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Title:

Experimental study of natural/synthetic fibers efficiency on the mechanical properties of composite materials

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Dedication

I dedicate this work to my beloved family, whose love, support, and sacrifices have been the foundation of my strength throughout this journey.

To my dear friends, with heartfelt appreciation to Abd Rahim and Abdelatif, for your unwavering encouragement, loyalty, and true friendship. And to Chemmami Aymen, my friend and thesis partner, whose dedication, teamwork, and shared efforts made this accomplishment possible. This achievement is as much yours as it is mine

Abstract:

The global demand for metallic materials has increased over the last decades, prompting many factories to seek new composite materials focused on improving mechanical properties.

A composite material is created by combining two or more components, including plant-based sources (such as jute, cotton, palms, and cactus) and animal-based sources (such as silk and wool), which possess advantageous physical and chemical properties. Incorporating natural fibers with industrial (synthetic) fibers represents a significant step toward hybridization.

In this study, we aim to present suitable solutions through the analysis of tested specimens to develop new materials characterized by excellent mechanical performance. The goal is to produce sustainable fibers that, on the one hand, reduce environmental impact by recyclability, and corrosion resistance, and, on the other hand, are cost-effective.

In fact, natural fiber composites (NFC) have become a promising alternative to synthetic fiber composites, as the industry increasingly relies on cultivable fibers, including jute, to promote sustainability and eco-friendliness.

Keywords: Synthetic fiber, Natural fiber, Hybrid composite materials, Polyester, Jute, Glass fiber.

ملخص:

شهد الطلب العالمي على المواد المعدنية ازديادًا ملحوظًا خلال العقود الماضية، مما دفع العديد من المصانع إلى البحث عن مواد مركبة جديدة تُركز على تحسين خصائصها الميكانيكية. تُصنع المادة المركبة من خلال دمج مكونين أو أكثر، بما في ذلك مصادر نباتية (مثل الجوت والقطن والنخيل والصبار) ومصادر حيوانية (مثل الحرير والصوف)، والتي تتميز بخصائص فيزيائية وكيميائية مميزة. ويمثل دمج الألياف الطبيعية مع الألياف الصناعية (الاصطناعية) خطوةً هامةً نحو التهجين. نهدف في هذه الدراسة إلى تقديم حلول مناسبة من خلال تحليل العينات المختبرة لتطوير مواد جديدة تتميز بأداء ميكانيكي ممتاز. الهدف هو إنتاج ألياف مستدامة، من جهة، تُقلل من التأثير البيئي بفضل قابليتها لإعادة التدوير ومقاومتها) بديلاً واعدًا NFCللتآكل، ومن جهة أخرى، فعالة من حيث التكلفة. في الواقع، أصبحت مركبات الألياف الطبيعية (لمركبات الألياف الاصطناعية، حيث يعتمد القطاع بشكل متزايد على الألياف القابلة للزراعة، بما في ذلك الجوت، لتعزيز الاستدامة والمحافظة على البيئة. الكلمات المفتاحية: الألياف الصناعية، الألياف الطبيعية، المواد المركبة الهجينة، البوليستر، الجوت، الزجاج.

المفتاحية الكلمات :.الزجاج ،الجوت ،البوليستر ،الهجينة المركبة المواد ،الطبيعية الألياف ،الصناعية الألياف

Résumé :

La demande mondiale de matériaux métalliques a augmenté ces dernières décennies, incitant de nombreuses usines à rechercher de nouveaux matériaux composites améliorant leurs propriétés mécaniques. Un matériau composite est créé en combinant deux ou plusieurs composants, notamment des fibres végétales (comme le jute, le coton, les palmiers et les cactus) et animales (comme la soie et la laine), qui possèdent des propriétés physiques et chimiques avantageuses. L'intégration de fibres naturelles à des fibres industrielles (synthétiques) représente une étape importante vers l'hybridation. Dans cette étude, nous souhaitons présenter des solutions adaptées, grâce à l'analyse d'échantillons testés, pour développer de nouveaux matériaux caractérisés par d'excellentes performances mécaniques. L'objectif est de produire des fibres durables qui, d'une part, réduisent l'impact environnemental grâce à leur recyclabilité et leur résistance à la corrosion, et, d'autre part, sont rentables. En effet, les composites à base de fibres naturelles (NFC) sont devenus une alternative prometteuse aux composites à base de fibres synthétiques, car l'industrie s'appuie de plus en plus sur les fibres cultivables, dont le jute, pour promouvoir la durabilité et le respect de l'environnement.

Mots clés : Fibre synthétique, Fibre naturelle, Matériaux composites hybrides, Polyester, Jute, Fibre de verre.

Contents

Figures List:

Chapter 1: review of composite materials

Chapter 2: Compoiste Materials properties

Chapter 3: specimens manufacturing

Chapter 4: Tension testing & discussion of results

Tables list

Chapter 1: review of composite materials

Chapter 2: Compoiste Materials properties

chapter 3: specimens manufacturing

Chapter 4: tension testing & discussion of results

General Introduction:

The global demand for metallic materials has continued to increase over the past decades, prompting many factories to seek new composite materials focused on improving mechanical properties using natural fibers, synthetic fibers, and metal networks and polyester. Developing high-strength, high-grade composite materials remain a challenge for industries, as they strive to ensure service continuity while protecting the environment. The aim of this work is to analyze experimental results to evaluate the impact of composite materials on improving and reinforcing mechanical characteristics.

This study is divided into four chapters, followed by a general conclusion.

The **first chapter** presents the evolution of composite materials manufacturing and discusses the different types of composites, such as synthetic, natural, and hybrid composites, developed to meet technical and economic requirements as suitable solutions. The **second chapter** focuses on the standards related to composites, including material classification, mechanical characteristics, specimen geometries, and testing standards. The **third chapter** describes the preparation process of natural and synthetic fiber composites, considering the number of layers and additive compounds. Various samples were tested through tensile tests, with a focus on patch repair for corrosion defects. The **fourth chapter** analyzes the hybridization of natural, synthetic, and additive fibers, emphasizing the influence of the number of layers on the improved properties of composite materials. Natural and industrial fibers are reinforced with natural and steel wires, and polyester can produce new solutions with excellent features for corrosion protection. These solutions are characterized by low cost, ease of preparation, eco-friendliness, and wide availability. Finally, a **general conclusion** is presented.

CHAPTER 1
Review of Composite Materials

1.1 Introduction:

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties. When combined, these materials create a new material with characteristics that are superior or different from those of the individual components. Typically, a composite material is composed of a matrix (or binder) and a reinforcement, which together produce a material that is stronger, lighter, or more durable than the individual constituents alone. Today, composites are widely used in various fields, from aerospace and automotive engineering to construction and sports equipment, due to their versatility and the ability to tailor properties to specific applications.

1.2 A Historical Look at Composite Materials:

The concept of combining different materials to improve performance is not new. Historical evidence shows that ancient civilizations used composite materials in construction and tool-making. For example, the use of straw-reinforced mud bricks in early architecture is an early example of a composite system, where the organic fibers provided additional tensile strength to the brittle mud. Recent studies have shown that these 900-year-old bows are nearly as strong as modern composite bows, capable of hitting targets up to 450 meters away. This longevity and performance showcase the durability and effectiveness of well-designed composite materials. [1]

The industrial revolution marked a pivotal moment, especially with the rise of polymers and plastics, which offered high resistance to heat and electricity. This opened up new possibilities for composite materials, particularly in the form of glass fiber resins, invented in the 1930s, which remain widely used in the industry today. Over the centuries, the evolution of composites can be divided into several key periods the ancient innovations which they use natural fibers and organic materials to enhance building materials then industrial revolution which is an introduction of laminated wood products and early forms of reinforced concrete. Modern Era the mid-20th century saw a breakthrough with the development of fiber-reinforced plastics, which revolutionized industries such as aerospace and sporting goods. [2]

Figure 1.1: Jute fiber[3]

1.3 Main Structure of Composite Materials:

Composite materials are defined by their structure, and base on [4][5][11] we can say that composite materials typically includes:

1.3.1 Matrix:

1.3.1.1 Role and Function :

The matrix is the major form that surrounds and binds the reinforcement. It offers deffirent curcial roles first of all It transmits external loads to the reinforcement, ensuring that the high-strength fibers or particles share the mechanical stress. And It protects the reinforcement from environmental damage (e.g., moisture, chemicals) and physical wear Also It has a feature of formation the composite into the desired shape and provides overall stability.[5][11]

1.3.1.2 Types of Matrices :

Depending on the application, matrices can be Polymeric Such as epoxy, polyester, or vinyl ester resins; common in aerospace, automotive, and sporting goods or Metallic Used in metal matrix composites (MMCs) for applications requiring high thermal and electrical conductivity also Ceramic which used in ceramic matrix composites (CMCs) for high-temperature and wear-resistant applications.[5][11]

1.3.2 Reinforcement:

1.3.2.1 Role and Function :

It’s the discontinuous element embedded within the matrix and is primarily responsible for enhancing the mechanical properties, such as strength and stiffness of the composite because fibers or particles provide resistance against deformation under load also toughness and impact resistance for the reason that the reinforcement can help absorb energy during impacts, reducing crack propagation.[5]

1.3.2.2 Forms of Reinforcement:

The reinforcement can come in various forms, each tailored for different performance characteristics first we have fibers are divided into several parts, such as natural fibers, synthetic fibers, and hybrid fibers. All of these types are used according to the shape of the fibers for example Continuous Fibers provide the highest strength and stiffness; typically used in high-performance applications like aerospace and short fibers which are more cost-effective and easier to process; used in applications where directional properties are less critical. Second we have particles Used in particulate-reinforced composites, where small particles are dispersed in the matrix to enhance properties such as wear resistance and thermal stability then we have Laminates Layers of materials bonded together, often combining different types of reinforcement for tailored properties.[4][5]

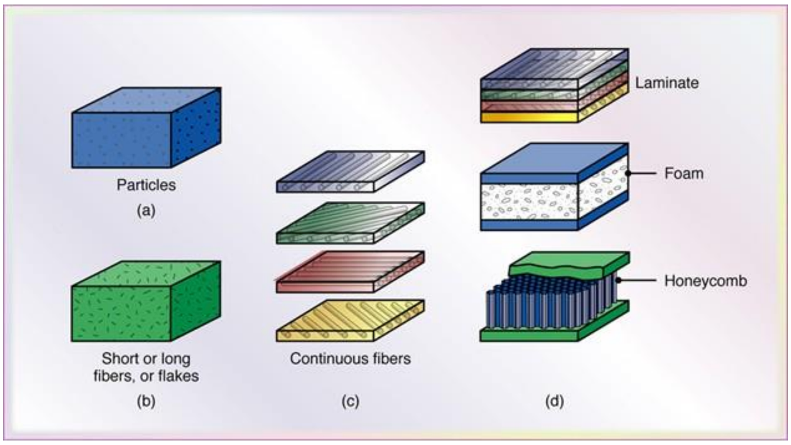


Figure1.2: Forms of Reinforcement.[4]

