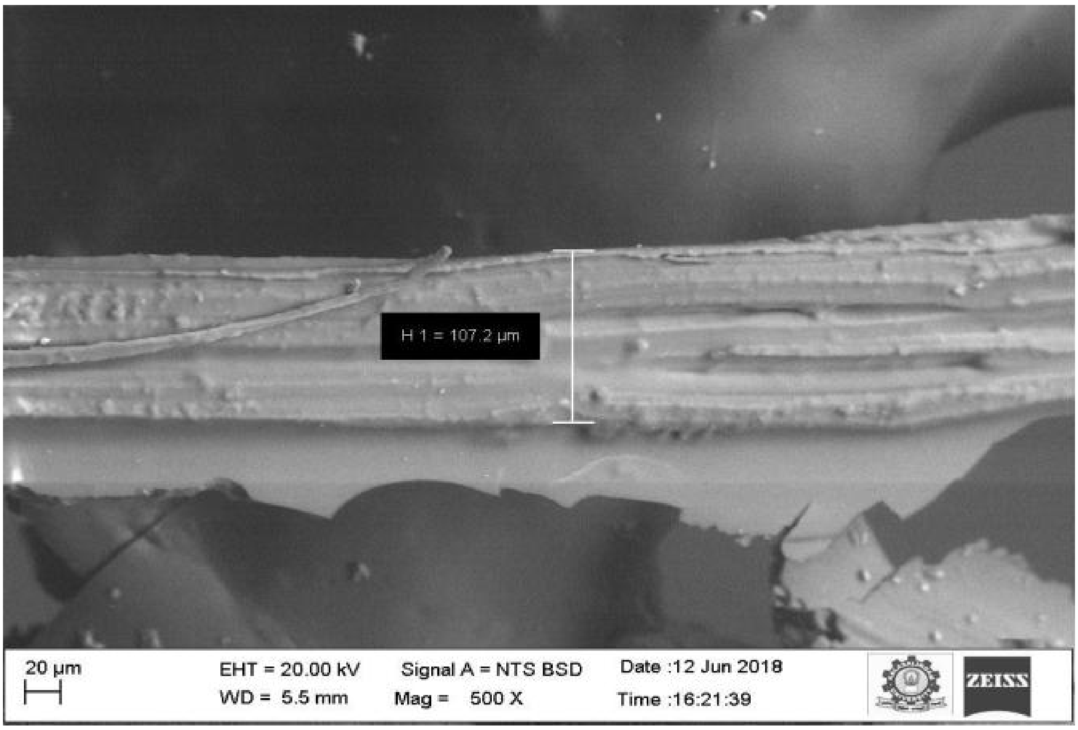


Figure 4.10 shows the Morphological analysis of the Neem/Indian Almond/Neem composite prepared. the positive effect of the chemical treatment is visible from the image 4.10 (a). The Figure 4.10 (b) shows the brittle fracture occurred in the composite fracture region which is explained by the Flat fractured surface. This brittle fracture ensures the increased hardness in the composite. The Figure 4.10 (c) shows the diameter of the Neem/Indian almond/Neem composite and also reduces in fractured region..

(a)


10 µm
EHT = 20.00 kV
Signal A = NTS BSD
Date :12 Jun 2018
WD = 5.0 mm
Mag = 2.00 K X
Time :16:18:57
ZEISS

(b)


H 1 = 107.2 µm
20 µm
EHT = 20.00 kV
Signal A = NTS BSD
Date :12 Jun 2018
WD = 5.5 mm
Mag = 500 X
Time :16:21:39
ZEISS

(c)

Figure 4.10 (a, b and c) Surface morphology of Neem/Indian almond/Neem composite

4.4 FINITE ELEMENT SIMULATION OF COMPOSITE

The finite element methods were mainly using methods for solving the problems of mathematical and engineering models. The different of problem solving of area using the finite element methods automobile, chemical, heat transfer, transport and medical industries.

