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(ANAUTONOMOUSINSTITUTIONUNDERVISVESVARAYATECHNOLOGICALUNIVERSITY,BELGAUM)

YELAHANKA,BANGALORE– 560064

PROJECT REPORT ON

Development of Natural Fiber Hybrid Composite Material for Aerospace Applications

Submitted in partial fulfilment for the course
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Submitted By

KAREEM PASHA	**1NT20AE026**
PRASHANT G NAIK	**1NT20AE043**
JAYANTH N	**1NT20AE025**

Under the guidance of
MR. ABHISHEK T K
Assistant Professor,
Department of Aeronautical
Engineering, NMIT, Bangalore

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DEPARTMENTOF AERONAUTICAL ENGINEERING

Nitte Meenakshi Institute of

Technology,Yelahanka,Bangalore –560064

2023-2024

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DEPARTMENT OFAERONAUTICAL ENGINEERING

CERTIFICATE

This is to certify that the Project Report titled **"Development of Hybrid Natural Fiber Composite Material For Aerospace Applications**" is a bonafide work Carried out by Mr. **KAREEM PASHA, PRASHANT G NAIK, JAYANTH N** Bearing USN:**1NTAE026, 1NT20AE043, 1NT20AE025** in partial fulfillment for the award of **B.E** Degree in **Aeronautical Engineering** of the Visvesvaraya Technological University, Belgaum during the academic year 2023-24.It is certified that all corrections/suggestions have been incorporated in the Report. The report has been approved as it satisfies the academic requirements in respect of Project work prescribed as per the Autonomous scheme of Nitte Meenakshi Institute of Technology, for the said Degree.

Name & Signature of the Guide | **Name & Signature of the HOD**

Name & Signature of the Principal

Name & Signature of the Examiners

Name of the Examiners	**Signature with Date**
1.	
2.	

ACKNOWLEDGEMENT

It is time for expressing my sincere gratitude towards all who are responsible for the successful completion of my Project phase1. Firstly, I would like to express my sincere regards and heart full thanks to my guide **Mr. Abhishek T K,** Assistant Professor, Department of Aeronautical Engineering, NMIT. For his constant encouragement, guidance and support and **Dr. Shrikanth H V** Professor and Head of Aeronautical Engineering Department, NMIT.

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KAREEM PASHA(USN:1NT20AE026)

PRASHANT G NAIK(USN:1NT20AE043)

JAYANTH N(USN:1NT20AE025)

DECLARATION

I hereby declare that the project entitled "Development of Natural Fiber Hybrid Composite Material for Aerospace Applications" was carried out under the guidance of Mr. Abhishek T K, Assistant Professor, Department of Aeronautical Engineering, NMIT. This work is Not been previously the basis for award of any degree nor has been submitted elsewhere for the award of any degree.

KAREEM PASHA (USN:1NT20AE026)

PRASHANT G NAIK (USN:1NT20AE043)

JAYANTH N (USN:1NT20AE025)

Place: Bengaluru

Date: 05-12-2023

ABSTRACT

Centuries back, the utilization of composite materials played a pivotal role in driving the industrial revolution. In historical eras, Egyptians employed straw as a reinforcing component in clay bricks to construct dwellings. The introduction of glass fiber and resins marked the integration of glass fiber-reinforced composites across diverse applications. Natural fibers, with their ample availability, relatively moderate specific strength compared to most organic counterparts, low density, and biodegradable attributes, have garnered increasing allure as reinforcements in polymer matrices in recent decades. Despite these merits, certain drawbacks, including compatibility issues with hydrophobic polymer matrices, diminished resistance to moisture, and a propensity to aggregate during processing, have curtailed the widespread adoption of natural fibers in composites. This review succinctly outlines and discusses recent literature on hemp, banana, and hybrid variants, delving into the mechanical properties of composites and scrutinizing the influence of diverse physical and chemical surface treatments on these materials.

The advent of polymers in the early 20th century set the stage for a materials revolution, yet it came with a significant environmental drawback owing to the poor biodegradability of these materials. This drawback translated into an increased strain on already diminishing landfill resources worldwide when disposing of these materials. The global annual disposal of millions of tons of plastics, particularly in packaging, has spurred the quest for innovative approaches to handle this non-biodegradable waste. These environmental challenges have fueled considerable interest in crafting composite materials using biodegradable sources, presenting natural fibers as an economical and eco-friendly substitute for synthetic fibers. Examples of such natural fibers include hemp, sisal, and flax, all actively employed in composite materials. Conventionally, synthetic polymers have served as matrices in composite materials, posing environmental concerns. However, there is a notable shift towards formulating new matrix materials sourced from natural and renewable resources to create environmentally sustainable "green" bio composites. Examples of these emerging biodegradable matrix materials encompass poly acetic acid, soy oil, and lignophenolic resins.

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CHAPTER 1

1.1 INTRODUCTION

Natural fibers are predominantly employed in interior applications, specifically in areas unaffected by moisture, such as doors, armrests, package trays, and automobile instrument panels. These fibers serve as reinforcements in both thermoset and thermoplastic systems. Basalt fiber has recently been included in this natural fiber category due to its biodegradable characteristics, utilized either in short fiber form or woven mats for reinforcement.

The performance of natural fiber composites (NFC) is categorized based on the fiber source, including bast fiber, fruit fiber, leaf fiber, seed fiber, grass fiber, animal fiber, and wood fiber (Fig.1.1).

Bast fiber	Flax, kenef, urena, mesta, ramie, rosella, jute, banana, palmyra, hemp, henequen, bamboo, bagasse, and ramie
Fruit fiber	Oil palm, coconut, african palm, and palmyra fruit
Leaf fiber	Sisal, pineapple, abaca, curaua, cabuja, african palm, dates palm & palmyra palm petiole fiber
Seed fiber	Cotton, kapok
Grass fiber	Bamboo, bagasse, wheat, barley, rice, reed, corn, rape, rye, esparto, elephant grass, cannary grass, and oat
Animal fiber	Silk, wool, and feathers
Wood fiber	Soft wood and hard wood

Table.1.1 Classification of Natural Fiber.

Numerous factors impact performance, encompassing fiber length and quantity, fiber surface properties, fiber and matrix strength, fiber-matrix interaction, fiber orientation, plant age and cultivation environment, fiber extraction method, void presence, and fabrication method.

The critical fiber length, determining optimal composite properties, varies across different fibers and matrices in short fiber composites. The volume fraction (Vf)/weight fraction (Wt) denotes the ratio of fiber quantity to matrix. Critical fiber content, the amount at which composites showcase peak performance, also varies with different fibers and matrices. Improving fiber-matrix interaction is achievable through diverse chemical treatments, and hybridizing with two or more fibers enhances composite performance. Utilizing fibers in continuous or woven forms contributes to superior composite performance.

Composite failure at peak load results from factors like fiber breakage, fiber pullout, matrix crack, fiber strain, matrix strain, and moisture. This review provides a summary of recent literature on natural fibers, such as hemp, banana, and their hybrids, examining mechanical properties and the influence of various physical and chemical surface treatments in both thermosetting and thermoplastic applications.

1.2 TYPES OF NATURAL FIBERS WE ARE UTILIZING

1.2.1 RAMIE FIBER

Ramie, a shrub indigenous to East Asia and classified under the Urticaceae family, is scientifically known as Boehmeria nivea. The fibers obtained from ramie exhibit an average length ranging from 40 to 250 mm and an average diameter of 45µm. Notably, these fibers are longer, stronger, and stiffer when compared to flax fibers. In recent times, there has been a surge in research focusing on the incorporation of ramie fibers as reinforcing components in composite materials, as observed in studies involving PP/ramie and PLA/ramie composites.

Ramie is one of the strongest natural fibers. It exhibits even greater strength when wet. Ramie fiber is known especially for its ability to hold shape, reduce wrinkling, and introduce a silky lustre to the fabric appearance. It is not as durable as other fibers, so is usually used as a blend with other fibers such as cotton or wool. It is similar to linen in absorbency, density, and microscopic appearance. It does not dye as well as cotton. Because of its high molecular crystallinity, ramie is stiff and brittle and will break if folded repeatedly in the same place; it lacks resiliency and is low in elasticity and elongation potential.

Cellulose (wt%)	Lignin (wt%)	Hemicellulose (wt%)	Pectin (wt%)	Wax (wt%)	Microfibrillar angle (°)	Moisture content (wt%)	Density (g/cm^3)
68.6 – 76.2	0.6 – 0.7	13.1 – 16.7	1.9	0.3	7.5	8.0	1.50

Table 1.2 Physical and chemical properties of ramie fiber

Fiber diameter (mm)	Fracture load (N)	Tensile strength (MPa)	Fracture strain (%)
0.034	0.467	560	0.025

Table 1.3 Mechanical properties of untreated ramie fibers

1.2.2 FLAX FIBER

Flax comes from the stem of the flax plant of the species Linum usitatissimum. Flax fibre is classified as a natural cellulose, bast and multicellular fibre. When the fibre is processed into fabric, it is called linen. Flax is one of the oldest **textile fibres** and some evidence dates as far back as 6,000 BC. It is one of the strongest fibres, and it is considered luxurious – requiring care during each stage of production, which is a costly process. They are known for their strength, durability, and absorbency, as well as their unique texture and luster. The fibres are processed to remove the woody part of the stem, leaving behind the long, flexible fibres that can be spun into yarn or woven into fabric. In addition to its traditional uses, flax fibre is becoming increasingly popular in modern times as a sustainable alternative to **synthetic fibres**. Flax for textiles is grown in a number of countries, including Austria, France, Poland, Germany and Denmark, but the best quality flax comes from Belgium, Ireland and Italy. Flax fiber is extracted from the bast or skin of the stem of flax plant. Flax fibers are arranged in the form of thin filaments, grouped in longitudinal slender bundles distributed circularly around a central wooden cylinder.

Cellulose %	Iemi-Cellulose %	Pectin %	Lignin %	Wax %	M. Ca %
71-75	18.6-20.6	2.2	2.2	1.7	10

Table 1.4 Physical and chemical properties of flax fiber

Densdity (g/cc)	Tensile Strength(Mpa)	Elastic Modulys(Gpa)	Specific Strength(s/g)	Specific Modulus(“/g)	Elongation at failure(%)
1.4	800-1500	60-80	571-1071	43-57	2.7-3.2

Table 1.5 Mechanical properties of flax fibers

1.2.3 HEMP FIBER

Subsequent to sisal, hemp emerges as one of the most extensively employed natural fibers for reinforcing composites. Acknowledged for its eco-friendly attributes, hemp holds the distinction of being one of the oldest fibers, with remnants of hemp fabric discovered in tombs dating back to approximately 8,000 BC, as documented in the Columbia History of the World. Despite the resin secretions in the flowering tops and leaves containing the well-known narcotic 9-tetrahydrocannabinol (THC), industrial hemp, with its THC content below 0.2%, precludes any narcotic use. Originating from central Asia, hemp, an annual plant, boasts a cultivation history exceeding 12,000 years. Its likely dissemination to central Europe during the Iron Age is substantiated by evidence of cultivation by the Anglo-Saxons in the UK (800-1000 AD). Presently, hemp cultivation prevails in the EU, Central Asia, the Philippines, and China. According to the Food and Agriculture Organization (FAO), China contributes to almost half of the global industrial hemp supply, with additional cultivation in countries such as Chile, France, the Democratic People's Republic of Korea, and Spain.

Cellulose %	**Hemi-Cellulose %**	**Pectin %**	**Lignin %**	**Others %**
70-74	17.9-22.4	0.9	3.7-5.7	0.8

Table 1.6 Physical and chemical properties of hemp fiber

Density (g/cc)	**Tensile Strength(Mpa)**	**Elastic Modulys(Gpa)**	**Specific Strength(s/g)**	**Specific Modulus(“/g)**	**Elongation at failure(%)**
1.4	550-900	70	393-643	50	1.6

Table 1.7 Mechanical properties of hemp fibers

2.3 Hemp Fibre

Hemp, a rapidly growing and sustainable plant, offers unique properties that make its fibers ideal for composite materials. This report explores the existing research on hemp composites, highlighting their advantages, potential applications, and remaining challenges.

Fig. 2.2 Hemp Fibre

2.3.1 Hemp Fiber Properties:

Hemp fibres possess distinctive properties that make them noteworthy material with diverse applications.

Tensile Strength (Mpa) :	421 --800
Elongation of Break (%):	1.62
Diameter (mm)	0.8 to 1.2mm
Density (g/cm3)	1.47
Young's Modulus (Gpa)	21--- 72

Table 2.2 Hemp Fiber Properties

- High specific strength
- Good tensile strength and stiffness
- Excellent moisture absorption and biodegradability
- Low thermal conductivity and fire resistance

2.3.1.1 Types Of Hemp Fibers:

Hemp fibers come in different types, each with unique characteristics and applications:
Bast fibers, Core fibers, Processing techniques for short or long fibers

2.3.1.2 Matrix Materials:

The choice of matrix materials is crucial in determining the properties and performance of hemp composites. Here are key considerations regarding matrix materials for hemp fibers:

2.4.2 Advantages:

Hemp composites offer a range of advantages that contribute to their appeal in various applications:

i. Sustainable and readily available resource: Hemp is a sustainable and readily available resource, requiring minimal resources for cultivation. Its rapid growth and versatility make it an environmentally friendly choice, reducing the overall environmental impact compared to some traditional materials.

ii. Good mechanical properties: Hemp composites exhibit good mechanical properties, including strength and stiffness. These properties make them suitable for a variety of applications where structural integrity,

2.5 Silk Fibre

This report offers a comprehensive overview ofexisting research on silk composites, highlighting their properties, potential applications, and challenges.

Fig. 2.3 Silk Fibre

2.5.1 Types Of Silk Fibers:

Bombyx mori silk, sometimes known as mulberry silk, is a popular kind of silk fibre. This kind is well-known for its extensive use and for its excellent combination of high strength and shiny beauty. Mulberry silk is acknowledged as the most common and well-recognised silk, with its exceptional characteristics establishing its popularity in a variety of uses.

2.5.2 Mechanical Properties:

Silk fibre mechanical properties, which are highlighted in this section, indicate a different set of qualities. Silk has a high tensile strength and specific strength, which indicate its ability to endure stress and strength compared to its weight. This property makes silk a formidable material in situations where strength and weight are critical. Silk also has excellent toughness and impact resistance, suggesting its capacity to absorb energy without splitting. This combination of mechanical properties distinguishes silk as a durable material, well-suited for a variety of applications requiring durability and impact resistance.

Table 03 Silk fiber properties

Tensile Strength	348 – 580 Mpa
Elongation at Break	2.9%
Diameter	0.8 – 1.2 mm
Density	1.52 g/cm³
Young’s Modulus	19.8 Gpa

Table 2.3 mechanical properties

i. Moisture absorption

ii. Limited high-temperature stability

iii. Fabrication techniques control

iv. Cost considerations

2.5.3 Manufacturing Techniques:

Silk composites are manufactured using a variety of procedures that are tailored to individual needs. Layup and compression moulding are important techniques that use thermosetting polymers like epoxy or polyester. This method enables the formation of structured layers, which contribute to the overall strength and integrity of the finished composite.

Another method is to weave and braid materials to facilitate prepreg or resin infusion processes. This approach improves resin dispersion inside the silk matrix, resulting in a cohesive and well-balanced composite structure. Furthermore, 3d printing has evolved as an innovative technology for silk composites. Using biocompatible filaments, this approach allows for the precise creation of complicated structures. The adaptability of 3d printing allows for the creation of complex and customised structures, thereby extending the field.