1.3.3 Interface (Interphase) Region:

1.3.3.1 Role:

The interphase of a matrix and reinforced composite is critical for load transfer efficiency. With a strong bond, the composite behaves as a single solid material and if the bond is weak, it may result in premature failure due to fiber pull out or delamination.[8] [5][11]

1.3.4 Design Considerations:

Enhancing interphase properties is achieved by surface modification of the reinforcement, which improves bonding, durability, and the performance of the composite

1.4 Overall Composites Architecture and Composites Classification:

1.4.1 Orientation and Distribution:

The performance of a composite depend not only on the fiber’s and matrix’s properties but also on the orientation of the fiber, so we need to know the materials' purpose. Then analyze and determine mechanical stresses to choose the right angle. For example, we want to make a piece with height resistance to traction so based on that we need to choose the right angle that does the job but also not forget the compression and shear stresses to make sure that the piece doesn’t fail when some of the shear or compression stresses applied. For each material chosen as the fiber, we need to check their mechanical characteristics.[22]

1.4.1.1 Orientation :

Composite materials can be unidirectional which mean fibers are aligned in one direction, optimizing strength and stiffness along that axis.or can be bidirectional or multidirectional which mean fibers are oriented in multiple directions, providing more isotropic properties, which is beneficial in applications where loads come from various directions.[22]

1.4.1.2 Volume Fraction :

The relationship between the reinforcement and the matrix greatly affects the composite's mechanical properties. In general, a greater volume fraction of reinforcement increases strength and stiffness, although it can negatively impact manufacturability and toughness.[23]

1.4.2 Composite Tailoring:

One of the key benefits of composite materials is their ability to tailor the design for example, the type, orientation, and distribution of reinforcements can be adjusted based on specific application requirements. This enables optimization of important engineering properties such as impact resistance, fatigue behavior, and thermal stability.[22][23]

In general, composite materials structures are:

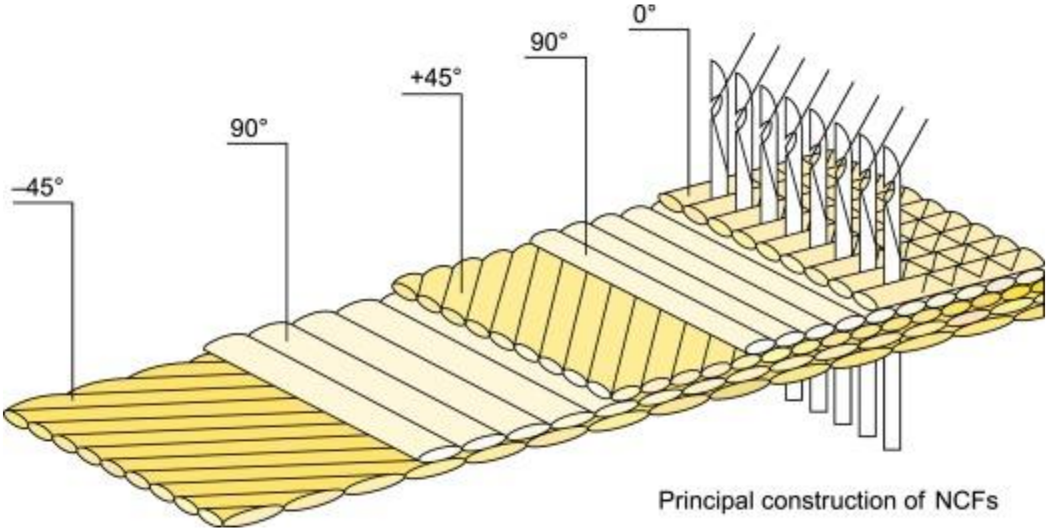


Figure 1.3: composite tailoring.[28]

1.4.3 Composites Classification:

Composites are divided in two kinds of materials; fist kind is focused on matrix contains and second kind is on reinforcement type [9]

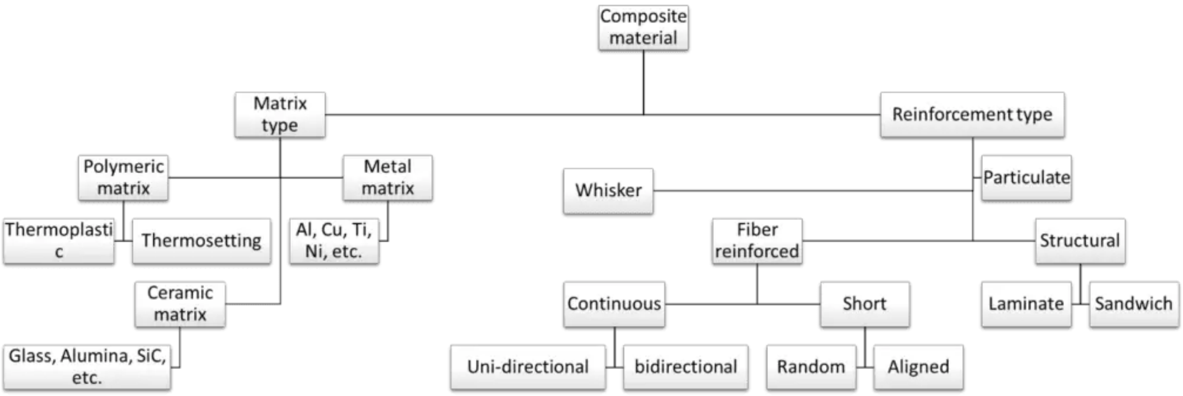


Figure 1.4: composites classification.[1]

1.5 Difference Between Normal Materials and Composite Materials:

Traditional materials including ceramics, and polymers have uniform composition and properties. However, the composite materials are heterogeneous.

1.5.1 • Homogeneity vs. Heterogeneity:

Standard materials maintain uniform properties throughout, unlike composites that are deliberately designed with different phases to optimize performance.

1.5.2 • Tailorability:

The composites characteristics can be altered by choosing the type, orientation and volume fraction of the reinforcement, unlike traditional materials which are limited to their pre-existing properties.

1.5.3 • Failure Mechanisms:

For composites, interface failure (e.g. delamination or fiber pull-out) is possible, while homogeneous materials fail through cracking or yielding.

1.5.4 • Manufacturing Techniques:

Composites also have specialized fabrication processes like layup, filament winding, and pultrusion that differ from conventional materials.

1.6 Key Manufacturing Processes

Several techniques have been developed to produce composite materials. Below are some of the most common processes:

1.6.1 Manual Layup Process[6]

1.6.1.1 Description:

This is one of the simplest and most widely used methods, especially for low-volume production or large, complex shapes (e.g., boat hulls, storage tanks). [6][16]

1.6.1.2 Steps :

First we start by mold making and a release agent is often applied to the mold or tooling to prepare it. Then fibrous reinforcements such as fabric or mat are applied onto the mold in Reinforcement Placement step. Next we applied reinforcement is scrubbed or rolled over with resin (polyester, epoxy, or vinyl ester) in a process known as Resin Application and we repeat this processes until the required thickness is achieved. The composite's room temperature or oven curing, based on the resin system, finalizes its Curing. Finally The composite part is separated from the mold in Demolding and Finishing processes, cured parts undergo trimming and finishing as required. [6]

1.6.1.3 Applications:

This manufacturing processes can be used in Marine Industry for building the hulls of vessels and small recreational boats also production of sporting equipment such as surfboards and windsurfing boards. Or even in prototyping and low-volume production for example Custom parts, architectural panels, and specialized components. [6]

1.6.1.4 Advantages:

Among the benefits of this method is the ability to easily manage intricate geometries.
And low cost for tools and equipment needed for small scale production. Also simple to set up operations with limited machinery and tools. [6][16]

1.6.1.5 Constraints:

Using this method may provid some difficulties for example high reliance on people for work, and requires skilled personnel. And The production efficiency is lower, the speed is slow, and the production cycle will be slightly longer, so it is not suitable for mass production of the product;. [16]

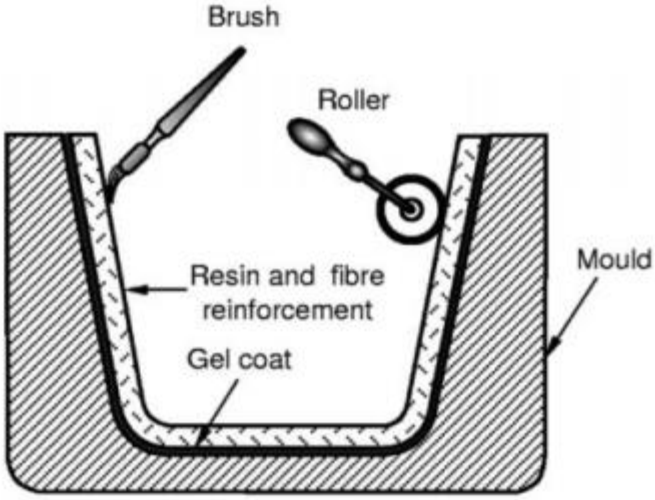


Figure 1.5: hand lay-up.[6]

1.6.2 Spray-Up Process[7]

1.6.2.1 Description:

This method is akin to hand layup, but it uses a spray gun to apply resin and chopped fibers or chopped strand mat onto a mold. It is frequently employed to manufacture large, curved components. [7]

1.6.2.2 Steps:

First Chopped fibers and resin Mixture prior to spraying, fibers are chopped and blended with resin (and occasionally, catalysts). Then The mixture is sprayed onto the mold, improving the rate at which material is deposited. The wet layup is compacted by hand or with tools to remove excess resin and air pockets. Finally after curing, the composite is removed and finished as necessary. [7]

1.6.2.3 Applications:

This processes can used in manufacturing large, curved panels for use in recreational vehicles, storage tanks, and swimming pools. Also used in the production of components where rapid buildup is beneficial, even if fiber alignment and mechanical performance are sacrificed. [25]

1.6.2.4 Advantages:

Among the benefits of this method it's provide quicker production than hand layup and Direct labor required is less for large parts per unit area. [25]

1.6.2.5 Constraints:

Using this processes may provide some difficulties for example reduced control over fiber orientation relative to hand layup and Lower mechanical performance. [25]

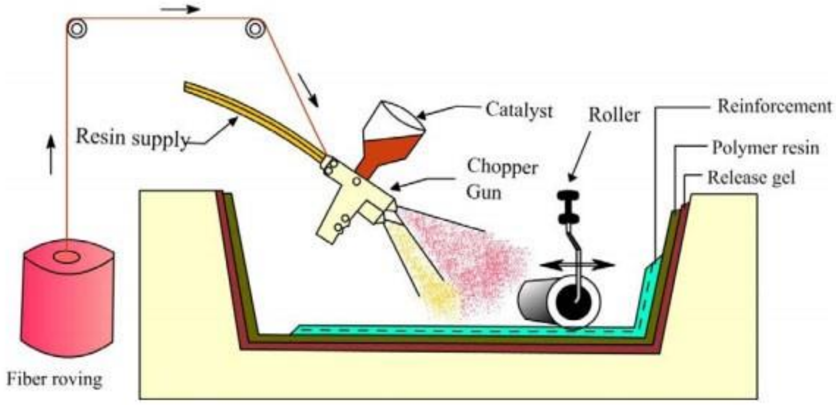


Figure 1.6: spray lay-up process.[7]