The major contribution of finite element simulation method was reduced the involvement of cost and the fastest system of analyzing too. The sport cycle frame was model using SOLIDWORKS and analyzed in ANSYS for compression performance. The SOLIDWORKS model of sport cycle frame was shown in Figure 4.11 - 4.18 and the meshing of model even as analyzing by ANSYSwas shown in Figure 4.19 - 4.21.

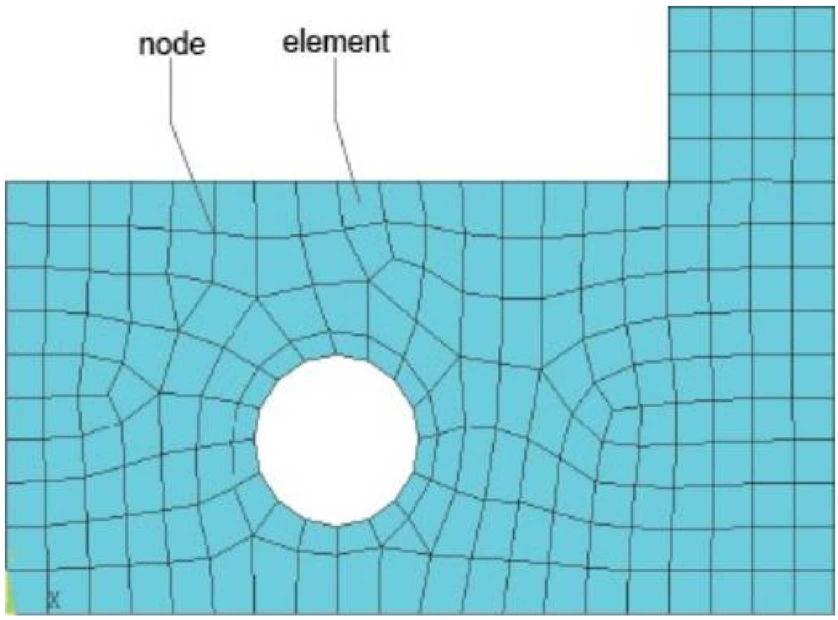


Figure 4.11 Representation of element and node

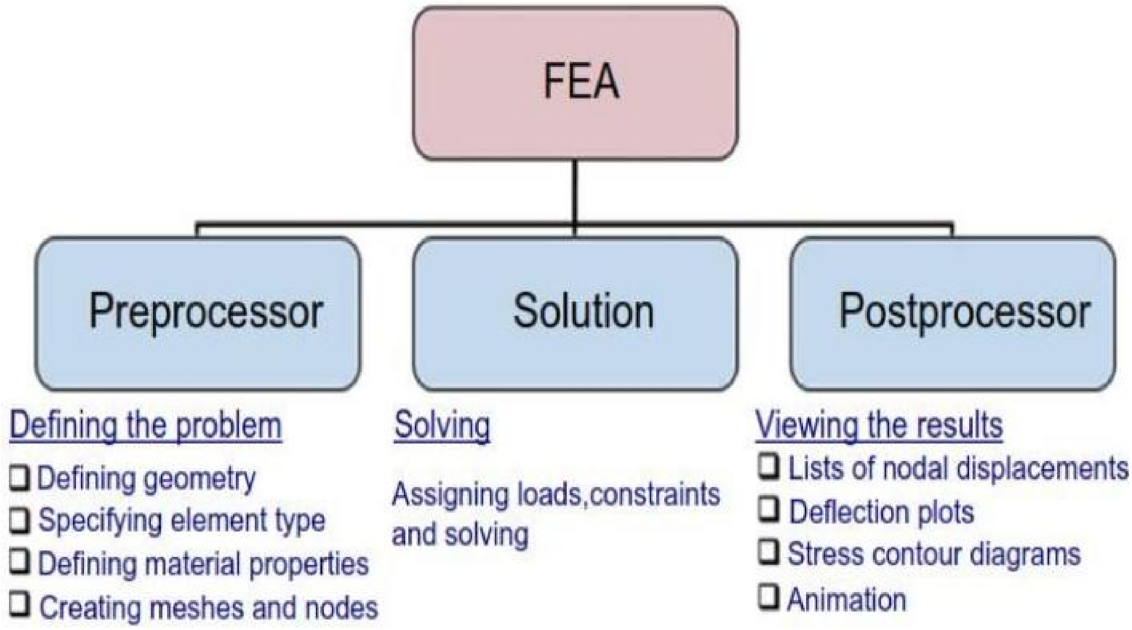


Figure 4.12 Overview procedure of FEA

4.4.1 FEA Steps

4.4.1.1 Preprocessing

In preprocessing, the invention geometry was shaped by the assist of modeling software like Catia, ProE, Solidworks etc. The simple geometry possibly will be modeled through the analyzing software itself. Behind modeling, the geometry was assigned into material properties, messing and structural or stress loads were sensible according to the purpose. In case of difficult geometries approximating aircraft part and engine parts design, HYPERMESH software was second-hand for meshing to give the practical result of the prototype.

4.4.1.2 Solving for solution

While preprocessing, the information like constituent stiffness, global stiffness and force vectors were stored in the shape of environment in the record. The data in the matrix form was solved through the make use of solvers. generally, Gaussian elimination method was second-hand to solve the matrix problem by