2.5.4 Applications:

Silk composites find diverse applications across various industries, showcasing their versatility and advantageous properties:

i. Aerospace

ii. Automotive

iii. Marine

iv. Medical

v. Sports and leisure

2.5.5 Advantages:

The utilization of silk composites brings forth several advantages, making them an appealing choice across various industries:

i. Sustainable and biodegradable

ii. Good biocompatibility

2.5.6 Resources Required

The resources listed below are necessary to carry out this study. These tools make it easier to choose materials, design frame structures, and carry out manufacturing.

i. Hemp, lenin & silk fibres ii. Epoxy resin & hardner iii. Moulds or tooling iv. Fabrication equipment v. Testing equipment vi. 3d printer vii. A tensile testing apparatus viii. A universal testing apparatus

ix. Computer-aided design (cad) software

2.5.7 Research Objectives

The goal of this project is to develop and analyze hemp fibre integrated frame structures for uavs. The project will involve the following steps:

i. Characterize the mechanical properties of hemp fibres.

ii. Design and fabricate hemp fibre integrated frame structures. iii. Perform static and fatigue tests on the frame structures.

iv. Analyze the results of the tests and identify the strengths and weaknesses of the frame structures.

v. Make recommendations for future improvements to the frame structures.

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- Mohamad Midani, Ph.D., date palm fibre composites, a novel and sustainable material for the aerospace industry
- Venkatesh.b1, Satyapal reddy.l2, Sathish Kumar.k3, Sudheer Gupta.n4 1assistant professor, department of Mechanical Engineering, b.v.r.i.t, narsapur, India Fabrication and testing of hemp fibre reinforced epoxy composites
- Breznik's biodegradable drone frame

Bard - "Development of hemp fiber reinforced frame structures for unmanned aerial vehicles" by bard, published in the journal of Advanced Materials in 2023

CHAPTER 3

3.1. Methodology

Raw Material Preparation:

a. Harvesting: Hemp plants are cultivated and harvested at the appropriate stage for fiber extraction. The fibers are commonly extracted from the bark of the hemp stem.

b. Retting: The harvested hemp stems undergo retting, a process that separates the fibers from the stem by promoting microbial decay. This can be done through water retting, dew retting, or chemical retting methods.

Fiber Extraction:

a. Decortication: The retted hemp stems are subjected to decortication, which involves mechanically separating the fibers from the woody core. This process can be done using machines designed for this purpose.

Fiber Treatment:

a. Cleaning: The extracted fibers are cleaned to remove impurities, residues, and other unwanted materials.

b. Sizing: The fibers may undergo sizing or coating to improve their compatibility with the matrix material and enhance adhesion.

Matrix Material Preparation:

a. Selection: Choose an appropriate matrix material for the composite. Common matrix materials for aerospace applications include epoxy resins due to their high strength and low weight.

b. Mixing: Prepare the matrix material according to the manufacturer's specifications. This involves mixing resin with a hardener in the correct proportions.

Composite Fabrication:

a. Hand Layup or Automated Layup: Arrange the treated hemp fibers in the desired orientation (usually unidirectional, woven, or random mat) within a mold.

b. Resin Infusion or Resin Transfer Molding (RTM): Inject or infuse the matrix material into the mold containing the arranged hemp fibers. This ensures proper impregnation of fibers with the resin.

c. Curing: Allow the composite to cure or harden. This process may involve applying heat and pressure, depending on the matrix material.

Post-Processing:

a. Trimming and Shaping: After curing, the composite may undergo additional processing, such as trimming or shaping, to achieve the final desired form.

b. Surface Finish: Apply surface finishes or coatings as needed for the aerospace application, considering factors like aerodynamics and protection.

Quality Control:

a. Testing: Conduct various tests, such as mechanical testing, thermal analysis, and non-destructive testing, to ensure the composite meets aerospace standards and requirements.

Final Inspection and Certification:

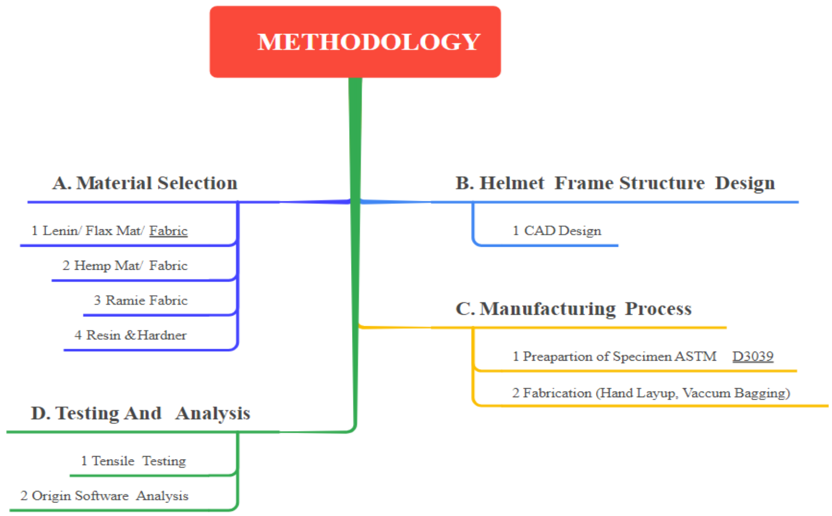
a. Visual Inspection: Examine the final composite for any defects or irregularities.

b. Certification: Obtain necessary certifications and approvals for aerospace applications.

3.2 Material Selection:

The process of choosing a material, which entails assessing hemp fibre composites' mechanical attributes and traits, is described in this section. Tensile strength, flexural strength, stiffness, density, and moisture absorption are the factors for selection. The mechanical performance of the composites may be improved by using various hemp fibre kinds and fibre treatments. The compatibility of the hemp fibres with the matrix made of epoxy resin is also discussed.

3.2.1 Hemp Mat/Fabric



3.2.2 Lenin (Flax) Mat/Fabric

Flax, scientifically known as Linum usitatissimum, is an annual plant valued to produce fibre obtained from its stems and seeds. Growing to heights of 0.6–1.2 meters, with stem diameters ranging from 1 to 3 mm, flax is esteemed for its superior quality and yield in comparison to other available fibres.

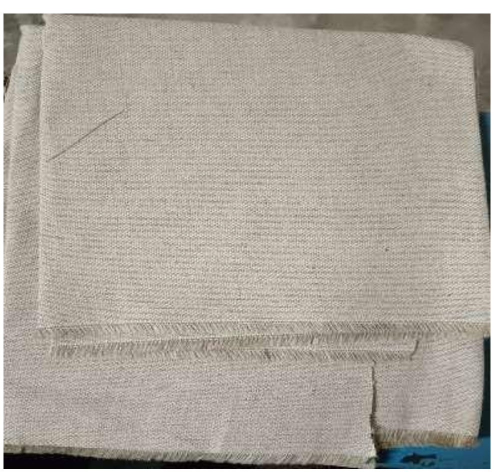


Fig. 3.1 Lenin Fabric

Fig. 3.2 Hemp fabric

Fig. 3.4 Epoxy Resin LY556 & Hardner HY951

3.4 Manufacturing Process:

1) Fiber Preparation: the hemp fibres are processed and prepared to ensure proper alignment, cleanliness, and compatibility with the epoxy resin matrix.
2) Layup: the prepared hemp fibres are laid up in a mould or tooling according to the predetermined design. Attention is given to achieving the desired fibre orientation and thickness distribution.

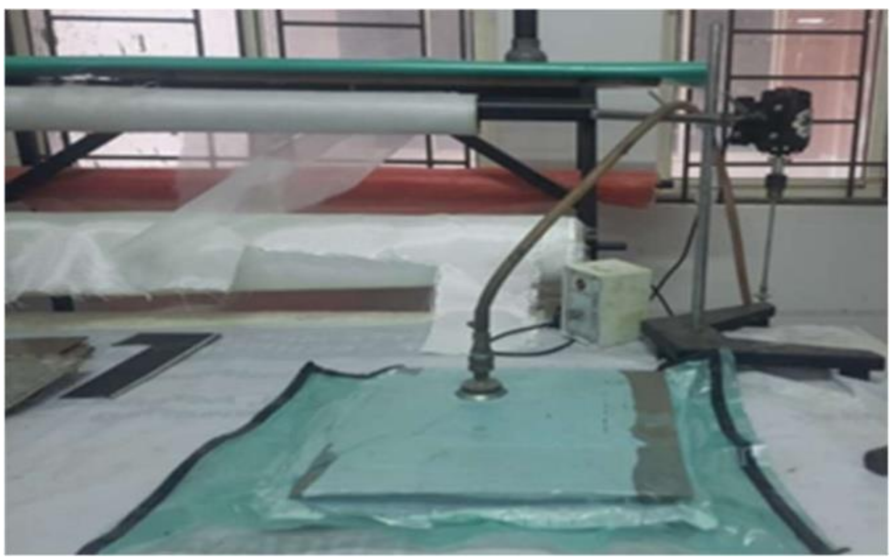


Fig. 3.5 vaccum bagging

3) Resin Infusion: the epoxy resin is infused into the fibre layup using vacuum infusion techniques. This ensures proper impregnation of the fibres and eliminates air voids.
4) Curing: the resin-infused structure is subjected to a curing process, typically involving controlled temperature and pressure conditions. Curing facilitates the hardening and bonding of composite materials.
5) Post-Processing: once cured, the hemp fibre integrated frame structures undergo post-processing steps such as trimming, sanding, and finishing to achieve the desired dimensions and surface quality

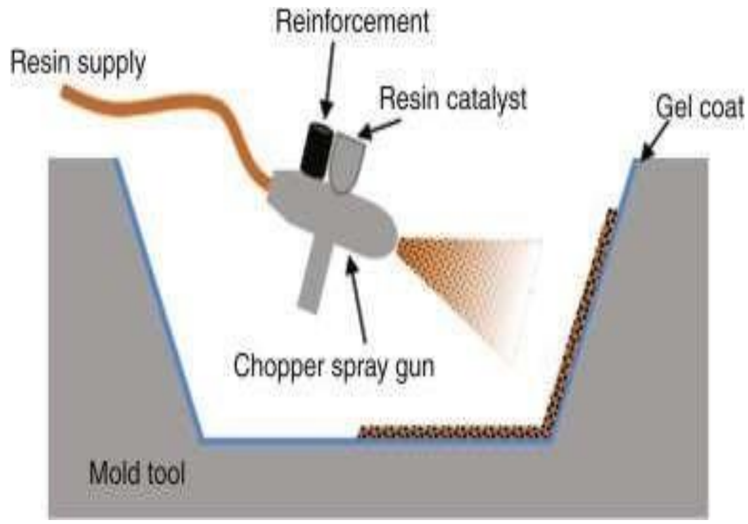


Fig. 3.6 Fibre Preparation & Layup

3.5 Testing And Analysis

Finite Element Analysis (FEA): to analyse the structural performance, load distribution, and stress concentrations in the frame structures under various operational situations, computer simulations utilising fea software will be carried out.

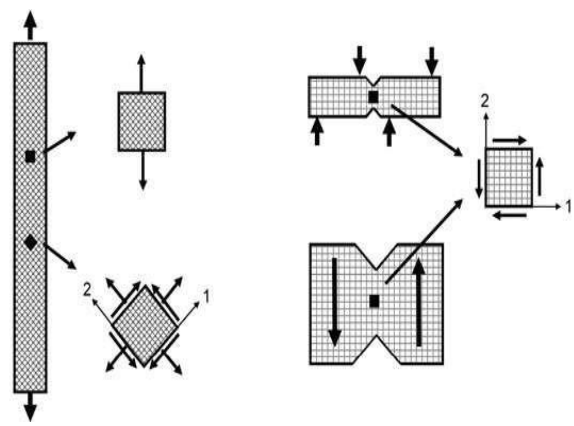


Fig. 3.7 In-Plane Shear Test Methods

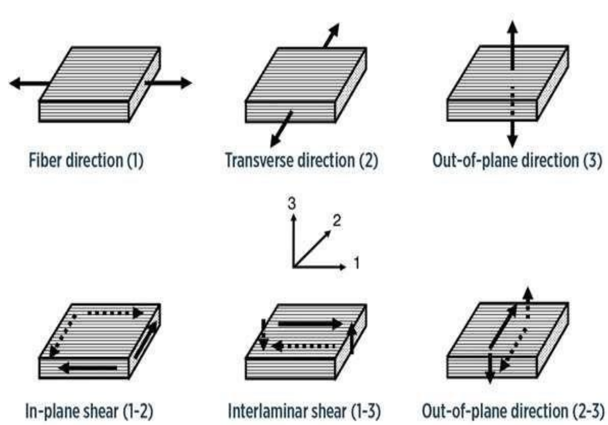


fig. 3.8 loading orientation for material testing

Mechanical Testing: to assess the mechanical qualities of the hemp fibre integrated frame structures, tensile, compressive, and flexural tests will be carried out.

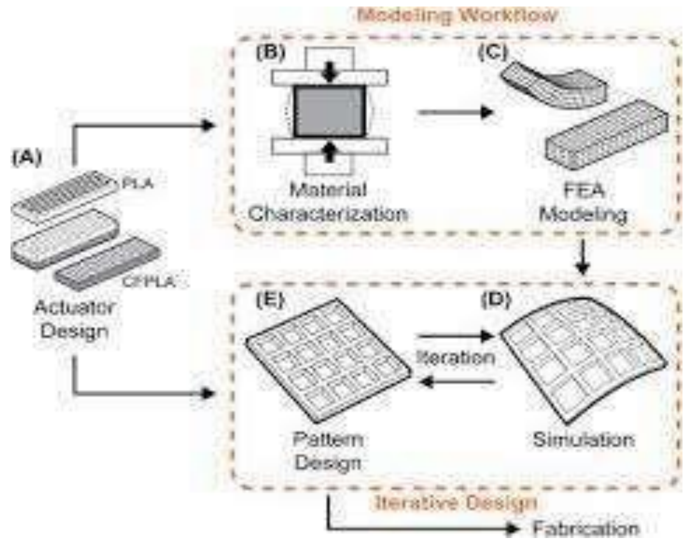


Fig.3.9 Modelling Workflow & Iterative Design

CHAPTER 4

4.1. Testing and analysis of fabric:

4.1.1 Fabric Testing

Tensile Strength test was conducted for for the fabric hemp-cotton fabric and flax cotton fabric

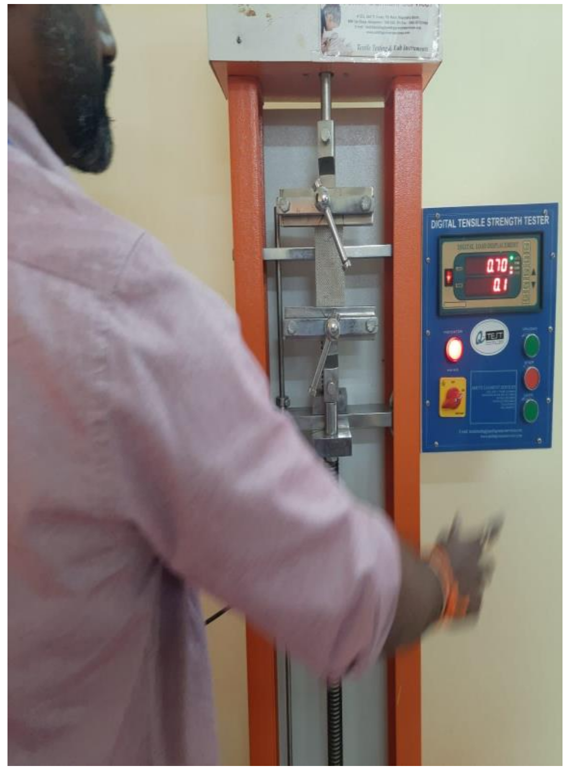


Fig 4.1fabric testing machine

Thickness Measurement

Sl No.	Thickness(mm)
1	0.65
2	0.64
3	0.6
4	0.62
5	0.63
Average Thickness	**0.68**

Table 4.1Hemp-Cotton Fabric Thicknesss

Sl No.	Thickness(mm)
1	1.22
2	1.08
3	1.13
4	1.21
5	1.25
Average Thickness	**1.178**

Table 4.2 Flax-Cotton Fabric Thickness

4.1.2 Tensile Testing of material:

Flax-Cotton Fabric Tensile Testing

a. Weft [Flax(6) x Cotton(2)]