1.6.3 Resin Transfer Molding (RTM)

1.6.3.1 Description:

RTM is a closed-mold technique wherein dry reinforcement is positioned within a mold and resin is injected under pressure. It is best suited for the manufacture of intricate parts of high structural integrity, uniform fiber volume distribution, and excellent surface finish. [11][27]

1.6.3.2 Steps:

First, Fibers or fabric are placed into the two-part mold cavity. Then the two-part mold is locked and sealed to maintain vacuum conditions and under controlled pressure, resin is injected into the mold to achieve complete fiber saturation then The hardened resin is cured with the application of heat in order to strengthen the composite material. Finally after curing, the part is demolded and subjected to finishing operations as necessary. [11][27]

1.6.3.3 Applications:

This method enables the design and manufacture of sophisticated and complex structures, enabling the formation of components with complex shapes and large surface areas, with a good surface finish on both sides. It is suitable for short and medium-duty production runs and is used in a variety of transportation applications. [27]

1.6.3.4 Advantages:

Among the benefits this method it's effectively manages fiber and resin uniformity as well as fiber content also exceptional surface finish along with geometric accuracy and gives an appropriate for medium and high production volumes. [25][27]

1.6.3.5 Constraints:

From the difficulties of this processes is increased tooling costs because of intricate geometric molds and demands close regulation. [26][27]

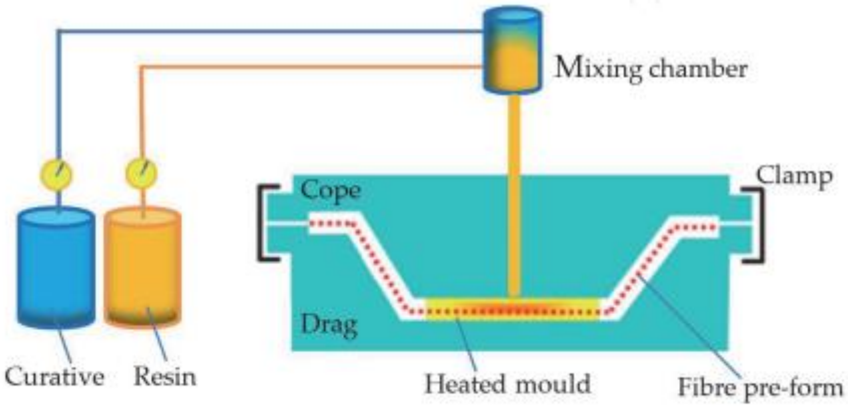


Figure 1.7: resin transfert molding. [11]

1.6.4 Filament Winding[10]

1.6.4.1 Description:

This method is applied in the creation of hollow cylindrical and spherical objects such as pipes and pressure vessels. Methodical winding of continuous resin-impregnated fibers onto a spinning mandrel creates these objects. [10]

1.6.4.2 Steps:

Start by Mandrel Preparation then fiber impregnation to ensure that fibers are either wetted in-line or before winding. Thereafter the fibers are wound onto the mandrel at predetermined angles to ensure optimum strength of the structure. The composite is cured while on the mandrel. In the last step the mandrel is removed and retained as part of the structure, depending on whether it is sacrificial or collapsible. [10]

1.6.4.3 Applications:

Using this metode you can made pressure vessels, tanks and high-pressure pipping also cylindrical structures like pipes. [10]

1.6.4.4 Advantages:

This can method can afford superior mechanical properties due to high fiber alignment and excellent axisymmetric construction efficiency. [10]

1.6.4.5 Constraints:

May this method have a limitation which is can handle basic geometrical shapes like cylindrical and spherical only and machinery and setup costs are steep. [10]

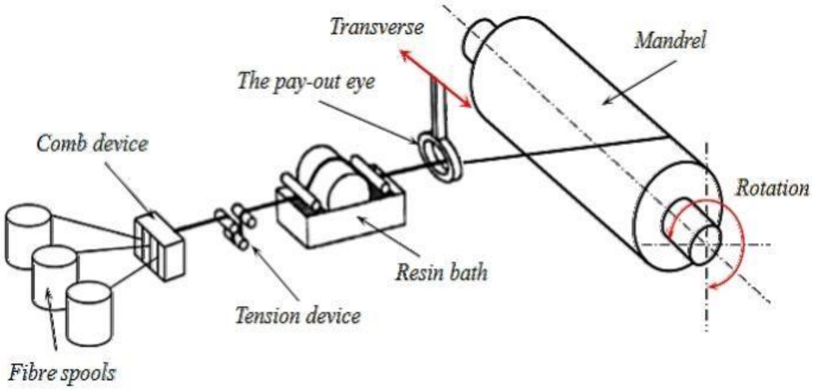


Figure 1.8: filament winding. [10]

1.6.5 Compression Molding[12]

1.6.5.1 Description:

Compression molding is the technique of putting a specific volume of resin (often pre-impregnated with reinforcement, also called prepreg) into a heated mold; the resin is then shaped and cured while the mold is closed under pressure. [12]

1.6.5.2 Steps:

First of all, start by Prepreg Preparation which the stage includes impregnating the reinforcement with resin under controlled environment, followed by a partial cure (B-stage) to retain stickiness. Then mold loading, the prepreg is set into a heated mold cavity. Thereafter the mold is closed, pressure and heat are applied to consolidate and cure the composite. Finally, Demolding and Finishing: The cured part is removed, excess material is trimmed. [12]

1.6.5.3 Applications:

This processes can made parts of high-performance automotive such as bumpers and panels also aerospace panels and sporting good. [12]

1.6.5.4 Advantages:

This method provide excellent mechanical properties and low void content, resulting from high pressure consolidation. Also Complex components of high strength are achievable and high volume production has require relatively short cycle times. [12]

1.6.5.5 Constraints:

During use this method may encounter some difficulties like Precision molds increase costs for tooling and systems using thermoset resin are restricted. [12]

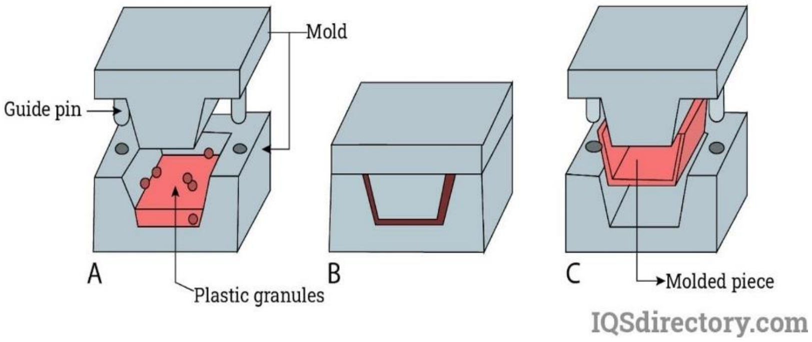


Figure 1.9: compression molding. [12]

1.6.6 Process Considerations

The matrix and reinforcement compatibility considerations together are very crucial for selecting composite manufacturing processes:

• Surface treatments or sizings are often applied to fibers to improve bonding with the resin.[8][16]

• Fiber Volume Fraction and Orientation: The amount and alignment of reinforcement affects [22][23]the mechanical properties of the final composite and determines how strong it is.

• Curing Conditions: Optimal mechanical properties and minimum defects will only be obtained with proper curing whether it is through ambient temperature, oven, or autoclave.

With technological progress, these methods of manufacturing are changing for the better in regard to the quality and efficiency.

1.7 The key parameters and properties of composite materials:

Composite materials come into being when two or more differing components-often a binding matrix paired with reinforcing fibers-are skillfully combined to produce traits that a single, uniform substance simply cannot deliver. Their greatest strength lies in the freedom to tailor the mix, balancing factors like light weight, stiffness, resistance to corrosion or impact, and any other target performance measure. Designers, testers, and engineers therefore must grasp both the behavior of these hybrids and the tools used to measure it, for that knowledge underpins good design, reliable quality control, and ongoing gains in performance.

1.7.1 Mechanical Properties

Mechanical properties are among the most critical parameters in determining the performance of composite materials. These include [14][17]:

1.7.1.1 Tensile Strength

Its the highest pull-force a composite endures before it finally snaps. Why It Matters? designers care because planes, cars, and even high-end bikes trust these limits every day.

Measurement: Engineers check the number on a universal testing machine under ASTM D3039.[14]

1.7.1.2 Compressive Strength:

Compressive strength refers to the maximum compressive force a composite material can withstand before failing. This measure is critical for components such as columns, beams, and some pressure tanks, which spend most of their lifespan under crushing loads. However, strength alone doesn't paint the full picture; engineers also consider the compressive modulus. This number shows how stiff a material is when bent under pressure. Testing it is much like checking tensile toughness: observers simply read the sharp part of the stress-strain diagram when the sample is compressed. When combined, the strength and compressive modulus give a clear picture of how a composite material behaves under stress.

1.7.1.3 Flexural Properties

Flexural strength and modulus of elasticity are two fundamental mechanical properties that reveal how a composite material handles bending forces before deforming or failing. Flexural strength refers to the highest stress a material can withstand before breaking, while modulus of elasticity measures stiffness, indicating how resistant it is to bending under load. These properties are critical in structural components such as beams, slabs, and floor systems.[14]

1.7.1.4 Impact Resistance

Impact resistance expresses a material's ability to resist fracture under sudden stress. It is also a measure of a material's durability.[14]

1.8 Why Composite Materials?

Composites deliver a remarkable strength-to-weight ratio, so materials like carbon-fiber-reinforced polymers fit perfectly in aerospace, automotive, and elite sporting gear, where shaving off extra grams boosts fuel economy and overall performance. A second key draw is customization; engineers simply mix and match matrix and reinforcement, crafting a material whose mechanical, thermal, or chemical traits exactly meet the job. Composites also shine in corrosion and chemical resistance[15], often leaving metals behind when equipment faces acids, seawater, or relentless weather. Finally, their layered, fibrous makeup absorbs shocks, giving them superior fatigue and impact resistance that lengthens service life and even lets them patch leaking pipes with confidence.