LS-DYNA or ANSYS analysis software. The solver willpower gets more time even as more number of elements of higher order was here in the geometry. To reduce the solver time, linear element was favorite and the number of elements determines the precision of the solution.

Figure 4.13 Overview procedure of cycle frame

Figure 4.14 Overview procedure of sport cycle frame

Figure 4.15 Overview procedure of mesh application

The race bicycle suddenly accident in the road, the mainly affected to the front and center of the position. That‟s reason compressive test was conducted in the bicycle model to the FEA analysis. Nowadays titaniumbicycle made upon, so that some particularly defect was formed in the race bicycle or normal bicycles. The compressive loading of the model is displayed in Figure 4.15 and the material properties considered are shown in Table 4.1

Table 4.2 Properties of Polymer Composites

Sl. No.	Property	Fibers Reinforced Polymer Composites
1.	Mass	1.5 kg
2.	Volume	6 10^{-5} m^3
3.	Density	1800 kg/m^3
4.	Weight	10 N
5.	compressive strength	10 10^9 N/m^2
6.	Young‟s Modulus	2.14 10^9 N/m^2
7.	Poisson‟s ratio	0.25

The uniform distribution load was applying in the bicycle modeled with Fibers Reinforced Polymer Composites are shown in figure 4.16 & 4.14 respectively and obviously display that the compressive stress distribution of bicycle case modeled with Fibers Reinforced Polymer Composites involved into less amount of uniform distribution of stress.