Sl No.	Load (kgs)	Load (N)	Elongation (mm)	Stress(N/mm^2)	Strain	Youngs Modulus(N/mm^2)
1	76.05	746.0505	0.7	23.38540361	0.004593176	5091.336442
2	74.9	734.769	0.9	23.03177817	0.005905512	3900.047771
3	94.7	929.007	0.8	29.12028562	0.005249344	5547.414411
4	80.1	785.781	0.6	24.63078013	0.003937008	6256.218153
5	91.8	900.558	0.6	28.22853453	0.003937008	7170.047771
Average	**83.51**	**819.2331**	**0.72**	**25.67935641**	**0.004724409**	**5593.012909**

b. Wrap [Cotton(6) x Flax(2)]

Sl No.	Load (kgs)	Load (N)	Elongation (mm)	Stress(N/mm^2)	Strain	Youngs Modulus(N/mm^2)
1	42.35	415.4535	2.2	13.02264093	0.014435696	902.1138535
2	42.35	415.4535	2.1	13.02264093	0.013779528	945.0716561
3	41.55	407.6055	2.1	12.77664063	0.013779528	927.2190628
4	39.3	385.533	2.1	12.08476478	0.013779528	877.0086442
5	44.75	438.9975	2.2	13.76064183	0.014435696	953.2371888
Average	**42.06**	**412.6086**	**2.14**	**12.93346582**	**0.014041995**	**920.9300811**

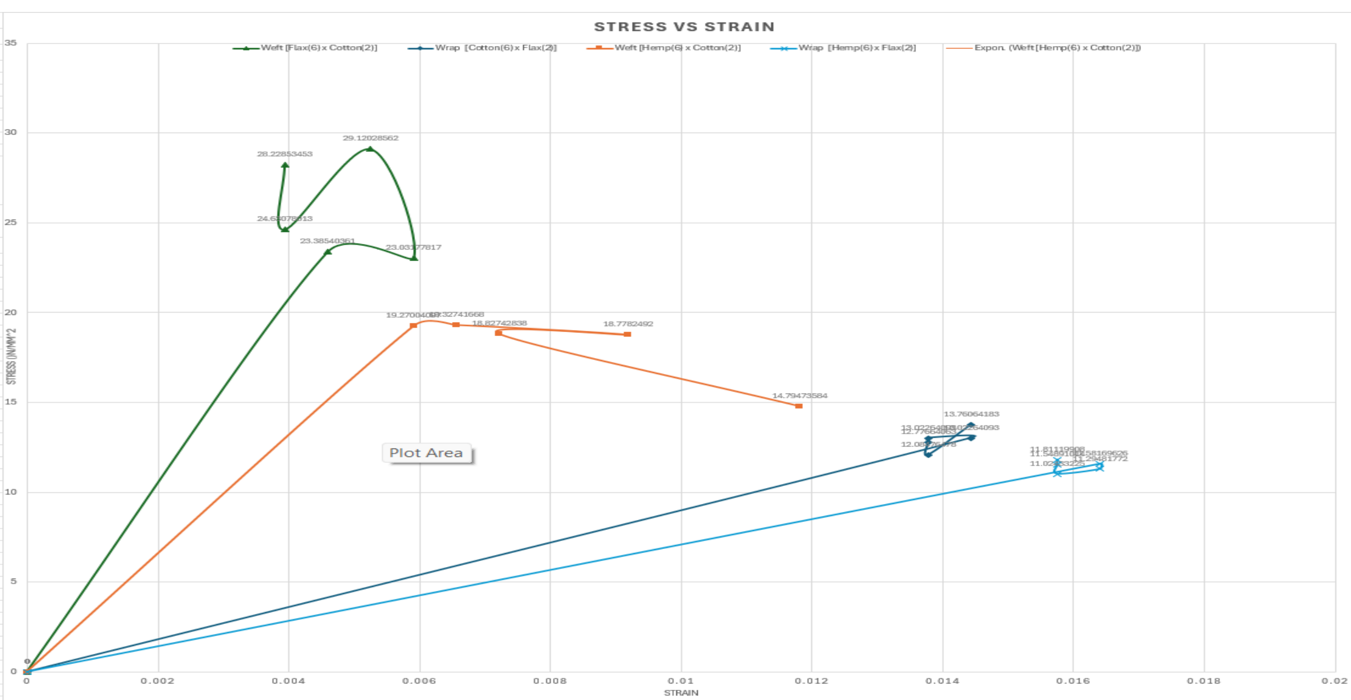
Hemp-Cotton Fabric Tensile Testing

a. Weft [Hemp(6) x Cotton(2)]

Sl No.	Load (kgs)	Load (N)	Elongation (mm)	Stress(N/mm^2)	Strain	Youngs Modulus(N/mm^2)
1	117.55	1153.1655	0.9	19.27004097	0.005905512	3263.060272
2	117.9	1156.599	1	19.32741668	0.00656168	2945.498302
3	114.55	1123.7355	1.4	18.7782492	0.009186352	2044.146556
4	114.85	1126.6785	1.1	18.82742838	0.007217848	2608.454623
5	90.25	885.3525	1.8	14.79473584	0.011811024	1252.620968
Average	**111.02**	**1089.1062**	**1.24**	**18.19957421**	**0.008136483**	**2422.756144**

b. Wrap [Hemp (6) x Flax(2)]

Sl No.	Load (kgs)	Load (N)	Elongation (mm)	Stress(N/mm^2)	Strain	Youngs Modulus(N/mm^2)
1	70.65	693.0765	2.5	11.58169626	0.016404199	706.0202037
2	68.9	675.909	2.5	11.29481772	0.016404199	688.5320883
3	67.25	659.7225	2.4	11.02433225	0.015748031	700.0450976
4	70.45	691.1145	2.4	11.54891014	0.015748031	733.3557937
5	72.05	706.8105	2.4	11.81119908	0.015748031	750.0111418
Average	**69.86**	**685.3266**	**2.44**	**11.45219109**	**0.016010499**	**715.592865**



Graph 4.1 Plot of Stress vs Strain for above values

4.2 Tensile test of laminates:

Tensile testing also known as **tension testing** is a fundamental materials science and engineering test in which a sample is subjected to a controlled tension until failure. Properties that are directly measured via a tensile test are ultimate tensile strength, breaking strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. Some materials use biaxial tensile testing. The main difference between these testing machines being how load is applied on the materials.

Tensile testing might have a variety of purposes, such as:

- Select a material or item for an application
- Predict how a material will perform in use: normal and extreme forces.
- Determine if, or verify that, the requirements of a specification, regulation, or contract are met
- Decide if a new product development program is on track
- Demonstrate proof of concept
- Demonstrate the utility of a proposed patent

Fig.4.2 Universal Testing Machine

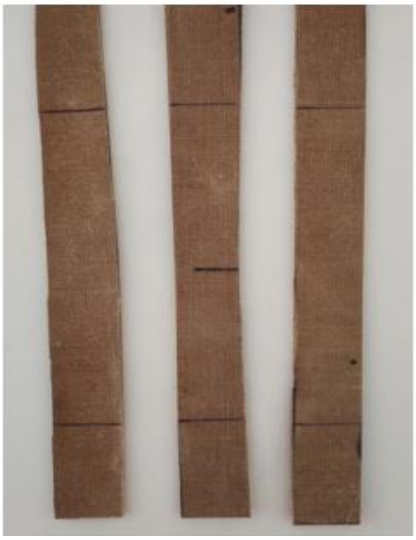


Fig 4.3 Hemp laminate

Fig 4.4 flax cotton

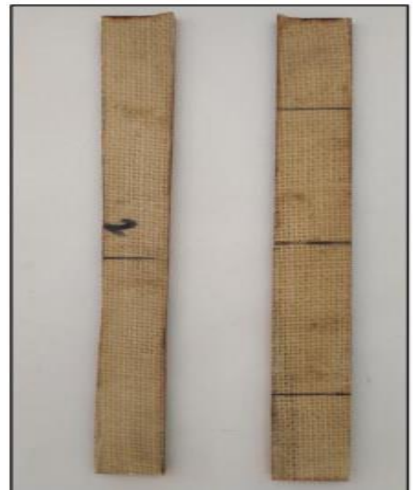


Fig 4.5 Ramie laminate

Fig 4.6 laminates

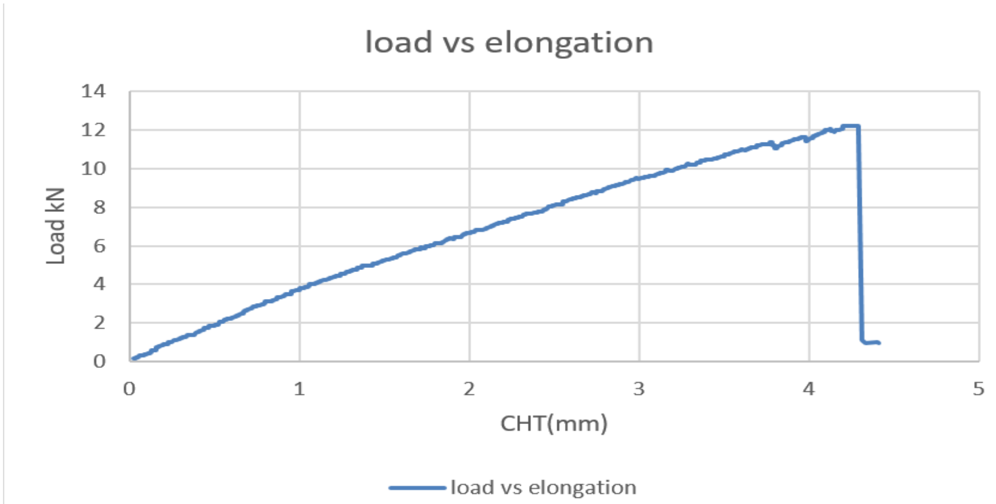
Fig 4.7 laminates

4.2.1 Tensile test of different specimen:

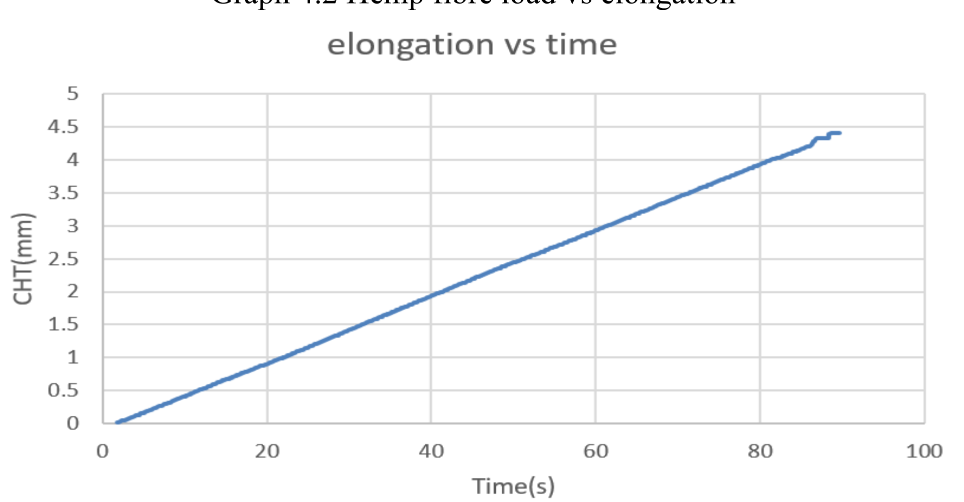
4.2.1.1 Hemp

Fiber type	No. layers	Sample No.	Thickness(mm)	Tensile strength(Mpa)
Hemp	8	1	7.7	44.21
			7.5	
			7.6	
			Avg. 7.6	
		2	7.3	43.94
			7.76	
			7.96	
			Avg.7.63	
		3	7.42	44.47
			7.55	
			7.47	
			Avg. 7.48	
			Approximate thickness =7.6	**44.20**

Table 4.3 Hemp fibre readings



Graph 4.2 Hemp fibre load vs elongation

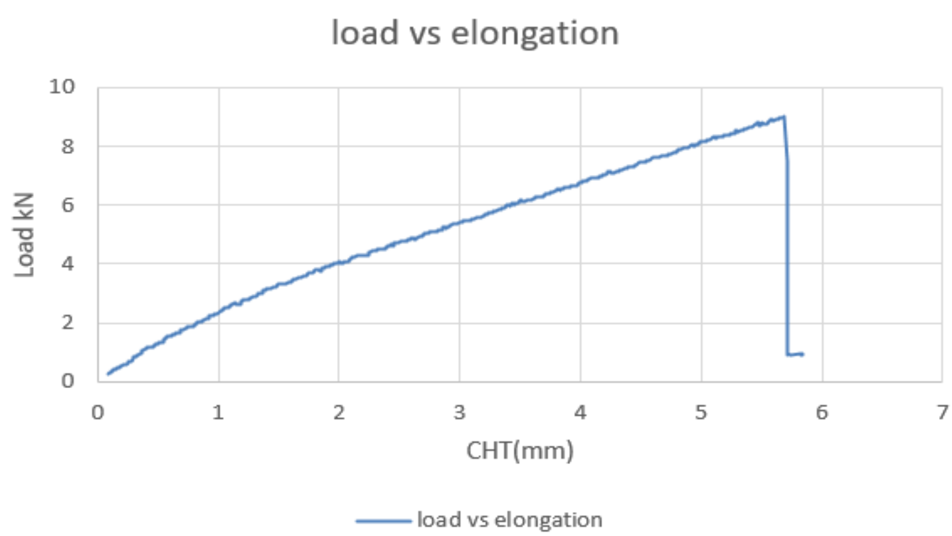


Graph 4.3 Hemp fibre elongation vs time

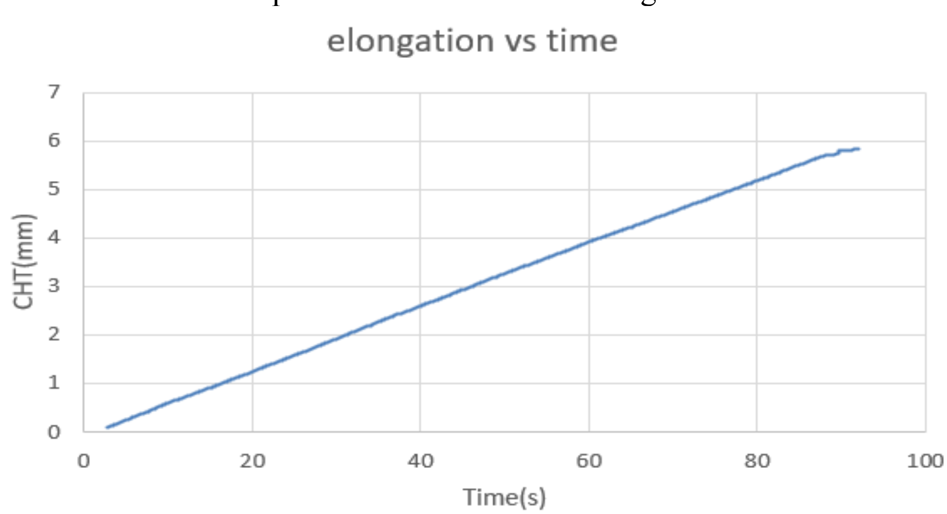
4.2.1.2 Flax:

Fiber type	No. layers	Sample No.	Thickness(mm)	Tensile strength(Mpa)
Flax	8	1	4.32	86.66
			4.32	
			4.27	
			Avg. 4.3	
		2	4.36	88.09
			4.35	
			4.32	
			Avg.4.3	
		3	4.31	88.04
			4.36	
			4.19	
			Avg. 4.2	
			Approximate thickness =4.2	**87.59**