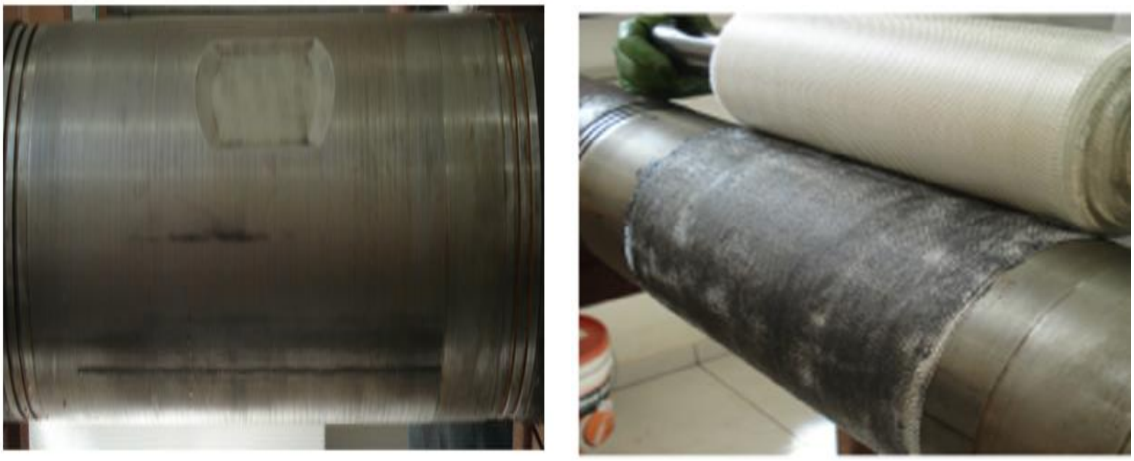


Figure 1.12: composite material patch.[15]

Using the hybrid composite of double patches of same materials or different double in same matrix can combine the performance mechanical and chemical of Hybrid composites. Hybridization technique is better step to improve the FRP composites made for different materials due to a combination between high abrasion resistance and high stretch or other mechanical properties. These composite fibers can be combined in various categories[15]. Composite materials can be molded into complex shapes that would be difficult or impossible to achieve with traditional metals or ceramics. This flexibility supports innovative design solutions and customized engineering.

1.9 Limitations of Composite Materials

Composites offer huge design freedom, yet that flexibility often pulls engineers in wildly different directions, so prototyping and testing now demand advanced modelling and lab work. Despite their benefits, composites still come with a set of drawbacks. First, These materials also face several mechanical performance challenges that may hinder their application in harsh environments. One of the most prominent of these challenges is the surface bonding between the matrix and the reinforcing materials. Poor adhesion can lead to debonding, significantly reducing the load transfer efficiency of the composite components. One of the main causes of mechanical failure of hybrid titanium composite laminates has been found to be the delamination of the titanium laminate and fiber-reinforced polymer (FRP) layers. This problem is particularly prominent in composites with large reinforcement ratios. Another major challenge is the brittleness associated with some of the reinforcements. Additionally, the mechanical properties of hybrid composites can be sensitive to environmental factors such as temperature and humidity. Moreover, the manufacturing processes can be complex and require precise control over various parameters.[13]

1.10 Conclusion

Composite materials are a revolutionary development in today's science and engineering, from which a unique combination of properties can be achieved, which can not be offered by the conventional material. High strength-to-weight ratio, corrosion resistance, and design flexibility make them suitable for engineer-designed material implementations for industry-specific,high performance applications like in the aerospace, automotive, construction and sports equipments. The.Composites offer the potential for tailored properties by careful selection and placement of matrices and reinforcements, new design possibilities and improved performance through weight reduction and longer lifetimes.

On the other hand, using composite materials is not without difficulties. The high manufacturing costs, complexity, and the anisotropy of composites requires advanced engineering design and analysis techniques. Composite materials offer unparalleled advantages in performance and customization but their limitations necessitate careful consideration solutions

CHAPTER 2

Composite Materials Properties

Case study: natural fibers, synthetic fibers, hybrid fibers

2.1 Introduction:

The experimental setup is a crucial step in the evaluation of composite materials, as it ensures the accuracy and reliability of the obtained mechanical properties. In this study, composite specimens were fabricated using a combination of natural and synthetic fibers Jute and Glass embedded in an epoxy matrix. The selection of these materials was based on their unique mechanical properties and complementary characteristics, which provide an optimal balance between sustainability and strength.

To accurately assess the mechanical behavior of these composites, standardized specimen geometries were prepared according to ASTM guidelines for tensile (ASTM-D3039). Furthermore, the specimens were manufactured using the hand lay-up method, a widely used fabrication technique in composite material processing due to its simplicity and effectiveness in achieving uniform fiber distribution.

This chapter provides a detailed description of the composite material selection, mechanical properties, specimen preparation, and testing methodologies employed in this study. The results from these experimental procedures will offer valuable insights into the structural performance of hybrid natural-synthetic fiber composites.

2.2 Materials and Clarifications:

The combination of Jute and Glass mat provides a balance between sustainability and mechanical performance. Base on the limitation of this combination with the temperature [19] and to ensure it to be more tough and hardness we choose barit, spablo, and steel wires networks to adjust this mechanical properties.

- Jute (Natural Fiber) :

Considering natural fibers as an excellent solution due to many advantages including low cost, recyclability and availability worldwide, they have been used as patch panel to repair defects instead of carbon fiber, fiberglass or carbon fiber and glass due to their low density, abrasion resistance and high mechanical resistance. The use of natural fibers is an ideal solution in many areas. This industry relies on diverse plants such as basalt, coconut, banana, sugarcane residue, hemp, kenaf, bamboo, jute, sisal, abaca, and cotton to reinforce any material such as steel, iron, and other composite materials, as well as cement. Natural fibers have excellent properties, including being environmentally friendly compared to traditional fibers. [15]. Jute fiber has gained significant importance in the bio-composite industry due to its diverse applications and favorable mechanical and physical properties compared to other natural fibers. Countries such as Sri Lanka, Bangladesh, Malaysia, and Indonesia serve as major suppliers, ensuring its abundant availability. Traditionally, jute has been widely used in the textile industry for manufacturing products like clothing, ropes, bedsheets, sacks, bags, and shoelaces. However, in recent years, its applications have expanded into various industries, including the automotive sector, where it is utilized in cup holders, dashboard components, and door panels. Major automobile manufacturers, such as BMW and Mercedes, are actively investing in research and development to integrate jute fibers into vehicle production, reducing overall weight and improving fuel efficiency.[19]

Beyond the automotive industry, jute fibers are increasingly replacing synthetic materials in the packaging sector, as well as finding applications in cosmetics, medical products, and even paint formulations. Many developed nations are taking significant steps toward promoting sustainable materials, encouraging the use of natural fibers like jute in construction for manufacturing windows, doors, floor mats, partitions, ceilings, and furniture. European governments, in particular, are collaborating with private organizations to drive the commercialization of jute-based products by offering incentives to industries that adopt eco-friendly materials.[19]

The growing interest In jute fiber is largely attributed to its unique advantages[20], including:

Renewability and biodegradability, making it an environmentally friendly alternative to synthetic fibers.Lightweight, Good impact absorption, and Cost-effectiveness.

Additionally, jute fiber has applications in agriculture and consumer goods industries, with its demand expected to grow in the coming years. Its renewable and biodegradable nature makes it an attractive alternative to synthetic fibers, aligning with global environmental initiatives. However, despite its promising potential, challenges remain, including limitations in processing techniques, lower mechanical performance compared to synthetic fibers, and the relatively high costs associated with jute fiber composites. Ongoing research aims to enhance its properties and unlock further industrial applications. With increasing consumer preference for sustainable materials, the market for jute fiber composites is expected to expand, particularly in Asia, which has become a hub for production and commercialization.[19][20]

- Glass chopped strand mat (Synthetic Fiber):

300 GSM Fiberglass Chopped Strand Mat (CSM) is a non-woven reinforcement material composed of randomly oriented chopped strands of E-glass fibers. With a nominal areal weight of 300 grams per square meter, this mat offers a balance between strength and flexibility, making it ideal for various composite applications such as boat building, automotive parts, aerospace structures, and construction components. The mat typically has a thickness of 0.5 to 1.0 mm and a density ranging from 0.25 to 0.30 g/cm^3, allowing for effective resin impregnation during lay-up processes. Its tensile strength ranges between 10–15 Mpa, and it exhibits an elongation at break of approximately 2–3%, indicating a moderate ability to absorb deformation before failure. These characteristics make 300 GSM CSM particularly suitable for creating laminates that require dimensional stability and good load distribution while maintaining ease of handling and moldability.

- TP100 Casting Type Polyester Resin:

The matrix material used was TP100, a casting-grade unsaturated polyester resin. This resin is known for its low viscosity, good wet-out of fibers, and ambient-temperature curing properties, making it ideal for hand lay-up applications. Its mechanical stability and affordability make it a popular choice for composite fabrication in both academic and industrial contexts.

- CERA COMPO DW:

Produced in the form of a formulated paste. Uses: For demolding polyester resins, and for demolding polyester, polyurethane, and gelcoat resin laminates. Store in a cool, dry place, protect from frost, and do not leave drums/containers open.

Figure 2.1: CERA COMPO DW.

- Catalyst – RP 50:
  The curing of the TP100 resin was initiated using RP 50 catalyst, a type of Methyl Ethyl Ketone Peroxide (MEKP) commonly used with polyester systems. This catalyst enabled room-temperature polymerization, with a typical gel time of 15–20 minutes and full curing occurring within 24 hours under ambient conditions.
- Accelerator – NL-49P:
  NL-49P is a cobalt octoate-based accelerator that enhances the activity of the catalyst and shortens the gel time. NL-49P is essential for initiating the redox reaction between the MEKP and the unsaturated polyester.
- Acétone EXP (Industrial-Grade Acetone):
  Acétone EXP was used throughout the fabrication process as a cleaning solvent for tools, containers, and work surfaces. Due to its high volatility and solvent strength, it was effective for quickly removing uncured resin residues from brushes, gloves, and molds during and after the hand lay-up process.

2.3 Mechanical Properties of Jute [18][25]

- **Jute Fiber :**

Table 2.1: mechanical properties of jute fiber.[18][19]

Mechanical properties	Values
Density (kg/cm^3)	1.4
Elongation at break (%)	1.5-1.8
Tensile strength (MPa)	700 - 800
Young’s modulus (GPa)	30
Cellulose content (%)	50-57
Lignin content (%)	8-10

This properties vary depends on different factors for example the length of the fiber for that some of the properties estimated in range of values like tensile strength.