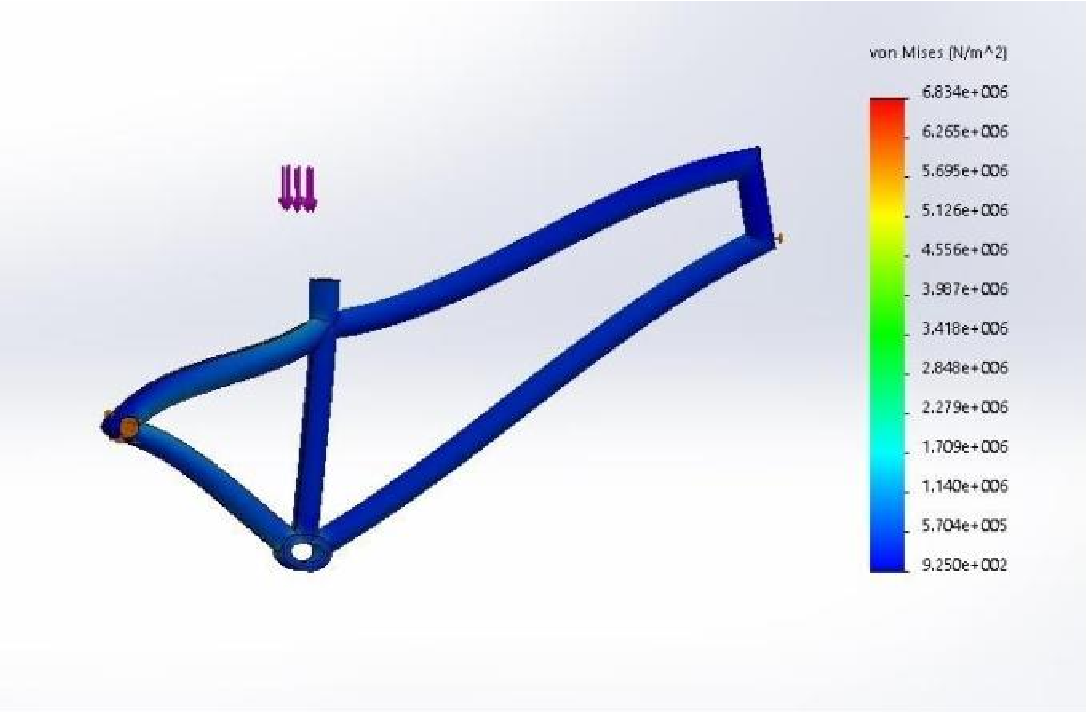


Figure 4.16 Application of compressive load of top end

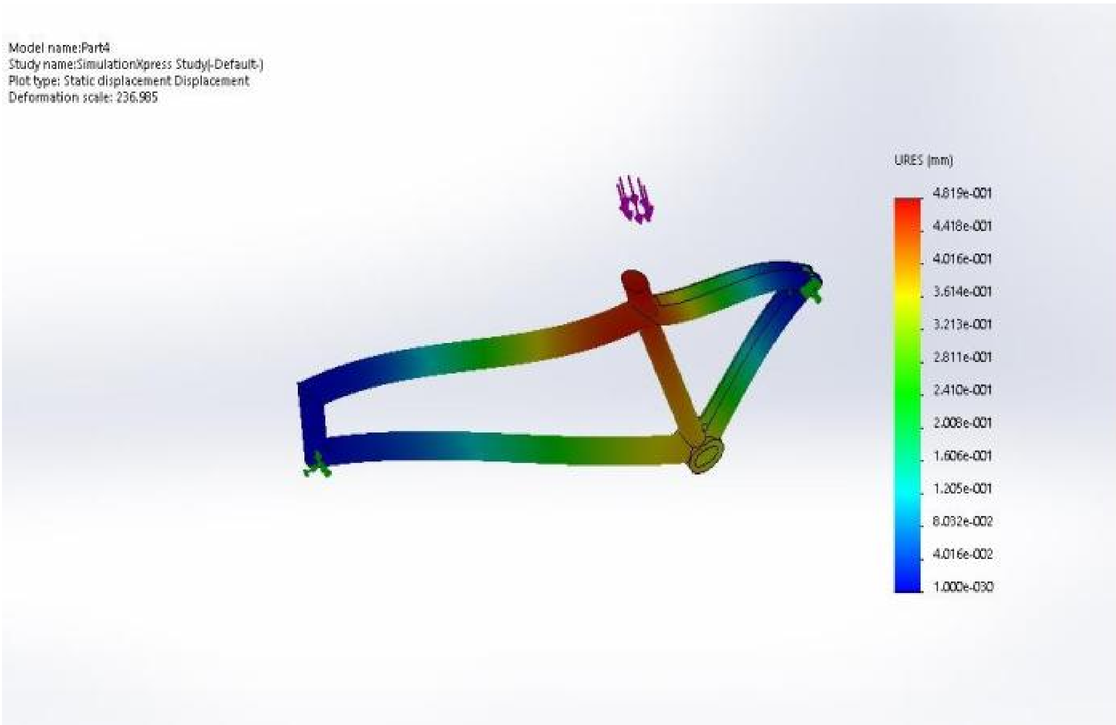


Figure 4.17 Application of compressive load of top side

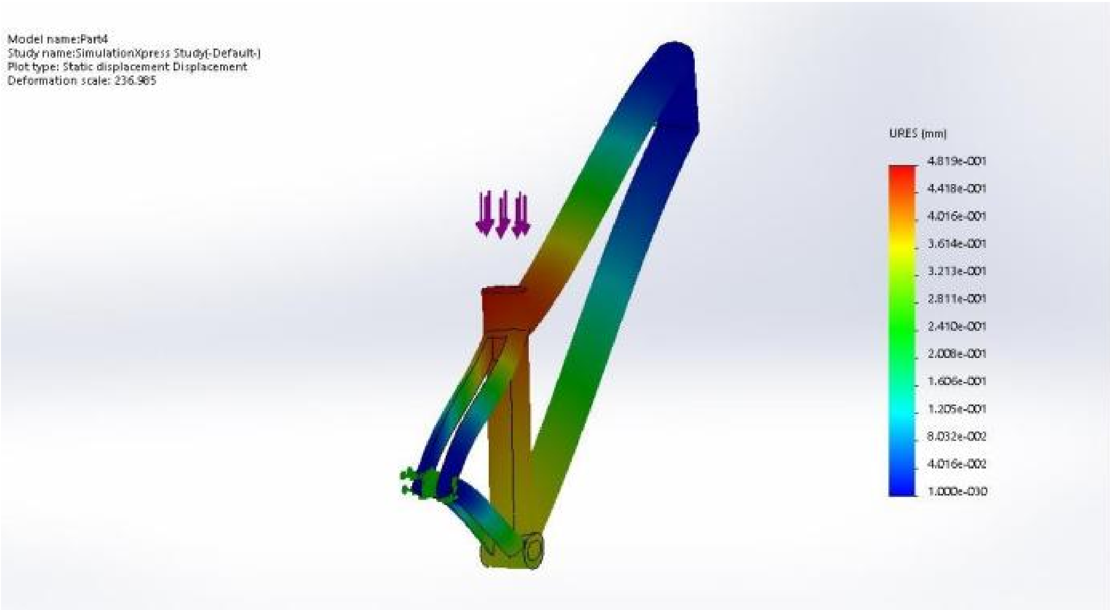


Figure 4.18 Application of compressive load of side end