Table 4.4 Flax fibre readings



Graph 4.4Flax fibre load vs elongation

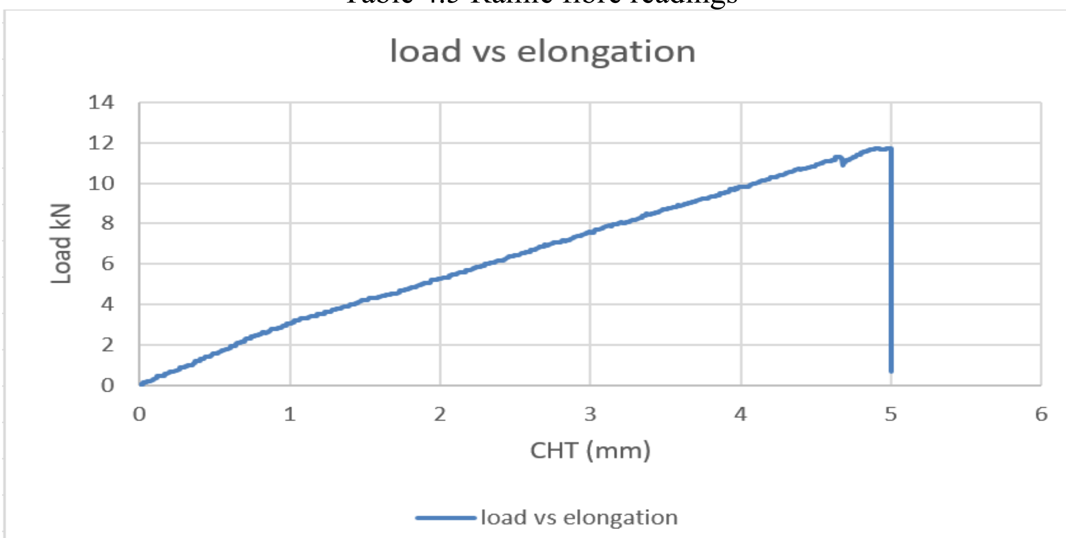


Graph 4.5 Flax fibre elongation vs time

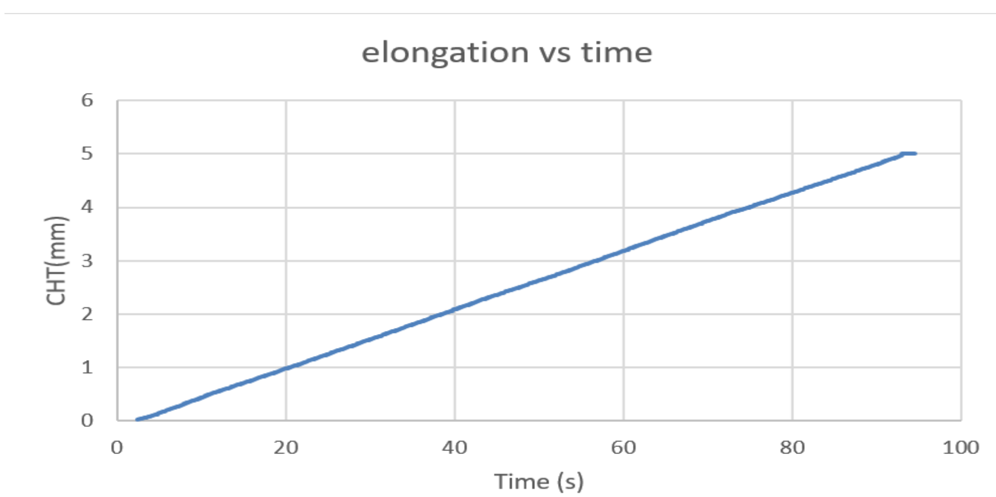
4.2.1.3 Ramie:

Fiber type	No. layers	Sample No.	Thickness(mm)	Tensile strength(Mpa)
Ramie	8	1	5.28	63.07
			5.10	
			5.26	
			Avg. 5.2	
		2	5.2	62.30
			5.29	
			5.20	
			Avg.5.23	
		3	4.9	62.48
			5.02	
			5.01	
			Avg. 4.97	
			Approximate thickness =5.2	**62.61**

Table 4.5 Ramie fibre readings



Graph 4.6 Ramie fibre load vs elongation



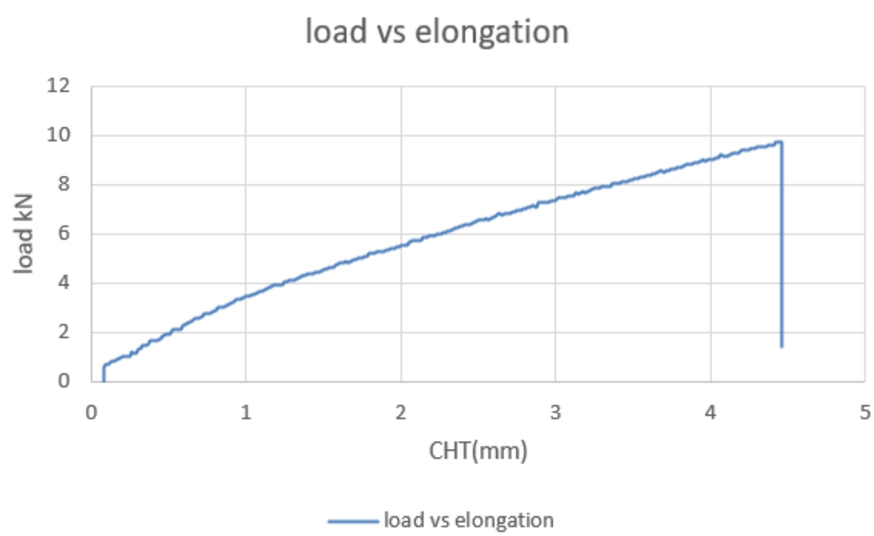
Graph 4.7 Flax fibre elongation vs time

4.2.2 Tensile strength of combinations(Hybrid) composites:

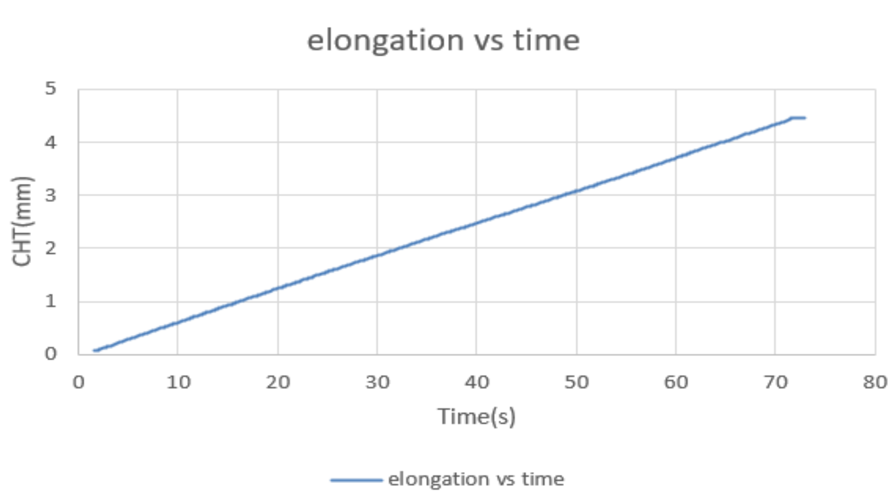
4.2.2.1 Hemp + Flax:

Fiber type	No. layers	Sample No.	Thickness(mm)	Tensile strength(Mpa)
Hemp+Flax	8	1	4.82	71.852
			5.25	
			5.18	
			Avg. 5.07	
		2	5.6	66.667
			5.71	
			5.63	
			Avg.5.64	
		3	6.2	62.48
			6.34	
			6.44	
			Avg. 6.35	
			Approximate thickness =5.74	**66.61**

Table 4.6 Hemp+Flax fibre readings



Graph 4.8 Hemp+Flax fibre load vs elongation

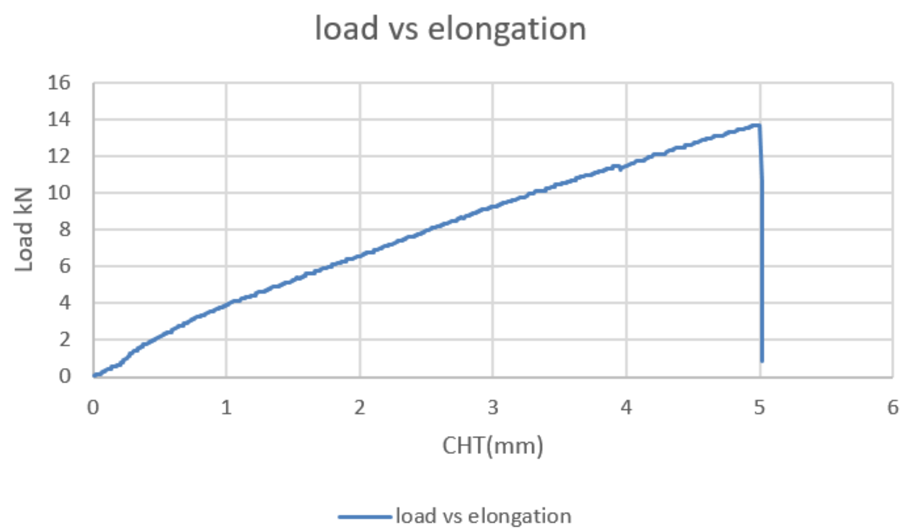


Graph 4.9 Hemp+Flax fibre load vs time

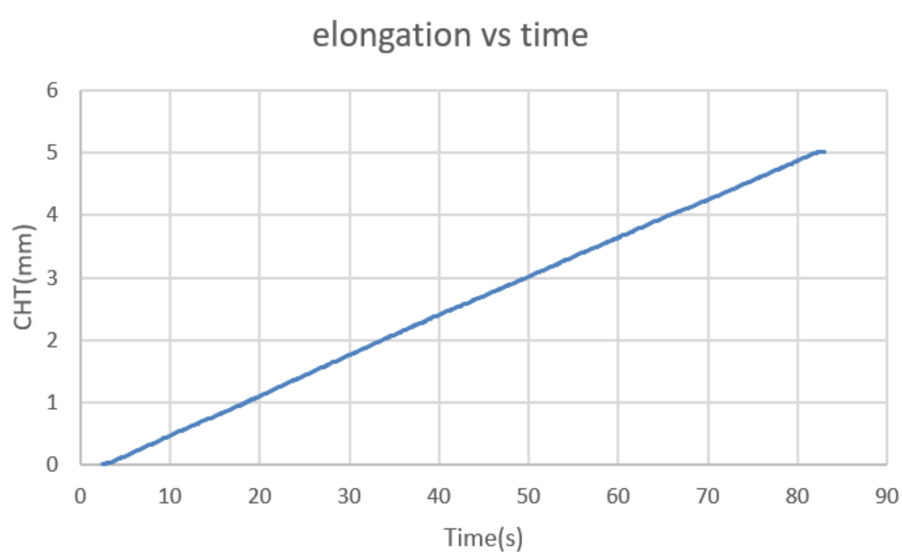
4.2.2.2 Hemp + Ramie:

Fiber type	No. layers	Sample No.	Thickness(mm)	Tensile strength(Mpa)
Hemp+Ramie	8	1	6.86	71.765
			7.14	
			6.31	
			Avg. 6.77	
		2	6.86	80.588
			6.65	
			7.2	
			Avg.6.9	
		3	6.33	72.647
			6.88	
			6.81	
			Avg. 6.67	
			Approximate thickness=6.8	**76.743**

Table 4.7 Hemp+Ramie fibre readings



Graph 4.10 Hemp+Ramie fibre load vs elongation

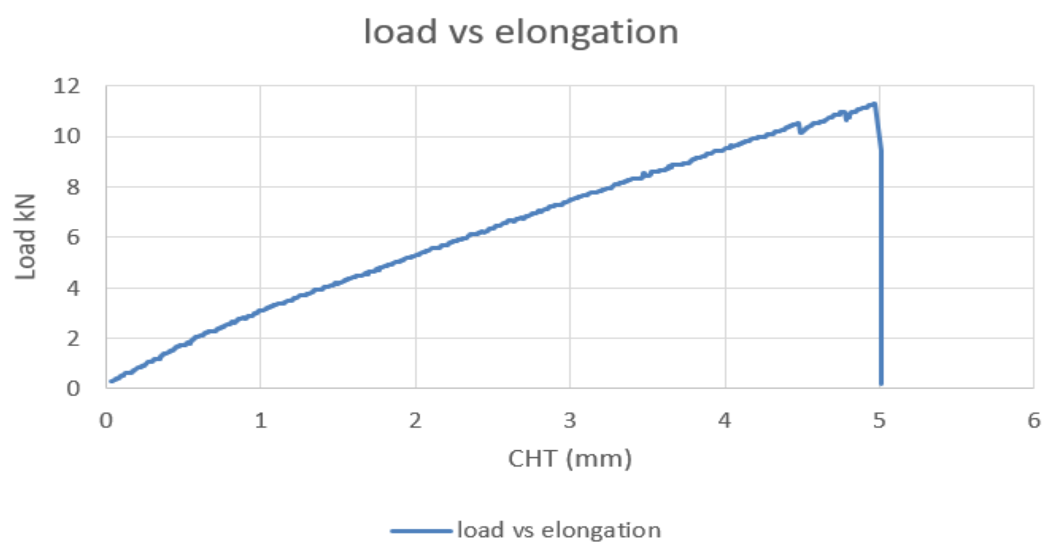


Graph 4.11 Hemp+Ramie fibre load vs time

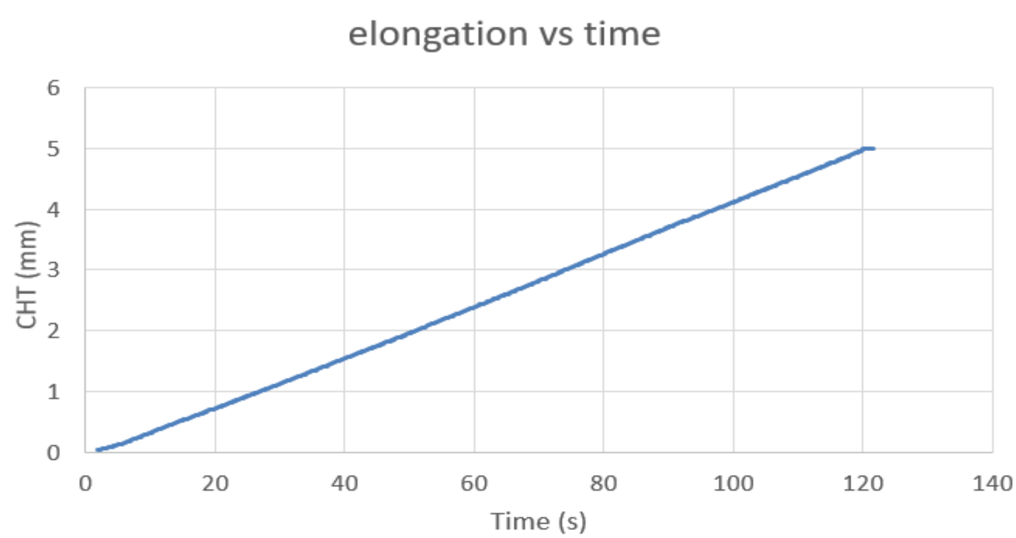
4.2.2.3 Flax + Ramie:

Fiber type	No. layers	Sample No.	Thickness(mm)	Tensile strength(Mpa)
Flax+Ramie	8	1	5.2	63.60
			5.23	
			5.0	
			Avg. 5.14	
		2	5.2	94.000
			5.26	
			4.5	
			Avg.4.98	
		3	4.37	90.400
			5.30	
			4.92	
			Avg. 4.86	
			Approximate thickness=4.9	**82.66**