Also, we found from experience that for each X gram of jute we need at least (6.3-6.5) * X gram of resin (Polyester resin), for example:

100 g of jute requires at least 630 g of polyester resin to ensure good surface, bonding and avoid issues like this:

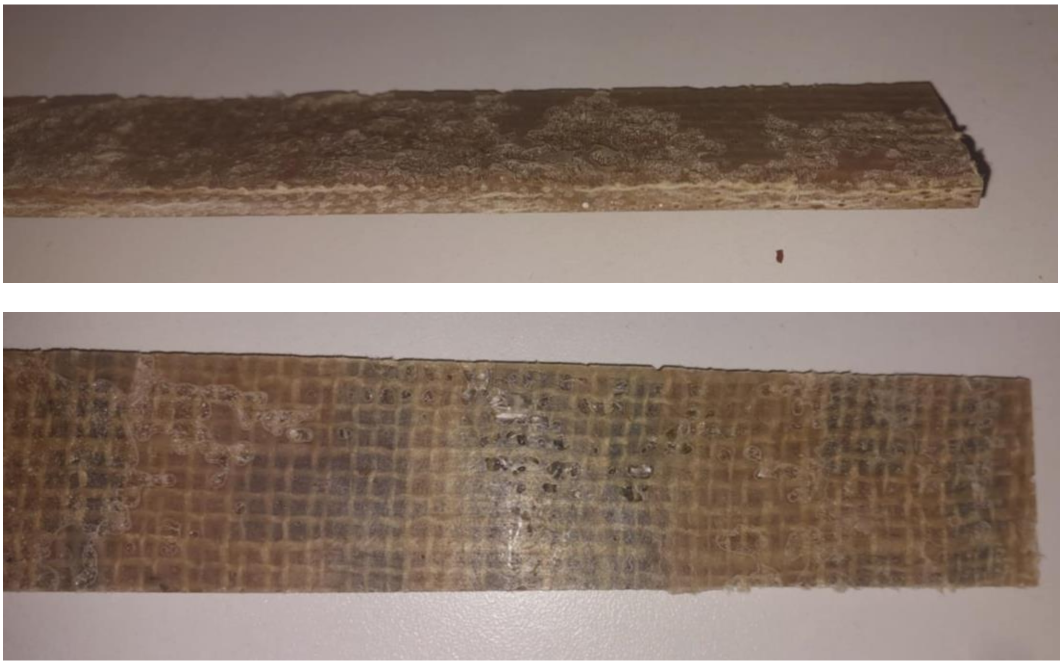


Figure 2.2: specimen with shape defects.

Also, for glass chopped strand mat 300, we need (2-2.5)*X for each X gram.

2.4 Specimen Geometry and Testing Standards:

The specimens were designed according to ASTM standards for mechanical testing:

- Tensile Test: ASTM D3039, which specifies the procedure for determining tensile properties of composite materials.[20]

2.4.1 ASTM D3039:

ASTM D3039 should be followed when testing lightweight materials specifically designed for applications such as automotive and aircraft components. This standard applies only to polymeric composites reinforced with short fibers or particles. When using ASTM D3039 for testing and writing a scientific paper on the subject, it is essential to discuss tensile strength and tensile modulus parameters. However, details of elongation are optional, as short fiber or particle reinforcements do not cause significant differences in elongation compared to the matrix material. This differs from long fiber reinforced composites, which are evaluated under ASTM D638. However, if a researcher observes significant differences in elongation due to new material compositions or higher reinforcement ratios, these results may be briefly discussed. The shape of the test specimen under ASTM D3039 must be perfectly rectangular. A dogbone shape is not preferred, as narrowing during elongation is not the primary focus of this test method. Since ASTM D3039 is application-oriented, it does not require a standard length, which simplifies sample preparation. Additionally, forming a dogbone-shaped sample can be challenging for materials processed by methods other than injection molding.

In most references, test specimens are typically manufactured according to ASTM D3039 with an overall length of 250 mm. The mechanical load applied during testing should range from 30 to 50 kN for glass fiber-reinforced polymers and natural fibers.[21]

Specimen Dimensions

- Tensile Test Specimens:
    - Length: 250 mm
    - Width: 25 mm
    - Thickness: 2.6-6.5 mm

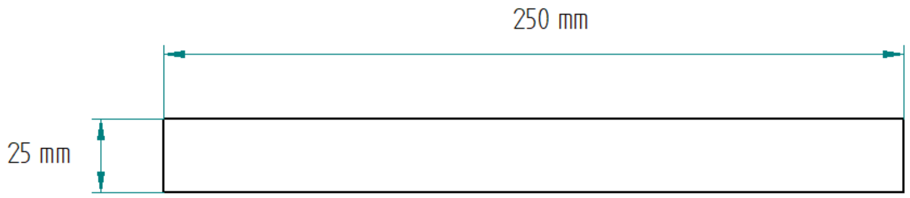
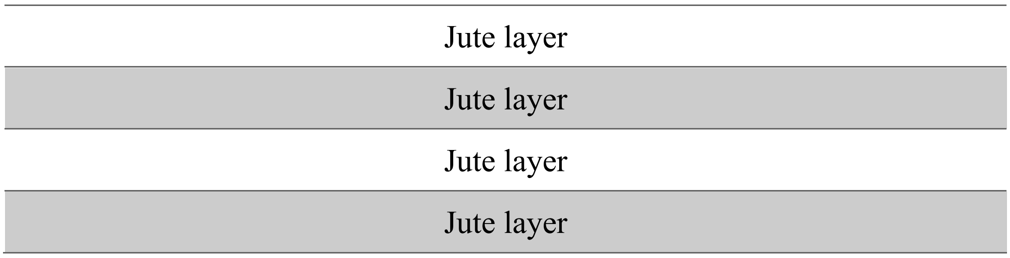


Figure 2.3: ASTM D3039.

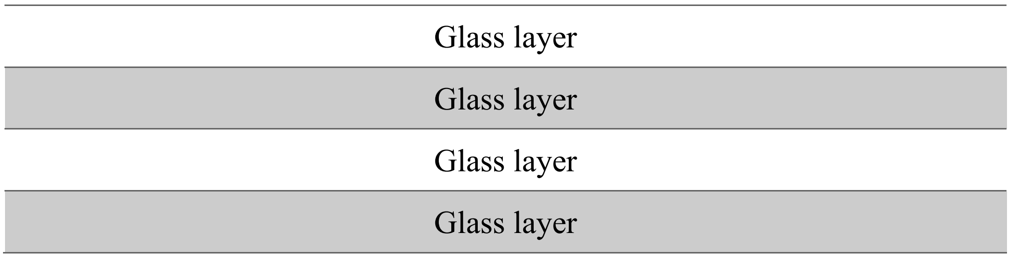
2.5 Specimen to be Tested:

Here are the schematic representation of composite for each one. The first (Jute/Resin) and the second one (glass chopped strand mat 300/Resin) we take both as reference to compare the final results and see how much we improve Jute/Resin by adding some natural/synthetic additive. Also we need to mention that For accurate comparison, the fiber volume fraction $V_f 35\%$ remain consistent across all samples. Otherwise, variations in the amount of fiber vs. matrix may lead to misleading conclusions.

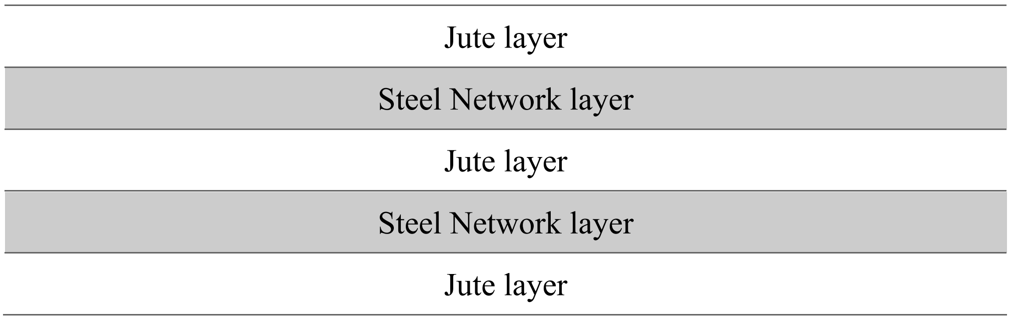
Jute + R



Glass + R



Jute + Steel Networks + R



Jute + Glass + R

Glass layer
Jute layer
Jute layer
Glass layer

Jute + Barite + R

Here, barite mixes with the matrix (Resin)

Jute layer
Jute layer
Jute layer
Jute layer

Jute + Spablo + R

Jute layer
Jute layer
Spablo layer
Jute layer
Jute layer

Jute + Spablo + R

Jute layer
Spablo layer
Jute layer
Spablo layer
Jute layer

Table 2.2: Expectation From the experience.[18][19]

Sample Code	Composition	Expected Improvement
Jute + R (Reference)	Jute fiber + Resin (Matrix)	Baseline (Reference)
Glass + R (Reference)	glass mat + Resin (Matrix)	Baseline (Reference)
Jute + Glass + R	Jute fiber + glass mat + Resin	Strength, toughness
Jute + Steel Networks + R	Jute fiber + Steel Network + Resin	Toughness, plastic region
Jute + Barite + R	Jute fiber + Resin with Barite	Hardness increase High-temperature resistance
Jute + Spablo + R	Jute fiber + Spablo + Resin	Strength

CHAPTER 3

Specimens Manufacturing

3.1 Introduction:

This chapter describes fabrication processes of composite specimens for tensile testing. It includes the selection of materials, the hand lay-up fabrication method, and the preparation of test samples according to ASTM D3039 guidelines for tensile testing of polymer matrix composites.

This chapter starts with explaining the reinforcement materials and matrix resins available to form different stacking sequences. These are natural and synthetic fibers, metallic meshes, and particulate fillers.

The hand lay-up method is described in detail starting from the mold preparation up to curing of the composite which includes resin mixing and fiber placement. Lastly, it details the process of trimming and shaping the cured laminates into standardized test specimens while ensuring compliance with ASTM D3039.Adhering to such procedures in the specimen preparation aimed at ensuring all samples achieved consistency in dimensions and surface finish to guarantee the reliability of the mechanical tests performed in the following chapter.

3.2 Fabrication Process:

The composite specimens were prepared with a polyester resin matrix using the hand lay-up method. Different reinforcements were added to evaluate the mechanical properties of the composites. The materials used are: A natural fiber added to study the effect of jute in hybrid combinations

3.2.1 Matrix :

- Polyester Resin: An unsaturated polyester resin was chosen for its user-friendly handling, cost-effectiveness, and rapid curing properties.

Figure 3.1: Polyester resin.

3.2.2 Reinforcements:

- **Jute Fiber**: A natural fiber selected for its decent tensile strength and environmentally friendly nature, offering the added benefit of biodegradability**.**.

Figure 3.2: Jute.