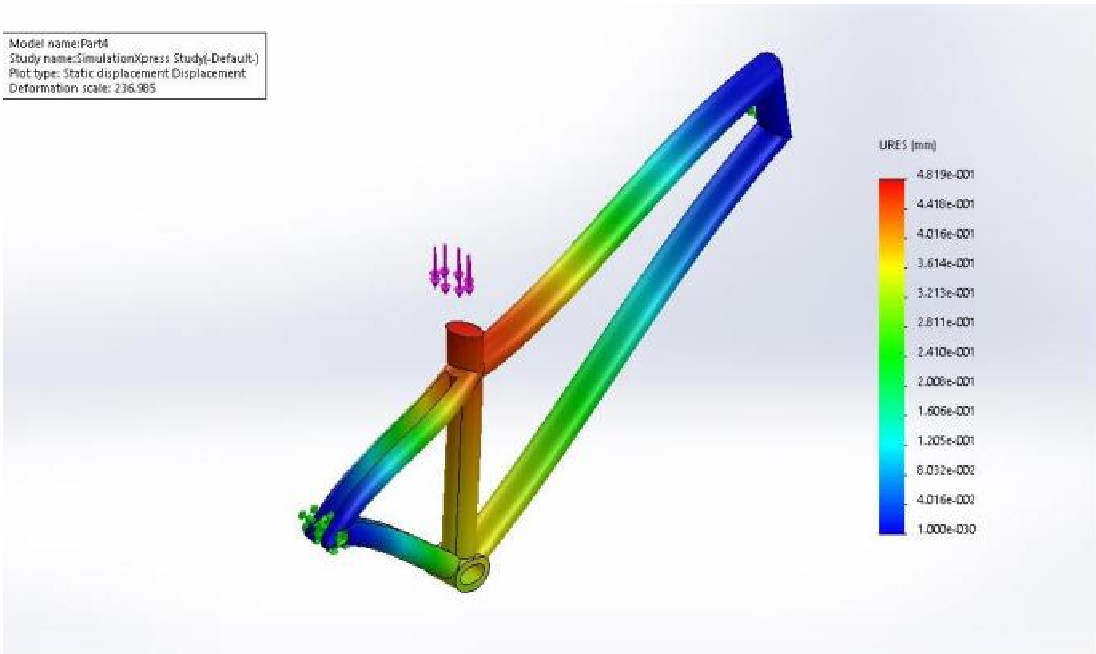


Figure 4.19 Application of compressive load of front en

×**Table 4.2 Simulation results**

Sl. No.	Property	Fibers Reinforced Polymer Composites
1.	Compressive strength	4.819 10^6 N/m^2
2.	Deformation	10.5×10^{-5} mm