Table 4.8 Flax+Ramie fibre readings



Graph 4.12 Flax+Ramie fibre load vs elongation

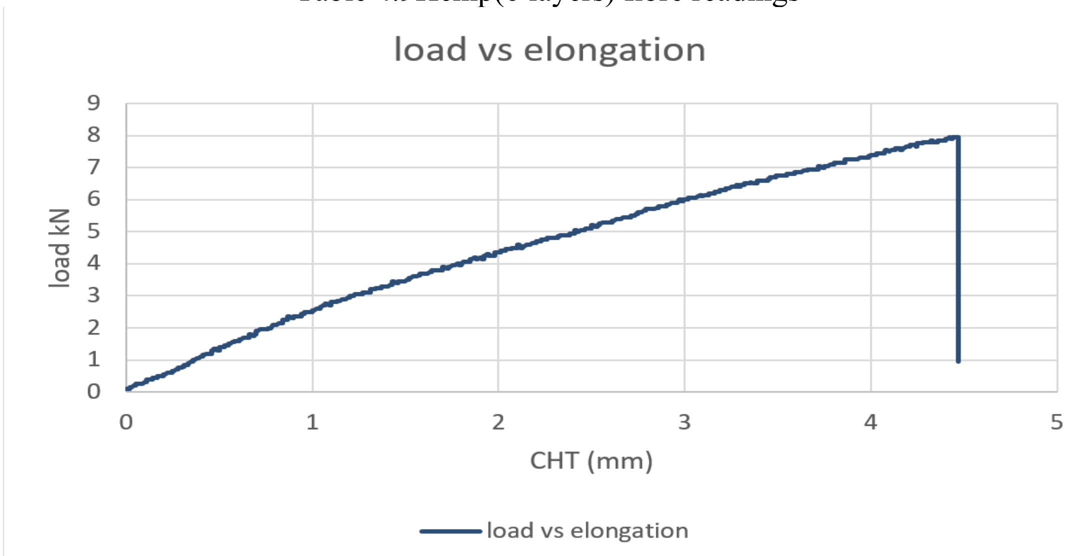


Graph 4.13 Flax+Ramie fibre load vs time

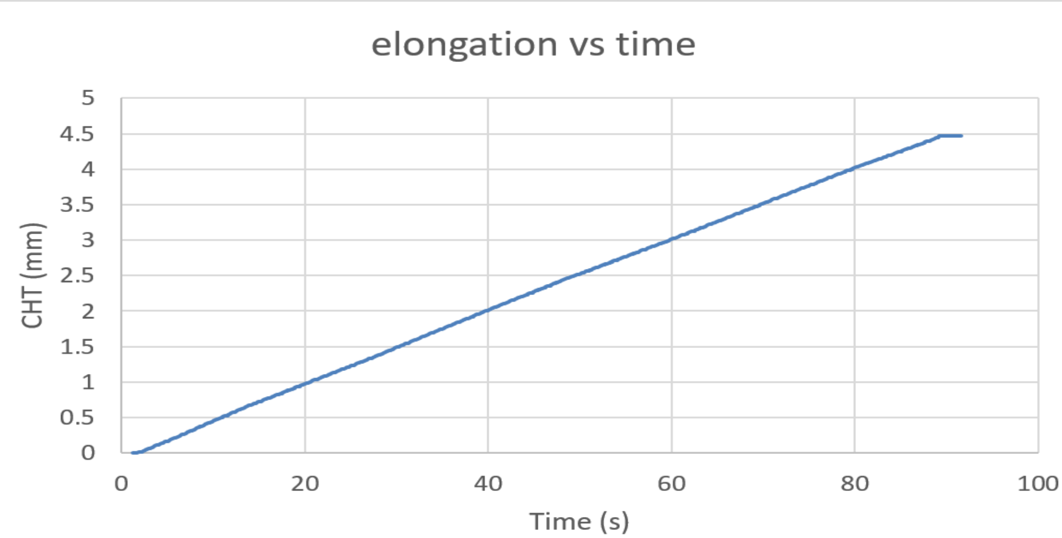
4.2.2.4 Hemp (6 layers):

Fiber type	No. layers	Sample No.	Thickness(mm)	Tensile strength(Mpa)
Hemp	6	1	5.2	60.33
			5.63	
			6.3	
			Avg. 5.76	
		2	5.9	69.000
			6.0	
			6.2	
			Avg.6.1	
		3	5.64	58.000
			6.24	
			6.36	
			Avg. 6.24	
			Approximate thickness=6.1	**62.44**

Table 4.9Hemp(6 layers) fibre readings



Graph 4.14 Hemp(6 layers) fibre load vs elongation

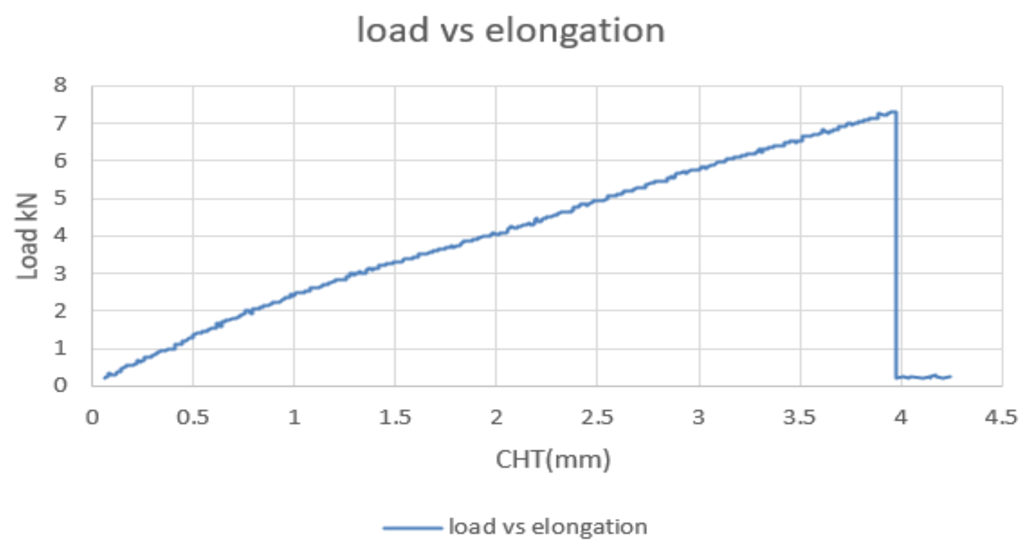


Graph 4.15Hemp(6 layers) fibre load vs time

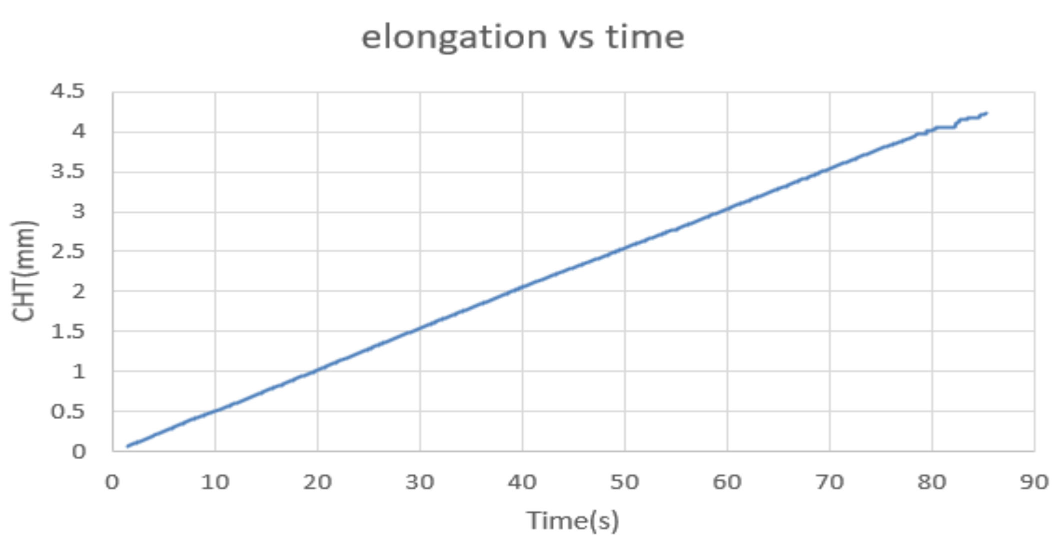
4.2.2.5 3Hemp+ 2Flax (3H+2F):

Fiber type	No. layers	Sample No.	Thickness(mm)	Tensile strength(Mpa)
3Hemp+ 2Flax	5	1	4.1	48.5
			4.2	
			4.3	
			Avg. 4.2	
		2	4.09	10.899
			4.19	
			4.29	
			Avg.4.199	
		3	4.1	49.000
			4.2	
			4.3	
			Avg. 4.2	
			Approximate thickness=4.2	**36.133**

Table 4.10 3Hemp+ 2Flax (3H+2F) fibre readings



Graph 4.16 3Hemp+ 2Flax (3H+2F) fibre load vs elongation



Graph 4.17 3Hemp+ 2Flax (3H+2F) fibre load vs time

4.3 Bending test of laminates:

The bending test is one of the main mechanical tests used in engineering and materials science to evaluate the flexural strength and ductility of different types of materials. In this article, we will cover in detail the bending test, exploring its definition, importance, advantages, obtained properties, applications and much more.

The bending test is a mechanical test used to evaluate the resistance of a material to plastic deformation caused by repeated bending. In this test, a sample of the material is subjected to bending forces until failure occurs. The objective is to determine the ability of the material to withstand bending without fracturing.

This test is performed by applying a load to a specific region of the sample, causing the material to flex. The load is gradually increased until fracture or cracking failure occurs. During the test, parameters such as the applied load, the deformation and the bending angle reached before failure are recorded.

Bending testing is widely used to determine the ductility and toughness of materials. Ductility refers to the material's ability to plastically deform without fracturing, while toughness measures the material's resistance to impact fracture.

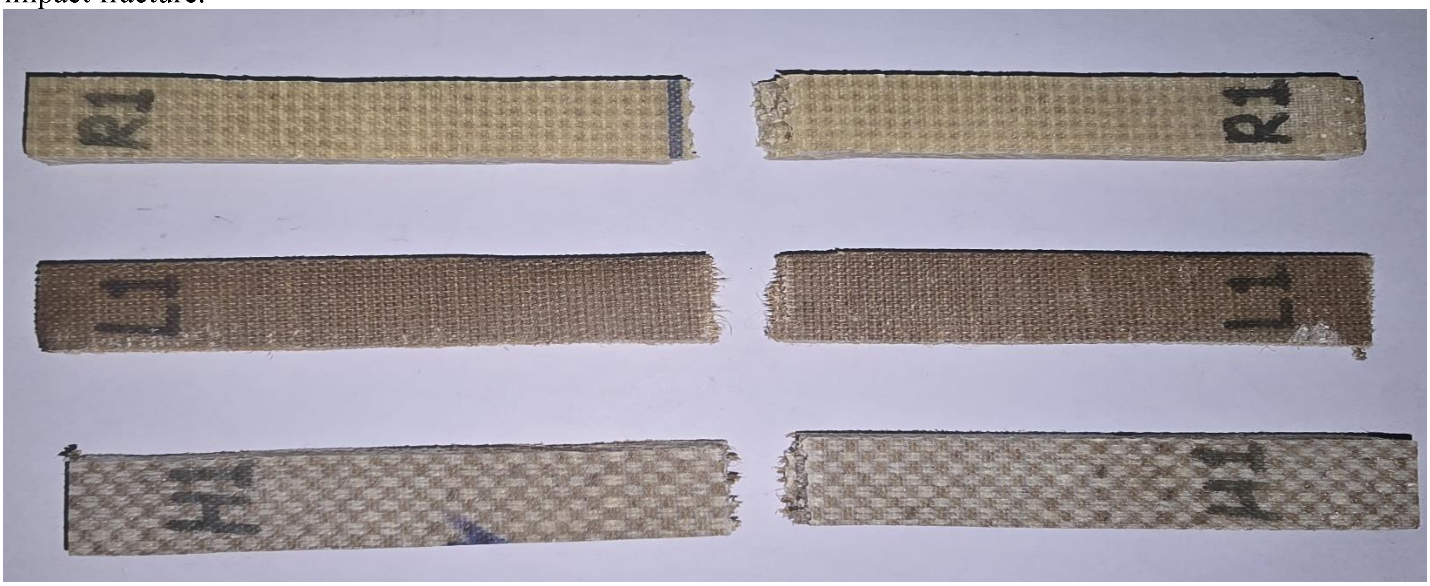


Fig 4.8 bending test sample

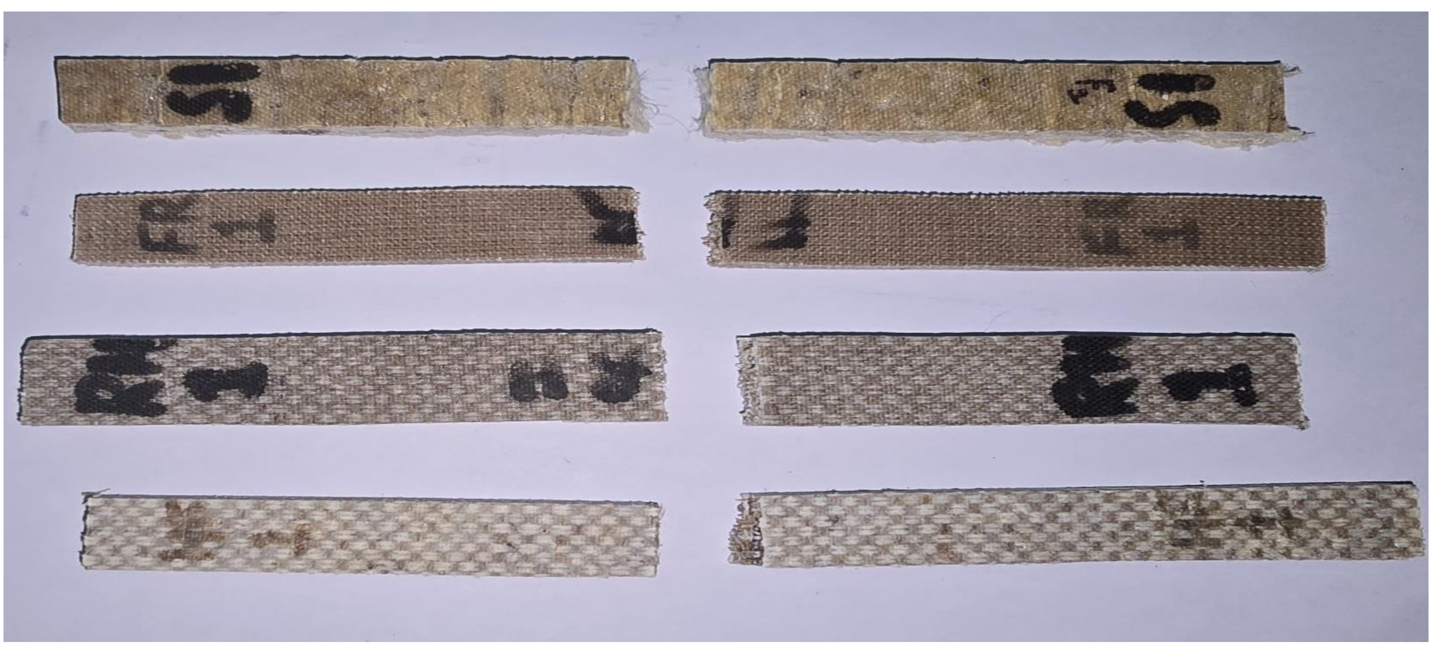
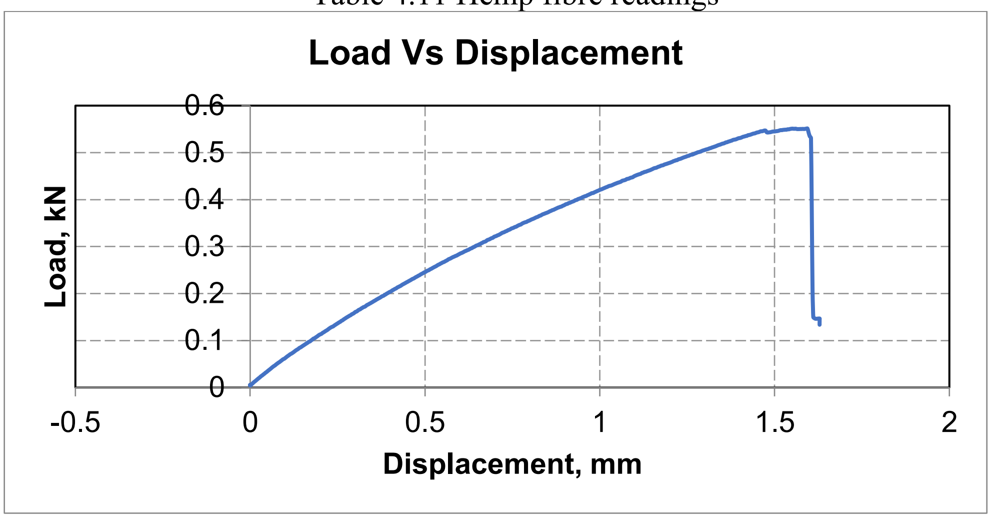