- **Glass chopped strand mat 300:**

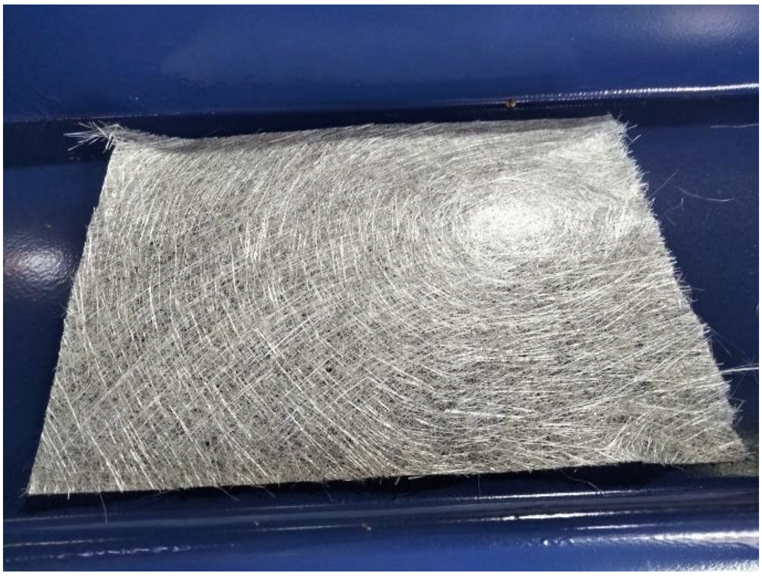


Figure 3.3: glass fiber chopped strand mat 300.

- **Steel Mesh:** A fine steel mesh incorporated to improve overall strength and boost resistance to impact loads.
- **Spablo Fiber:** A natural fiber was incorporated to study its effect with jute in composites hybridized structures.

Catalyst/Accelerator :

Figure 3.4: catalyst and initiator.

3.2.3 Resin Mixing and Dosage Process (Standard Method):

The polyester resin TP100, manufactured by FIPEXPLAST, was employed for the composite test samples. TP100 was cured using a two-step process consisting of the addition of accelerator NL-49P and catalyst RP-50. As per the manufacturer's guidelines, the resin is divided into two equal portions:

•Each half is processed separately. One half is handled by adding 0.4% NL-49P (i.e., 0.4 g per 100 g of resin). It is preferable to prepare this half first, since NL-49P does not require curing on its own. This allows the resin to be safely stored for a limited time.

•The second half is catalyzed with 3% RP-50 catalyst (i.e., 3 g per 100 g of resin).

After both halves are prepared, they are combined in equal proportions to initiate curing. This approach is especially useful in manual temperature controlled environments for temperature controlled hand lay-up procedures.

Always begin by preparing the accelerated resin first. It is advisable not to combine the catalyst and the accelerator directly. Blend both resin portions only when you are set to apply them.

Table 3.1: Standard Resin Dosage Table.

Mixture Part	Resin (g)	Accelerator (g)	Catalyst (g)	Function
Accelerated Resin	100	0.4	–	Prepare with accelerator
Catalyzed Resin	100	–	3.0	Prepare with catalyst
Final Mix	200	0.4	3.0	Mix both to start curing

3.2.4 Equipment and Tools:

In order to maintain precision and uniformity throughout the fabrication process, the following materials and tools were used:

Flat rectangular **metal mold** (with mold release agent)

Figure 3.5: release agent and mold.

Digital Balance: Ensures the resin and catalyst/initiator ratios are within prescribed limits of ±0.0005g.

Brushes and Rollers: Apply the resin on fiber layers during the hand lay-up process.

Gloves and mixing cups: Safety and preparatory items associated with handling and mixing materials, in this case, resin components.

Weights: Used to compress the composite lay-up and maintain good fiber-resin contact and uniform thickness during curing.

Curing Environment: Specimens were cured in ambient room temperature conditions of about 25–30°C. This temperature range is suitable for solidifying the resin without the use of hot curing process.

3.3 Hand Lay-Up Fabrication Process:

The composite specimens were fabricated manually using the hand lay-up method. Below are the major steps

Mold and resin Preparation:

A release agent was applied to the mold surface, which was then thoroughly scrubbed to make certain that all metal residues were eliminated. This step was crucial for removing the laminate without any issues post-curing. Even pressure was applied while curing the specimens so that the laminate would be of uniform thickness.

Figure 3.6: mold and resin preparation.

Resin Application and Reinforcement Layering:

Each reinforcement layer was added into the mold as per its assigned stacking order. A brush was used to apply resin evenly to the surface so that all of the fibers or fillers would soak up the resin fully.

Stacking Sequences for Specimens: The following stacking configurations were fabricated:

- **J/J/J/J:** Pure jute fiber composite with four plies (used as reference)
- **G/G/G/G:** Pure glass fiber composite with four plies (used as reference)
- **G/J/J/G:** Hybrid composite with glass fiber on the outer layers and jute in the core
- **J/Steel-mesh/J/Steel-mesh/J:** Alternating layers of jute and steel
- **J/J/Spablo/J/J:** Hybrid composite incorporating spablo fiber layer with jute
- **J/Spablo/J/Spablo/J:** Hybrid composite incorporating two spablo fiber layers with jute

Compaction and Air Removal: Upon completion of the final layer, a flat plate was placed on top of the stack and light weights were utilized to compact the laminate. This step is important for improving fiber-resin bonding as well as reducing porosity.

Curing: The temperature was kept at room temperature for curing (25–30°C) for 24 hours. No post-curing in an oven was done which represents a low cost, realistic manufacturing scenario.

Demolding and Finishing: The laminates were carefully removed from the molds while maintaining the edges to ensure all specimens checked were as per standards, and no other surface treatment was done before the tests were carried out.

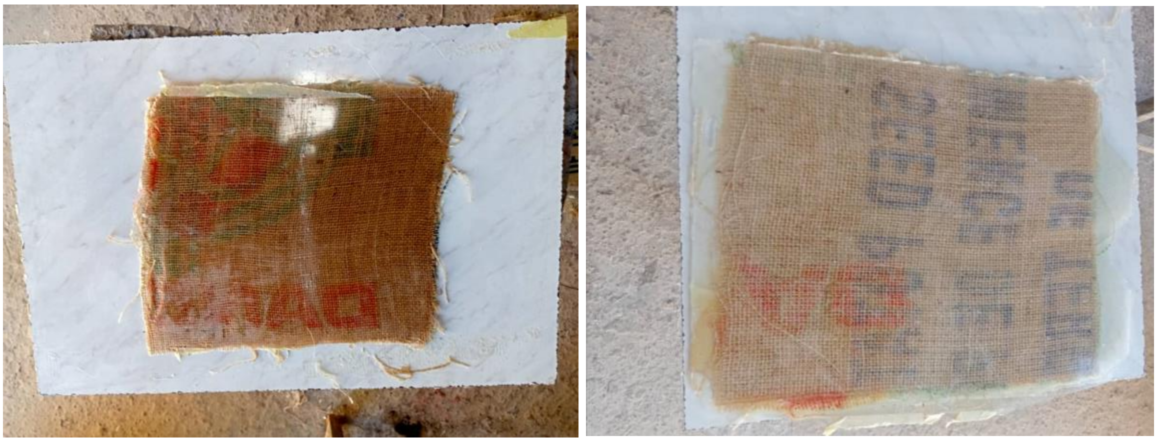


Figure 3.7: composite materials samples.

3.3.1 Specimen Preparation for Tensile Testing:

After the composite laminates were cured, they prepared aligned specimens underspecified steps for tensile testing according to ASTM D3039:

Cutting: Using a mechanical cutter or saw, each laminate was turned into strips measuring 250 mm × 25 mm.

Surface Finishing: Edges were rounded off to prevent line deviations that would impact accuracy.

Labeling: Each specimen was distinctly marked with a stacking sequence to facilitate identification during testing.

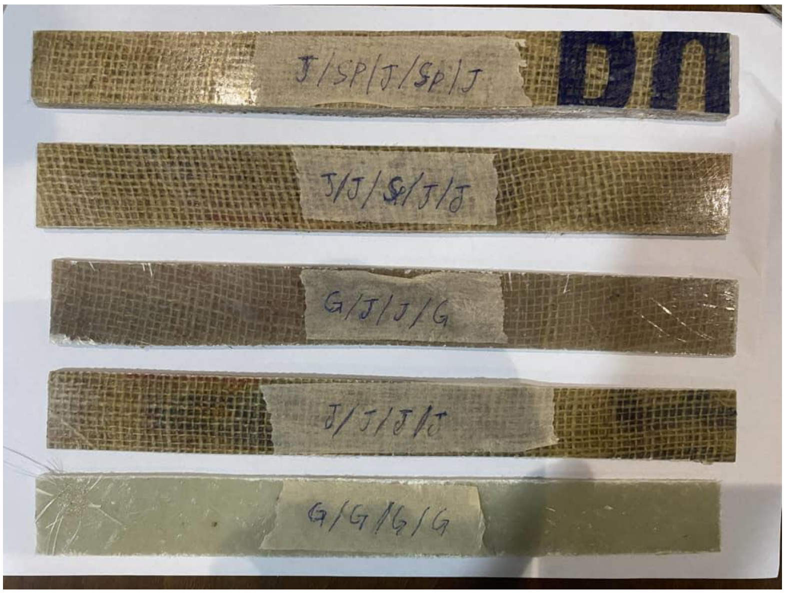


Figure 3.8: composite materials specimens.

3.4 Conclusion

This chapter gave a comprehensive description of how the composite tensile specimens have been prepared and fabricated. Different types of reinforcement were combined with polyester resin to yield five different stacking configurations using the hand lay-up technique, which included natural fibers, synthetic fibres, steel mesh, and even particulate fillers. This facilitated the investigation of both pure and hybrid composites. Each laminate was assembled, compressed, and cured at room temperature, then cut and polished to ASTM D3039 specifications. The standardized specimens are essential for the mechanical tests performed in the next chapter, which will provide valuable insights. The reinforced composites that result from the processes detailed above along with the different types of reinforcements and sequences will be crucial to understanding the tensile strength of the composites.

CHAPTER 4

Results and Discussions

4.1 Introduction

Mechanical testing of composites is crucial for the understanding of the behavior of composites under load and the appropriate use of composites. In chapter 4, the tensile properties of all composites are analysed in full:

Glass Chopped strand mat/polyester**,** Jute/polyester**,** Jute/glass chopped strand mat/polyester(hybrid)**,** Jute/spablo (1 layer)**,** Jute/spablo (2 layer)**,** Jute/steel network**,**

Jute/barite (3%)/polyester

This chapter in detail displays stress curves and failure behavior, along with the main mechanical properties of tested composite materials that include tension, Young's modulus and elongation when breaking. this chapter compare materials and highlight the improvement gained. We should mention that WP 310 gunt was the tensile test machine used:

Figure 4.1: tensile test machine.