Based on the simulation results, it is concluded that the Fibers Reinforced Polymer Composites modeled bicycle showed the less amount distribution of load was given in the compressive analysis. additionally, the compressive strength and deformation of the Fibers Reinforced Polymer Composites materials were obtained from the simulation results (Table 4.2) and resulted that the Fibers Reinforced Polymer Composites material exhibit the superior properties than the steel. Hence, the Fibers Reinforced Polymer composite is recommended in the place of steel for structural applications.

4.5 SUMMARY

Natural fibers based hybrid composites were prepared using hand lay-up method. The prepared composite viz. Indian almond/Neem/Indian almond and Neem/Indian almond/Neem showed minimum amounts of voids (≈6%).

The composites were examined by tensile, flexural, impact and wear tests to understand the mechanical strength of the material. The chemicalbonding of the fibers used were investigated by the FTIR analysis. Moreover, the surface morphology of the fibers was performed to understand the bonding between the fiber and matrix. The results showed that the tensile and flexural strengths of Neem/Indian almond/Neem composite were enhanced by6.8% and 5.5% respectively due to the presence of high strength neem fiber atouter layer. Impact results reported that the impact strength of Indian almond/Neem/Indian composite was increased by 13% owing to the cracks observed on the surface of the Indian almond fiber that absorbed more energy while applying load.

CHAPTER 5

CONCLUSION

In this investigation, natural fiber reinforced polymer composite was prepared and its mechanical properties were analyzed.

5.1 THE STUDY INCLUDES

1. Preparation of hybrid polymer composite using two natural fibers viz. neem and Indian almond fruit fiber by hand lay-up method
2. Examination the voids formation in prepared composites by density measurements
3. Investigation of tensile and flexural properties of prepared composites using Universal Testing machine
4. Investigation of impact properties of prepared composites using Izod impact testing machine
5. Investigation of wear resistance of the prepared composites using pin-on-disc wear testing machine
6. Investigation of chemical bond of fibers using FTIR analyzer
7. Investigation of surface morphology of fibers using SEM

5.2 EXPERIMENTAL STUDY

1. Tensile and flexural strengths of Neem/Indian almond/Neem composites displayed superior strength compared to Indian almond/Neem/Indian almond composite due to the presence of high strength Neem fiber in outer layer
2. The impact strength of Indian almond/Neem/Indian almond composite showed greater value compared to Neem /Indian almond/Neem composite owing to the presence of more cracks in

Indian almond fiber that absorbed more shock energy while loading

3. The Indian almond/Neem/Indian almond composite showed more wear rate compared to Neem/Indian almond/Neem
4. FTIR analysis reported that the more chemical bonds were appeared in Neem fiber than Indian almond fiber which enhanced the tensile and flexural properties of Neem/Indian almond/Neem composites
5. SEM analysis revealed more cracks on Indian almond fruit fiber

5.3 SCOPE FOR THE FUTURE WORK

In the present investigation, two hybrid composites were prepared using Neem and Indian almond fruit fiber and investigated about their mechanical properties. Further, the scope for the future work is existed as described below.

1. There is a scope for manufacturing the hybrid composite using coupling agent to increase the bonding strength between the fibers and polymers
2. In this current investigation, mechanical properties have been analyzed. Hence, there could be the possibilities to investigate about the thermal analysis using thermo gravimetric analyzer, dynamic mechanical analysis and differential scanning calorimetry
3. There is a scope for the hybrid composite for biodegradation test and water absorption test
4. There could be the possibilities to manufacture the hybrid composites by different combinations of natural fibers

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