Fig 4.9 bending test sample

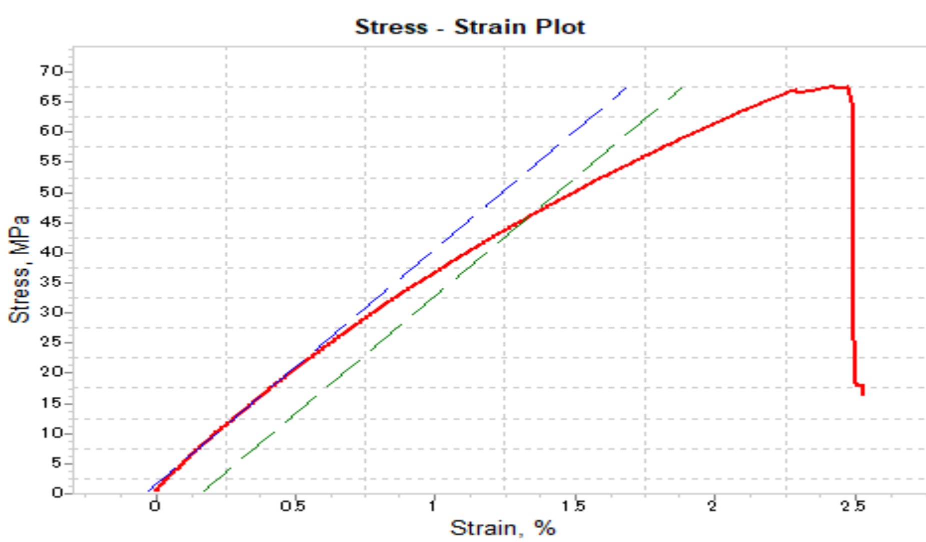
4.3.1 Bending test of different specimen:
4.3.1.1 Hemp:

Fiber type	No. layers	Sample No.	Thickness(mm)	Peal load (kN)
Hemp	8	1	7.5	0.551
			7.5	
			7.6	
			Avg. 7.6	
		2	7.3	0.671
			7.76	
			7.96	
			Avg.7.63	
		3	7.42	0.796
			7.55	
			7.47	
			Avg. 7.48	
			Approximate thickness =7.6	**0.672**

Table 4.11 Hemp fibre readings



Graph 4.18 Hemp fibre load vs diaplacement

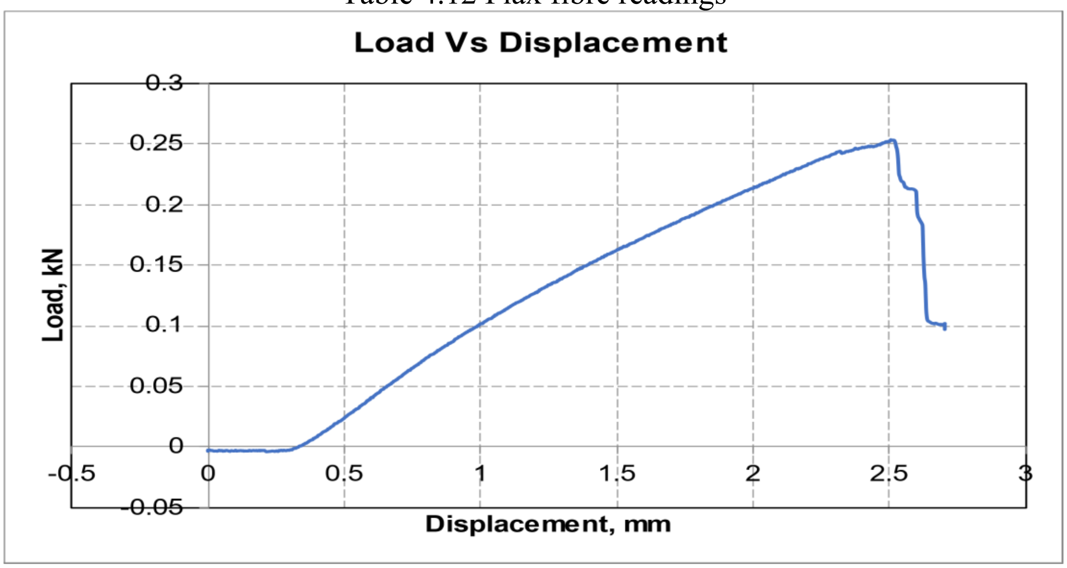


Graph 4.19 Hemp fibre stress vs strain

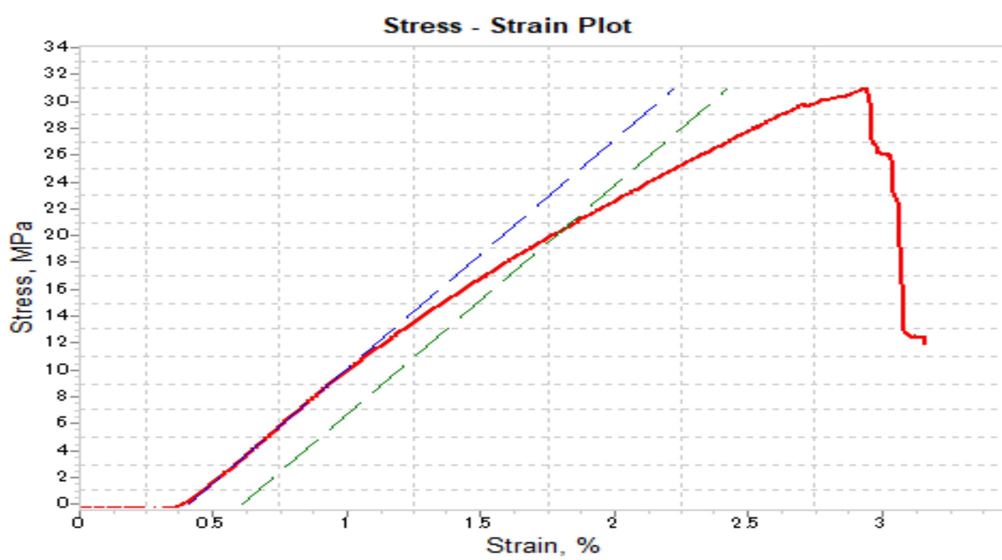
4.3.1.2 Flax:

Fiber type	No. layers	Sample No.	Thickness(mm)	Peal load (kN)
Flax	8	1	4.32	0.253
			4.32	
			4.27	
			Avg. 4.3	
		2	4.36	0.217
			4.35	
			4.32	
			Avg.4.3	
		3	4.31	0.216
			4.36	
			4.19	
			Avg. 4.2	
			Approximate thickness =4.2	0.2286

Table 4.12 Flax fibre readings



Graph 4.20 Flax fibre load vs diaplacement

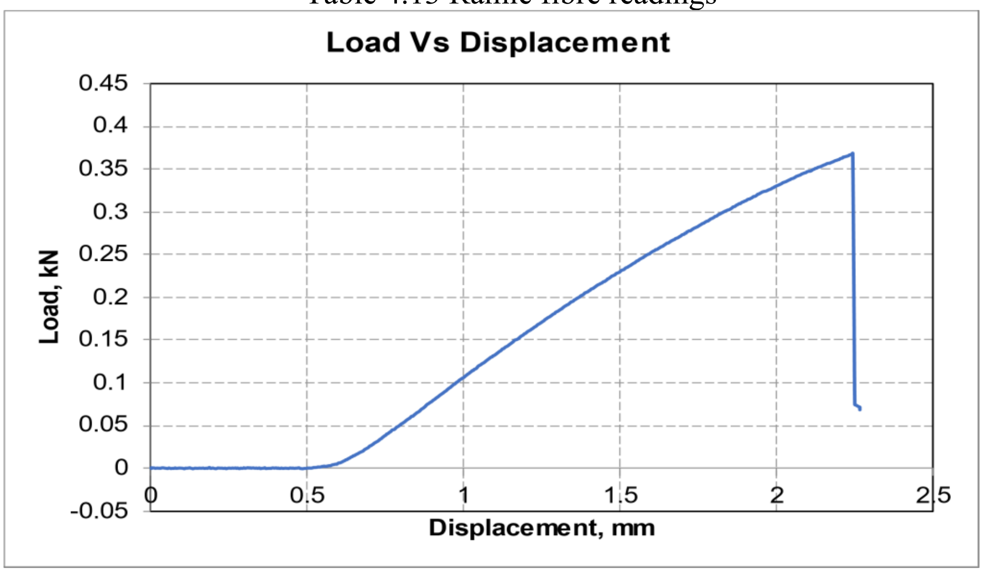


Graph 4.21 Flax fibre stress vs strain

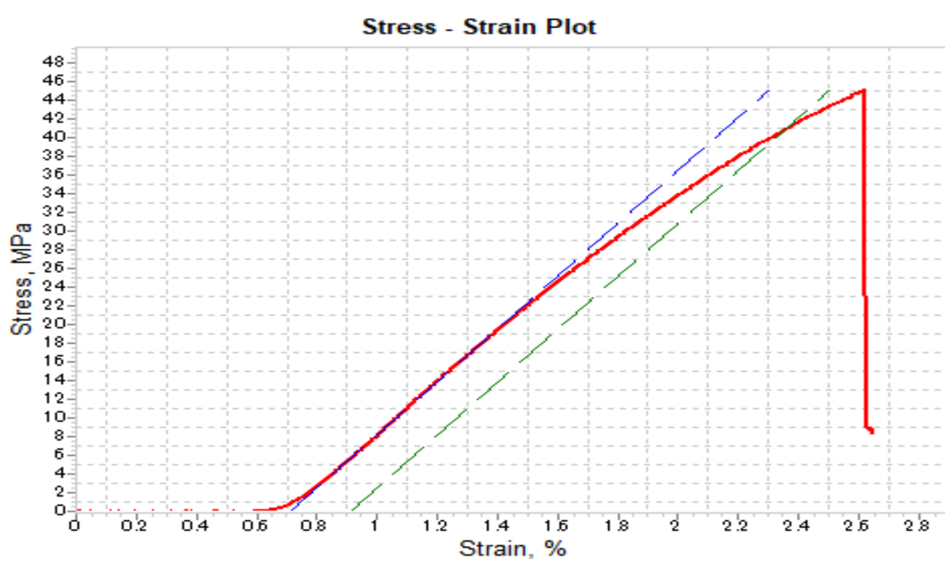
4.3.1.3 Ramie:

Fiber type	No. layers	Sample No.	Thickness(mm)	Peal load (kN)
Ramie	8	1	5.28	0.369
			5.10	
			5.26	
			Avg. 5.2	
		2	5.2	0.333
			5.29	
			5.20	
			Avg.5.23	
		3	4.9	0.382
			5.02	
			5.01	
			Avg. 4.97	
			Approximate thickness =5.2	**0.361**

Table 4.13 Ramie fibre readings



Graph 4.22 Ramie fibre load vs diaplacement



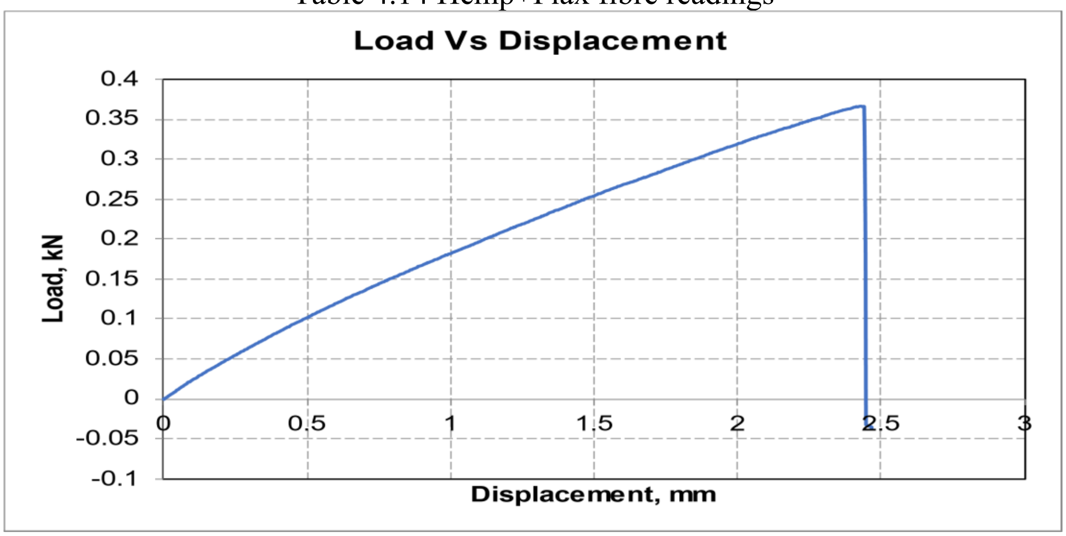
Graph 4.23 Ramie fibre stress vs strain

4.3.2 Bending test of combinations(Hybrid) composites:

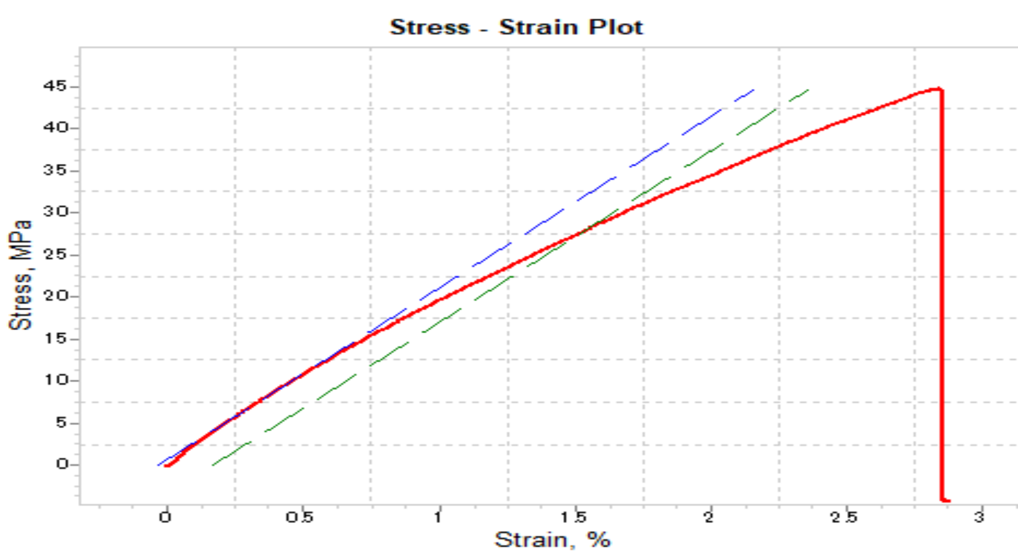
4.3.2.1 Hemp + Flax:

Fiber type	No. layers	Sample No.	Thickness(mm)	Peal load (kN)
Hemp+Flax	8	1	4.82	0.365
			5.25	
			5.18	
			Avg. 5.07	
		2	5.6	0.461
			5.71	
			5.63	
			Avg.5.64	
		3	6.2	0.403
			6.34	
			6.44	
			Avg. 6.35	
			Approximate thickness =5.74	**0.409**