4.2 Comparative Tensile Test Analysis

4.2.1 Stress-Strain Curves :

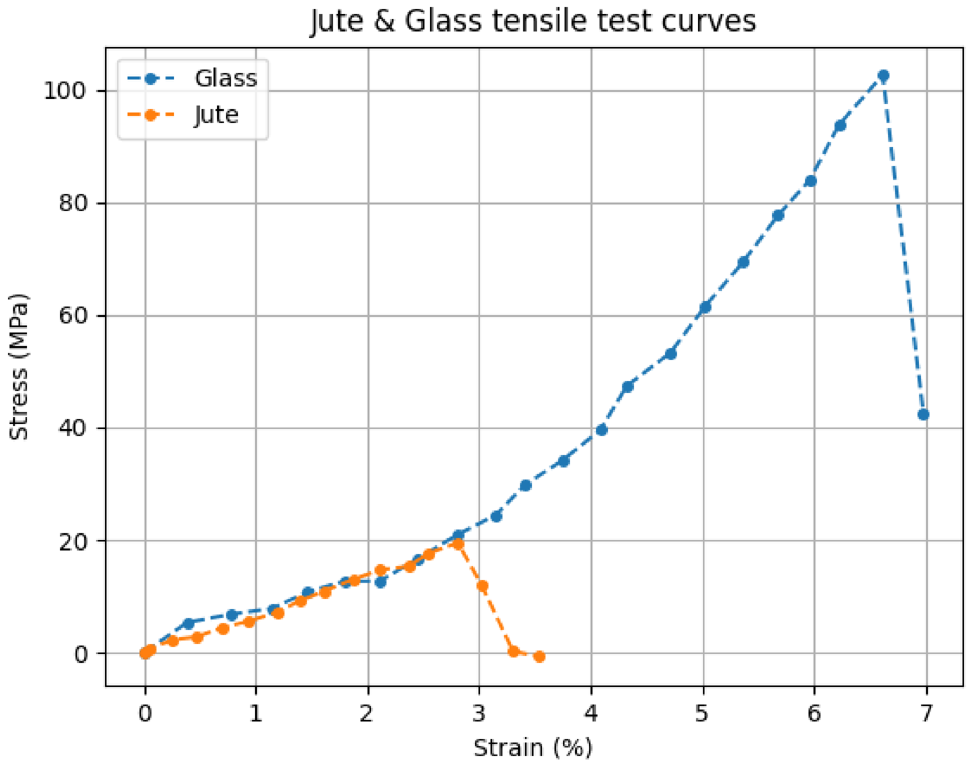


Figure 4.2: Different tensile test curves.

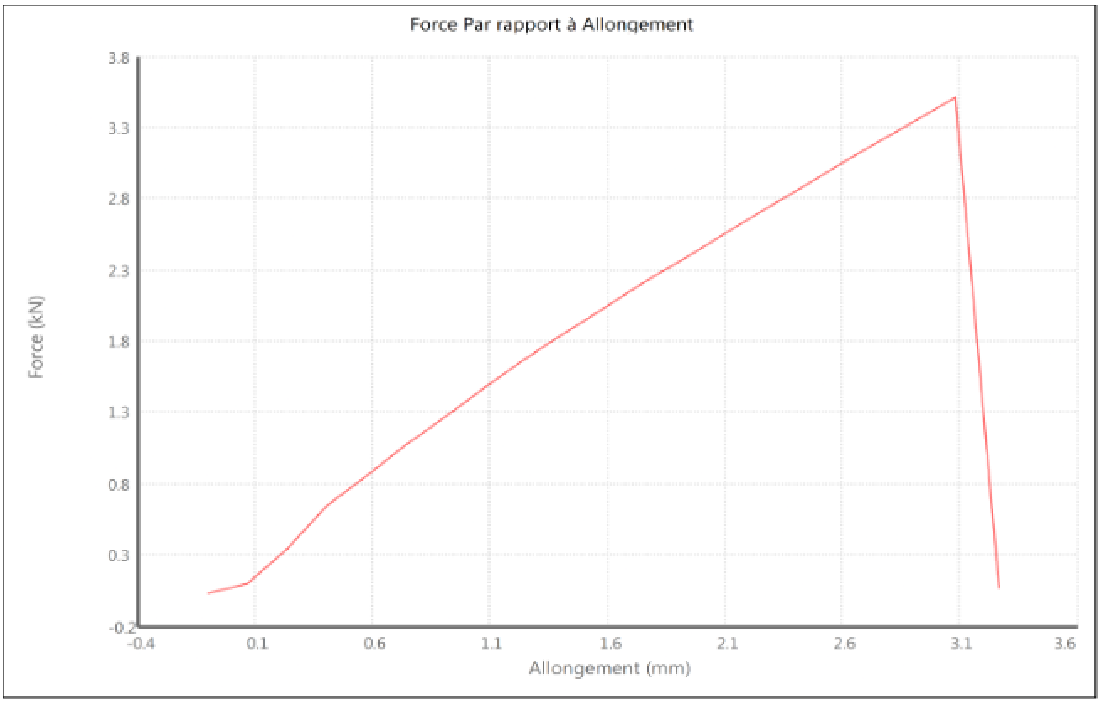


Figure 4.3: tensile test curve of J/J/Sp/J/J.

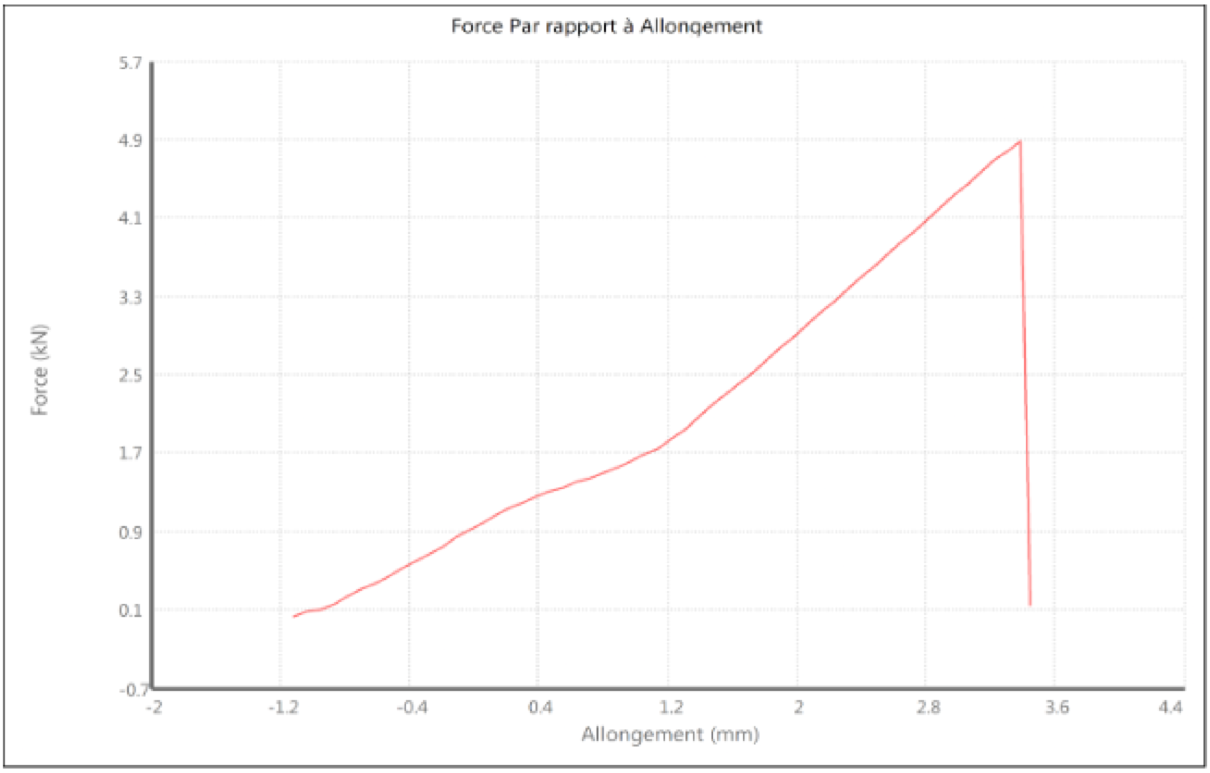


Figure 4.4: tensile test curve for J/Sp/J/Sp/J.

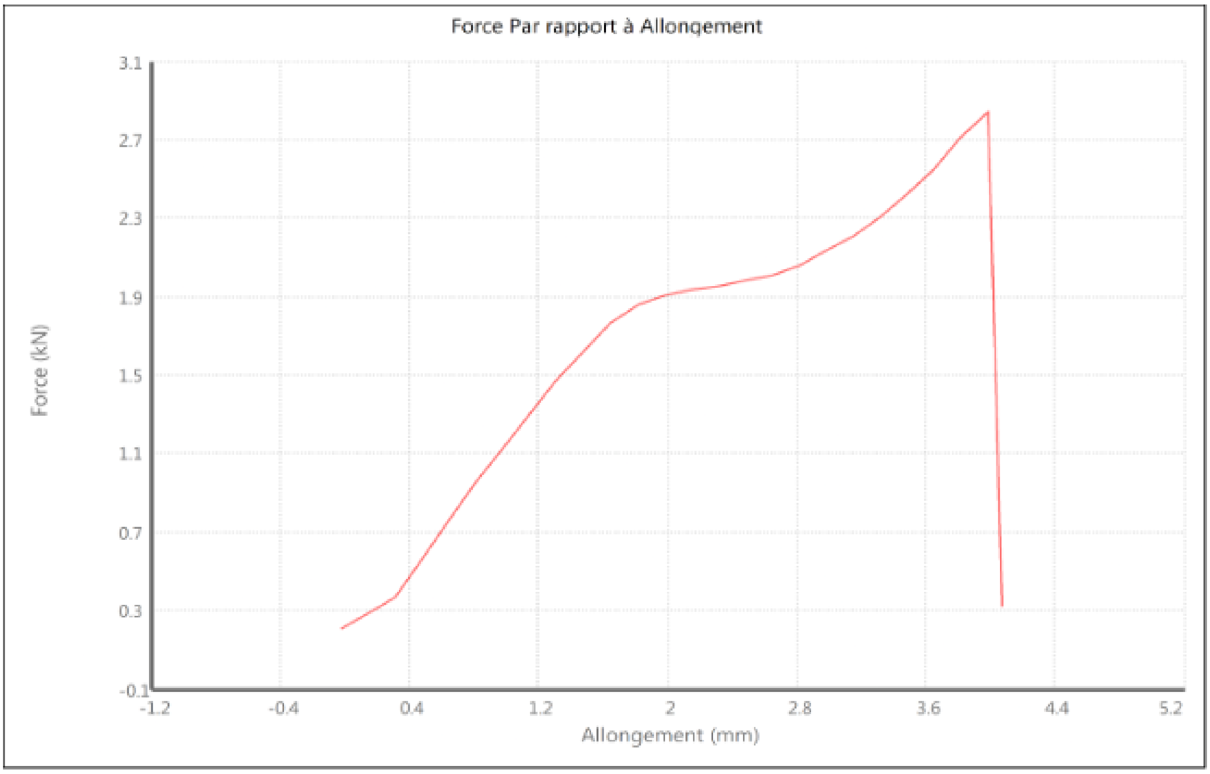


Figure 4.5: tensile test curve of J/S-network/J/S-network/J.