Table 4.14 Hemp+Flax fibre readings



Graph 4.24 Hemp+Flax fibre load vs diaplacement

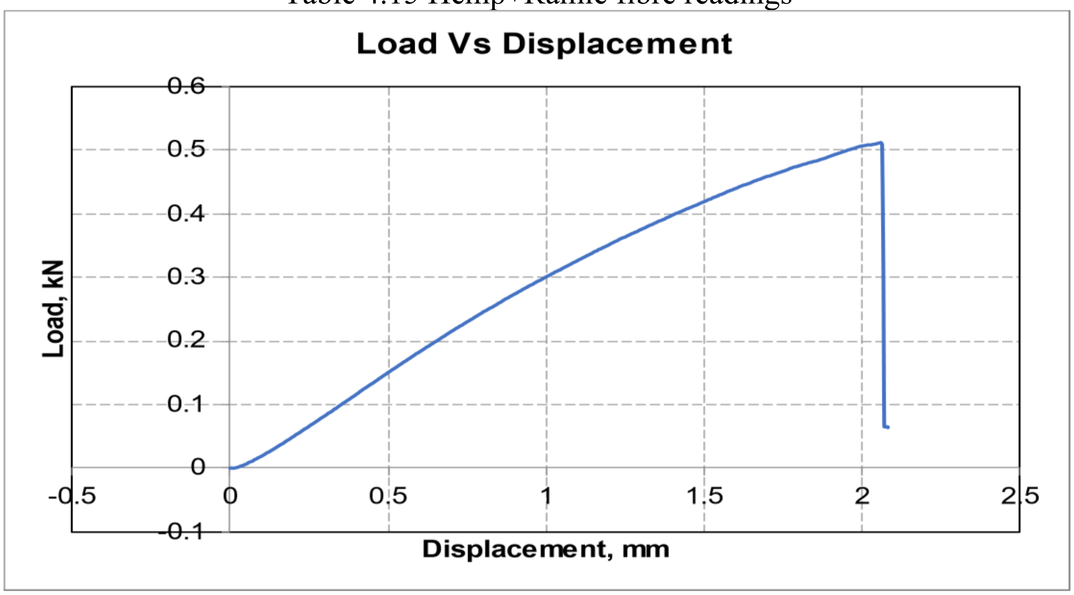


Graph 4.25 Hemp+Flax fibre stress vs strain

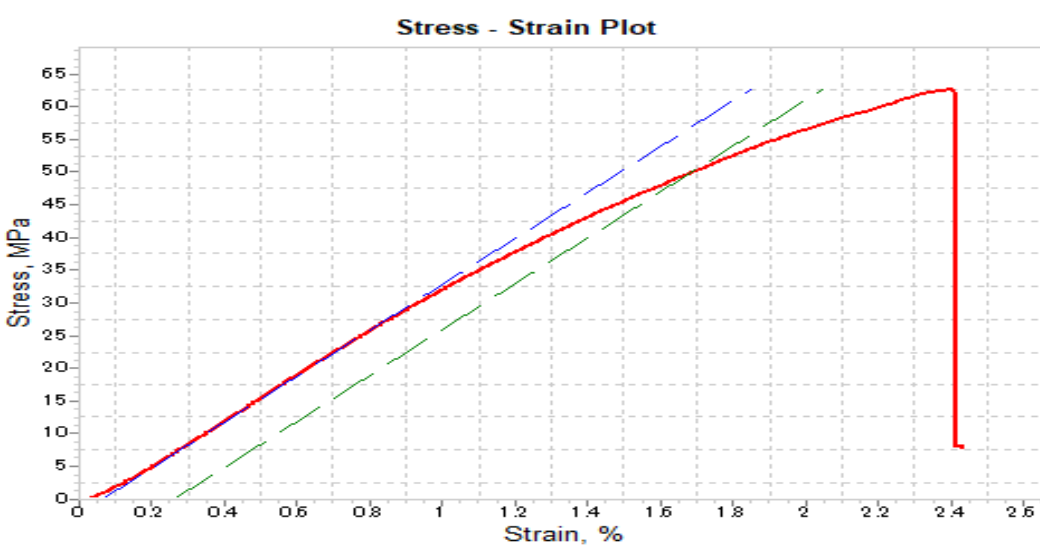
4.3.2.2 Hemp + Ramie:

Fiber type	No. layers	Sample No.	Thickness(mm)	Peal load (kN)
Hemp+Ramie	8	1	6.86	0.513
			7.14	
			6.31	
			Avg. 6.77	
		2	6.86	0.484
			6.65	
			7.2	
			Avg.6.9	
		3	6.33	0.447
			6.88	
			6.81	
			Avg. 6.67	
			Approximate thickness=6.8	**0.481**

Table 4.15 Hemp+Ramie fibre readings



Graph 4.26 Hemp+Ramie fibre load vs diaplacement

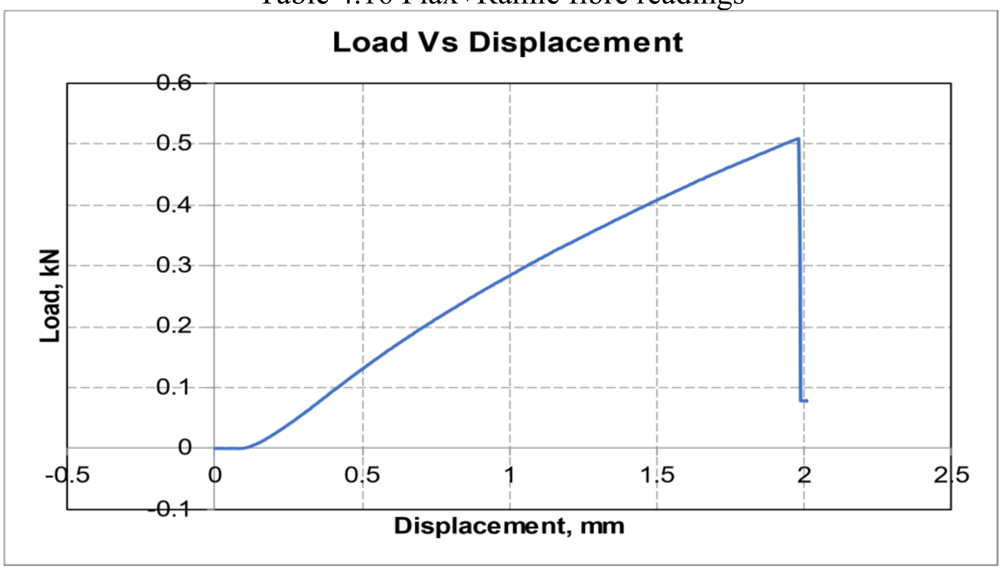


Graph 4.27 Hemp+Ramie fibre stress vs strain

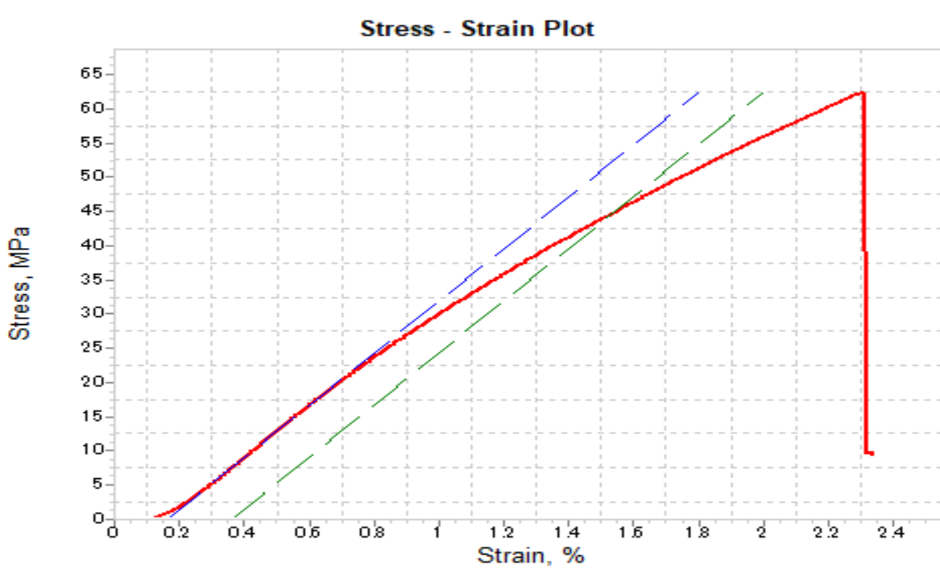
4.3.2.3 Flax + Ramie:

Fiber type	No. layers	Sample No.	Thickness(mm)	Peal load (kN)
Flax+Ramie	8	1	5.2	0.51
			5.23	
			5.0	
			Avg. 5.14	
		2	5.2	0.459
			5.26	
			4.5	
			Avg.4.98	
		3	4.37	0.467
			5.30	
			4.92	
			Avg. 4.86	
			Approximate thickness=4.9	**0.478**

Table 4.16 Flax+Ramie fibre readings



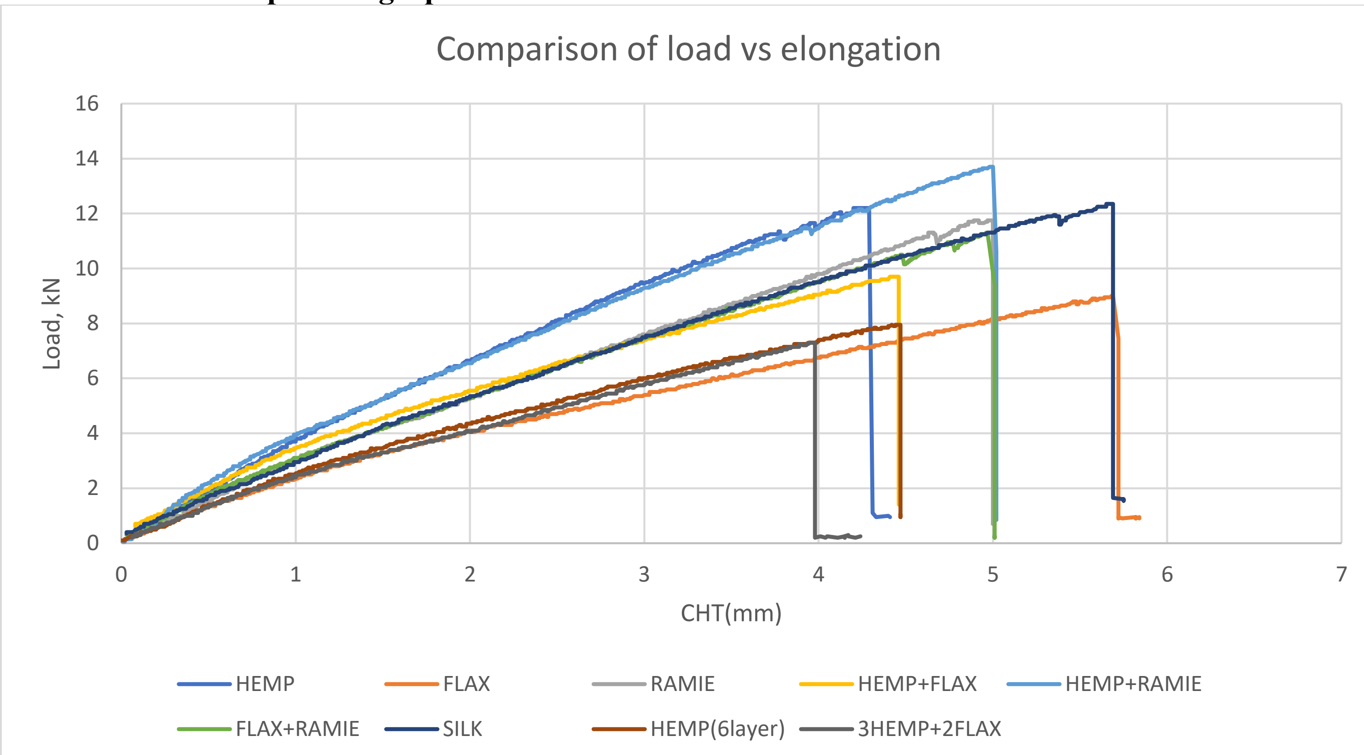
Graph 4.28 Flax+Ramie fibre load vs diaplacement



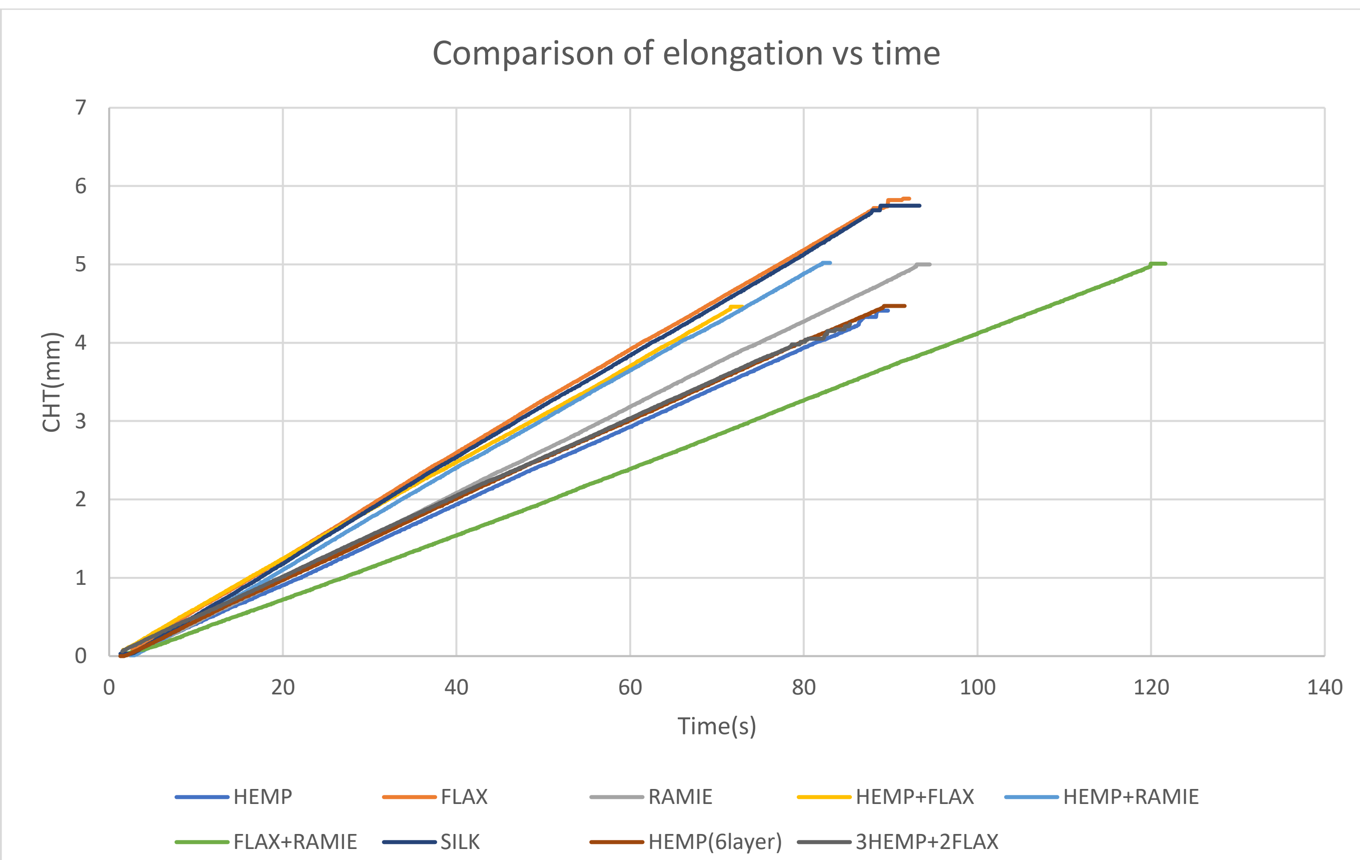
Graph 4.29 Flax+Ramie fibre stress vs strain

4.4 Comparison of test results:

4.4.1 Tensile test comparison graph

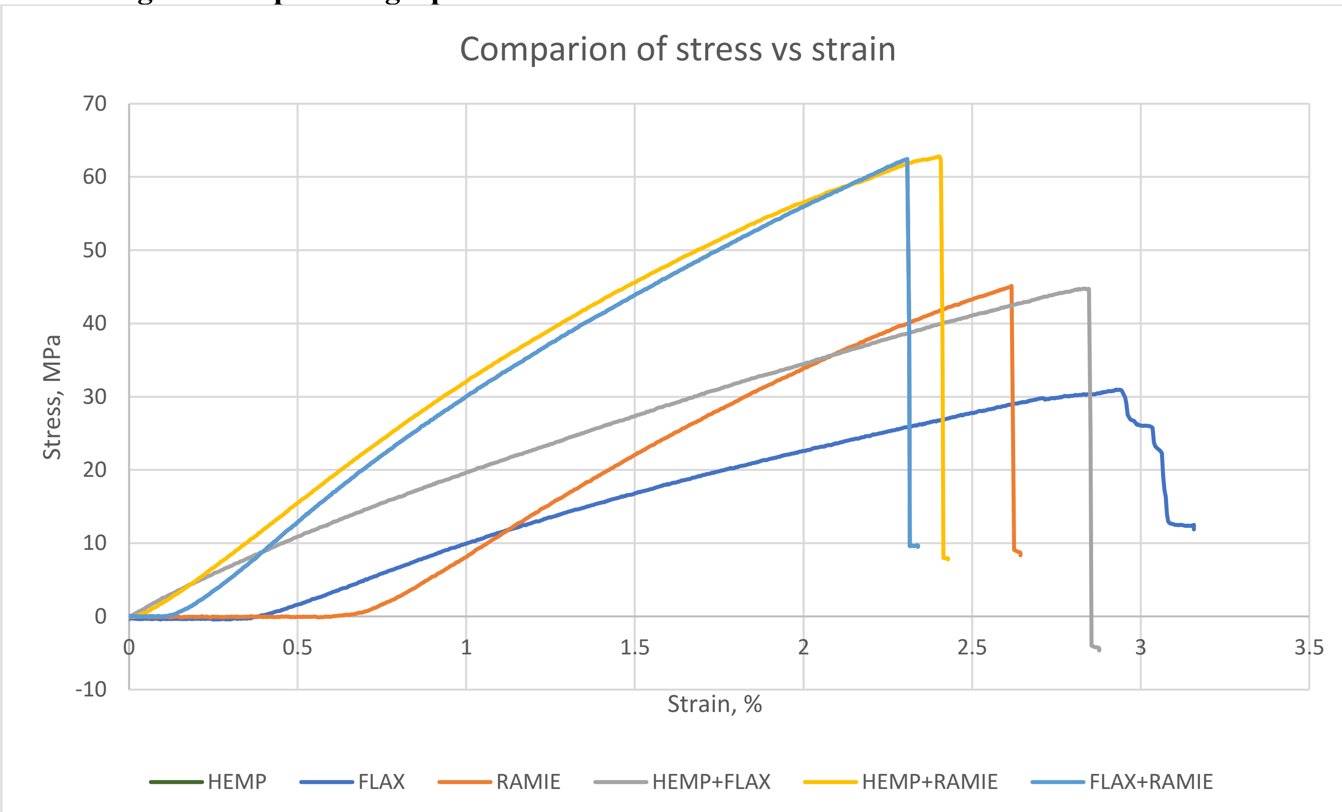


Graph 4.30 load vs elongation comparison results of tensile test

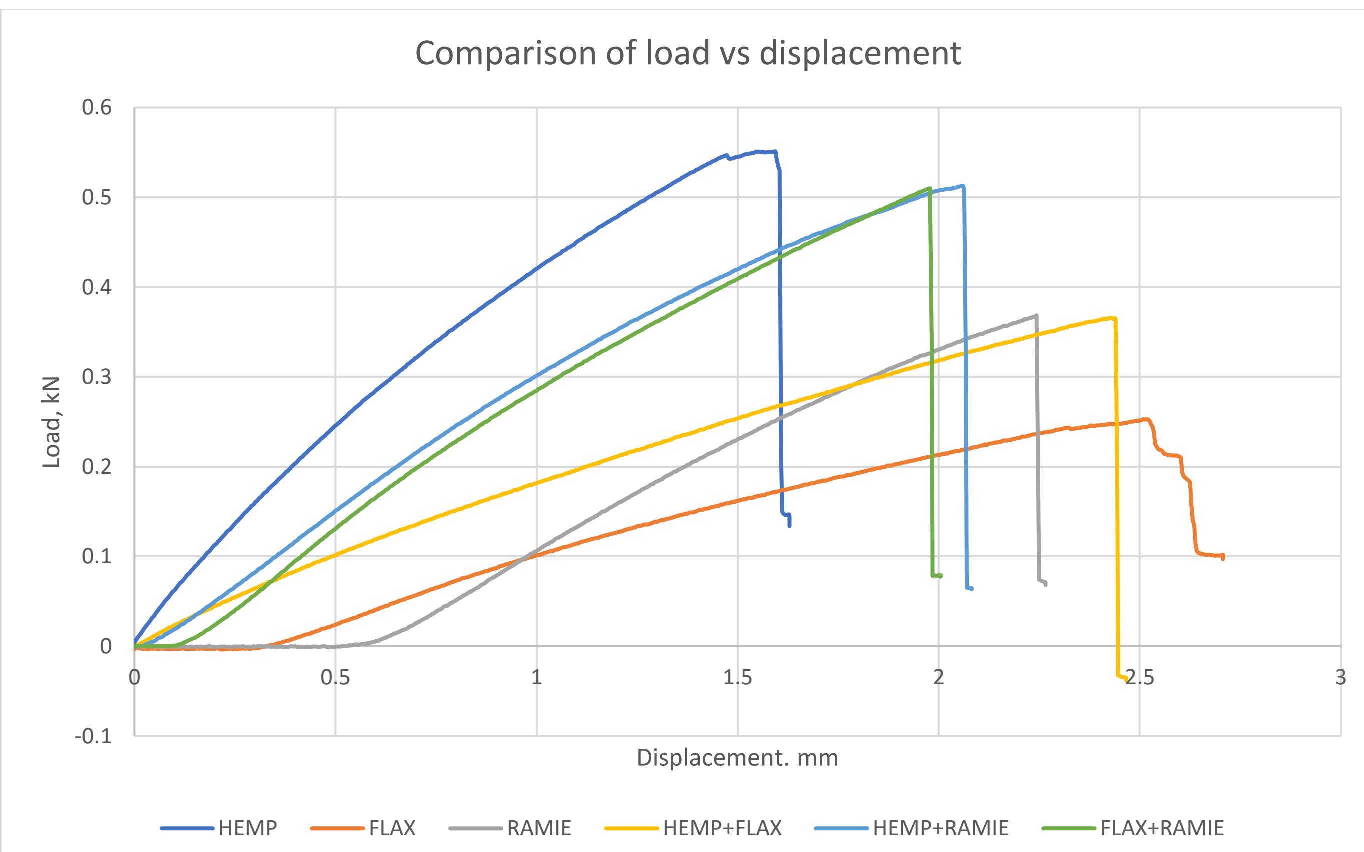


Graph 4.31 elongation vs time comparison results of tensile test

4.4.2 Bending test comparison graph:



Graph 4.32 stress vs strain comparison results of bending test

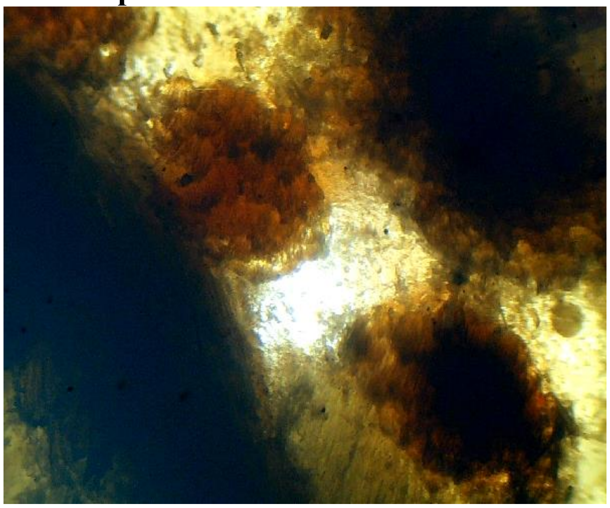


Graph 4.33 load vs displacement comparison results of bending test

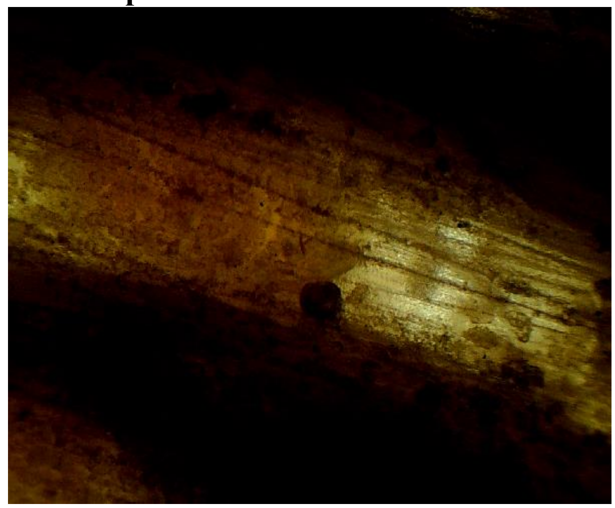
CHAPTER 5

5.1 Microscopic imaging of fibres:

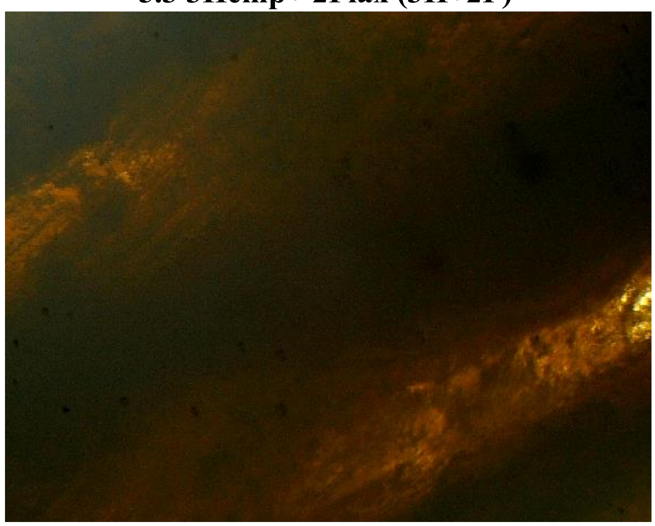
5.1 Hemp



5.2 Hemp+Ramie

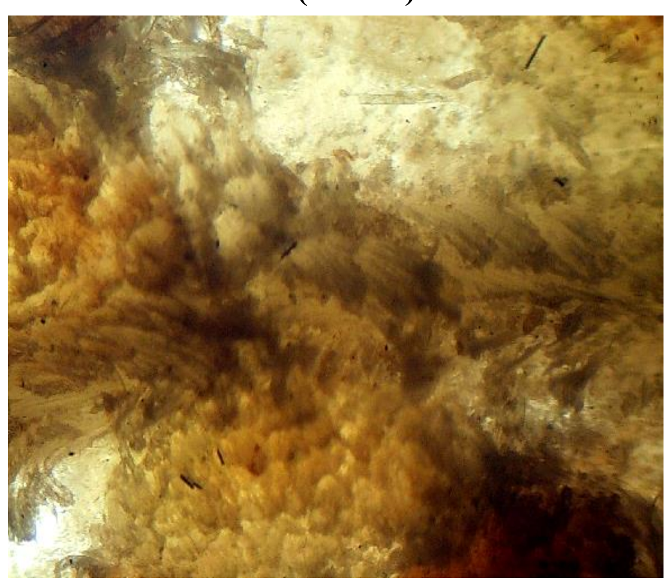


5.3 3Hemp+ 2Flax (3H+2F)



5.4 Hemp+Flax(broken)

5.5 Flax+Ramie(broken)



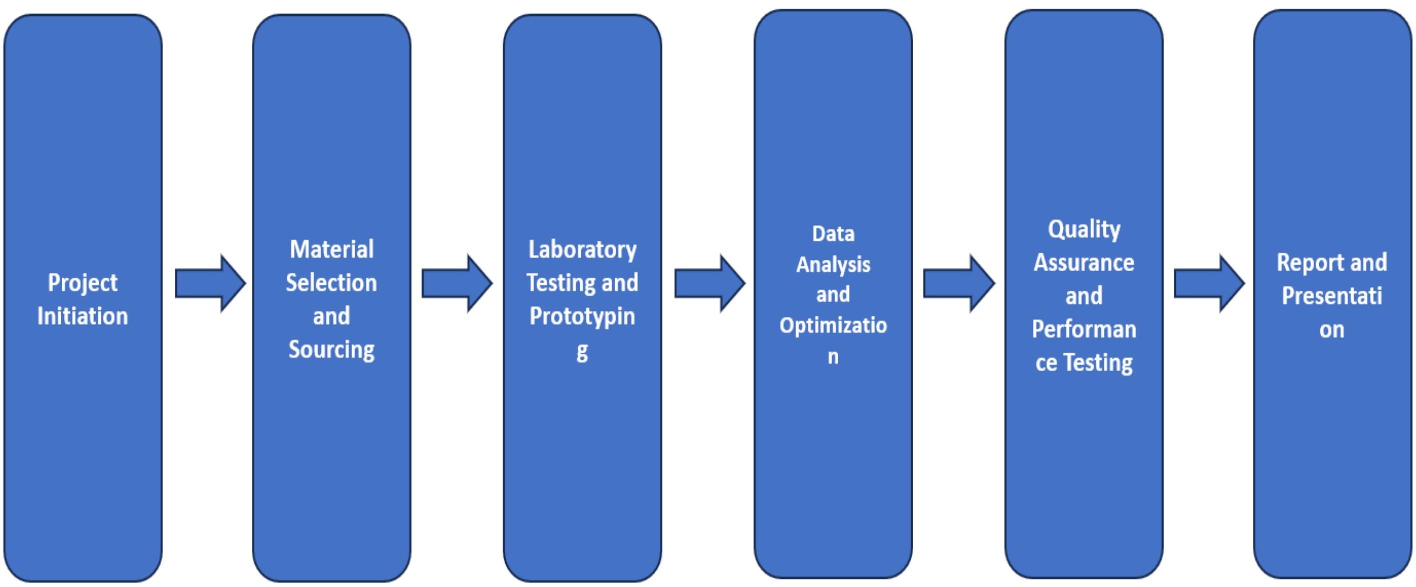
CHAPTER 6

6.1 Future plan and its timeline for completion

Future of Natural Fibre Helmets for Aviation Ground Crews

- Additional study and Development: Conduct a comprehensive study to investigate and optimise the performance properties of natural fibre materials used in helmet manufacturing. Investigate innovative processing processes, material combinations, and protective coatings to improve the helmet's durability, comfort, and safety.
- Refine and iterate current helmet prototypes in response to feedback from airline ground crew personnel and industry stakeholders. Incorporate user-centric design changes to ensure the helmet's best fit, functionality, and usability in real-world operational conditions.
- Certification and Compliance: Work to secure the regulatory certifications and approvals required for the deployment and usage of natural fibre helmets following aviation safety requirements. Work with regulatory authorities, testing labs, and certification organisations to ensure safety.
- Manufacturing Scale-Up: Form collaborations with manufacturers and suppliers to increase manufacturing capacity for natural fibre helmets. Invest in modern manufacturing technology and production methods to satisfy the need for long- lasting aviation safety equipment while keeping costs low and quality high.

Market Penetration and Adoption: Create strategic marketing and distribution initiatives to encourage the use of natural fibre helmets by aviation ground workers, airlines, airports, and other stakeholders



(Completed) (Completed) (Completed) (Completed) (Completed) (Completed)

CHAPTER 7

7.1 CONCLUSION:

- To summarise, the creation of a natural fibre helmet for aircraft ground workers is a positive step forward in aviation safety and sustainability.
- This novel helmet provides a feasible alternative to typical synthetic materials by utilising natural fibre features such as lightweight, strength, and biodegradability.
- Through thorough testing and consultation with industry experts, the natural fibre helmet has proved its capacity to offer suitable protection for aircraft ground staff while minimising environmental effect.
- Furthermore, its adoption demonstrates a commitment to sustainability and ethical manufacturing processes, which aligns with the industry's efforts to reduce carbon footprints and promote environmentally friendly solutions.
- As technology evolves and awareness of environmental problems rises, the natural fibre helmet serves as a beacon of progress in.
- As technology advances and public awareness of environmental issues rises, the natural fibre helmet serves as a symbol of progress in establishing safer, greener, and more sustainable aircraft operations in the future.

7.2 ACKNOWLEDGEMENT:

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