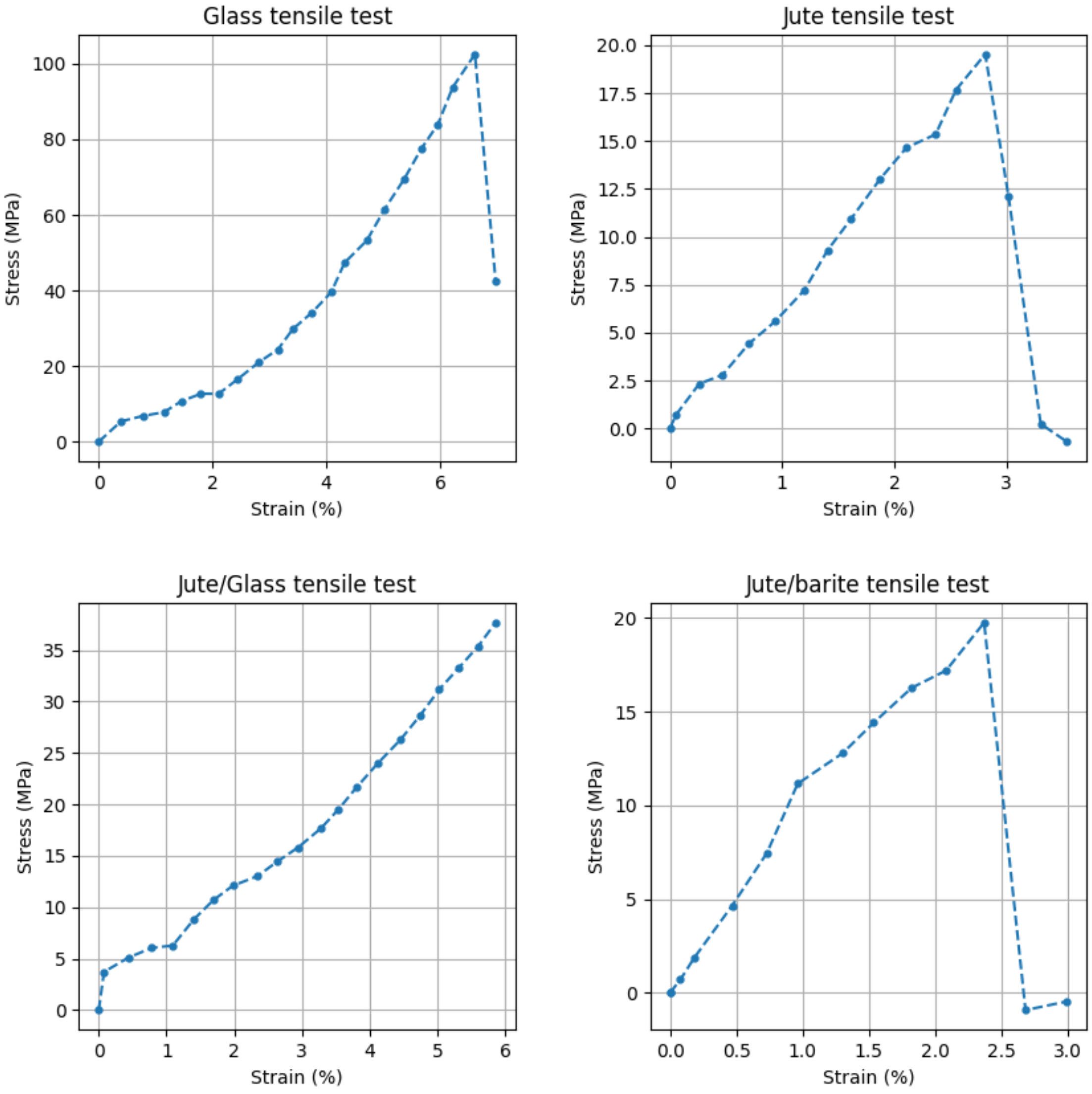


Figure 4.6: stress-strain curves.

4.2.2 Results Analysis and Discussion:

4.2.2.1 Glass Tensile Test

The tensile behavior of the glass chopped strand mat composite is characterized by a linear elastic response up to approximately **6.6% strain**, followed by brittle failure. The composite reached a **maximum tensile strength of approximately 102.54 MPa**, which is designated as **100%**, serving as the reference for comparative analysis. This high tensile strength, combined with brittle fracture behavior, is typical for glass fiber composites, making them ideal for structural applications where stiffness and strength are the primary design criteria. Practical applications include automotive body panels, boats …etc where high load-bearing capacity and dimensional stability are essential despite the risk of sudden brittle failure under overload

4.2.2.2 .Jute Tensile Test (≈19.0% of Reference UTS)

The tensile test of the pure jute composite displayed significantly different behavior from the reference material, characterized by a lower tensile strength of approximately **19.53 MPa**, corresponding to around **19.0%** of the reference glass composite's UTS. Unlike the brittle fracture of glass, the jute composite exhibited a more gradual, ductile failure. This lower strength reflects the inherent limitations of natural fibers in high-load structural contexts, but the material's flexibility make it suitable for different application areas. Pure jute composites are well suited for automotive interior panels and non-critical structural elements in eco-friendly product designs, where moderate mechanical properties combined with sustainability are key priorities.

4.2.2.3 Jute/Glass Hybrid Tensile Test (≈36.7% of Reference UTS)

The hybrid composite combining jute with glass fibers showed intermediate mechanical behavior, successfully balancing the ductility of jute with the stiffness of glass fibers. The material reached an **ultimate tensile strength of approximately 37.67 MPa**, representing about **36.7%** of the reference UTS. While considerably lower than the pure glass reference, this hybrid strength is nearly **double** that of pure jute, clearly demonstrating the positive effect of hybridization. The failure was more gradual than that of the glass composite, highlighting improved damage tolerance and making the hybrid composite a strong candidate for semi-structural applications. Potential uses include internal automotive parts such as trunk floors and roof panels, where a balance of strength, toughness, cost efficiency, and environmental impact is desirable.

4.2.2.4 Jute/Barite Tensile Test (≈19.3% of Reference UTS)

The composite combining jute with barite filler achieved a **maximum tensile strength of approximately 19.76 MPa**, corresponding to **19.3%** of the reference UTS, slightly higher than that of the pure jute composite. While the tensile behavior was initially similar to jute, the composite exhibited a sharper, more brittle failure following peak stress, with **early failure** attributed to stress concentration effects caused by the rigid barite particles. Despite these defects, this compound composition may still be suitable for specialized applications where mechanical performance is secondary for functional properties such as decorative elements requiring additional mass or fire resistance

4.2.2.5 Tensile test of Jute-Pablou Hybrid Composite (≈380.5% OF UTS of Reference)

Tensile response of the **Jute-Spablo** hybrid composite is linear elastic up to sudden failure in most instances of less ductile to non- ductile manner. The force-displacement plot is sharply and steadily increased, and then it reaches the **maximum tensile strength of 390.2 MPa**, which is equal to **380.5%** of the UTS of the reference UTS of the glass chopped strand mat composite (102.54 MPa). This higher strength is a testament to the dominant role of the Spablo layer in the middle of the laminate, which significantly reinforces the softer jute outer plies. The failure occurred at **12.3% strain** (or 3.08 mm elongation).

4.2.2.6 Tensile Test of Jute/Splabo Hybrid Composite (≈241% of Reference UTS):

The specific shape of the tensile curve of the hybrid composite alternative J/sp/J/sp/J (jute/splabo hybrid) clearly indicates a well-defined linear elastic region. followed by strain **6.78%** of the region with a rapid failure until maximum load is reached. This composite achieved **highest tensile strength of 246.8MPa**, being approximately **241%** of the UTS of reference glass chopped strand mat composite (102.54MPa). This signifcant improvement in tensile strength confirms the **reinforcing effect of the Splabo layers.**

4.2.2.7 Jute/Steel-network Composite Tensile Test (≈256.3% of Reference UTS)

A specimen featuring a hybrid arrangement of jute/steel mesh/jute/steel mesh/jute, subjected to tensile testing. The results highlight how its layered construction achieves a certain balance between ductility and overall strength. The maximum tensile strength recorded was **262.8 MPa**. This is a considerable figure; in fact, it's about **256.3%** higher than the 102.54 MPa we see in a reference glass composite. The hybrid showed a significant capacity to bear loads. Furthermore, the strain measured at the point of failure was **15.93%,** suggesting good deformation capabilities before that failure.

Table 4.1: Key Mechanical Properties

Material	Max Stress (MPa)	Max Force (kN)	Failure Strain (%)	Young's Modulus (GPa)
Glass/Polyester	**102.54**	**5.127**	**6.61**	**3.1**
Jute/Polyester	**19.53**	**2.051**	**3.02**	**0.9**
Jute/Glass/Polyester	**37.67**	**3.955**	**5.86**	**1.8**
Jute/Barite/Polyester	**19.76**	**2.075**	**2.37**	**1.2**
Jute/Spablo/Jute Hybrid	**390.2**	**3.512**	**12.32**	**4.0**
Jute/Steel-Network Hybrid (JSS)	**262.8**	**2.839**	**15.93**	**2.4**

$\sigma = E\varepsilon \rightarrow E = \frac{\sigma}{\varepsilon}$ Following this equation can calculate Young’s Modulus

Where:

σ: $Stress$, ε: $Strain$

For particulate-reinforced composites such as jute/barite, optimizing particle size and improving dispersion are critical to enhancing mechanical performance. In parallel, modifying the polymer matrix itself can offer substantial improvements. Using hybrid resin systems such as blending polyester with toughening agents or partially substituting it with epoxy can significantly increase both tensile strength and fracture toughness. Additionally, refining the architecture of fiber reinforcements through optimized fiber orientations and stacking sequences, such as cross-ply or angle-ply laminations, provides further potential for mechanical enhancement.

4.3 Conclusion:

Through experiments we see that glass is not the only reinforcement that gives good results. As we have seen, we were able to strengthen J/J/J/J through other natural materials. We obtained a good UTS by adding Spablo. We also saw an increase in hardness as a result of adding Barite, which shows that it has an effective role in improving the mechanical properties of composite materials. Also, by adding steel shell, we can conclude that it is possible to add a Plastic Part by adding reinforcement that has this property. It may not have appeared well in tensile test curve (Figure 4.5), and this is due to the nature of the metal used.

Improving the mechanical properties of composite materials is not always by adding Reinforcement or increasing fiber volume fraction. Compare J/J/Sp/J/J and J/Sp/J/Sp/J, we see that adding one layer of Sp gave a higher UTS than adding two layers of Sp. One of the reasons that led to this result is that the relationship between the matrix and the reinforcement is weak. Adding another layer of Sp did not provide a good interface region (weak bonds) which led to increase in void content. Despite the encouraging performance demonstrated by the studied composites, there are still many opportunities for improvement. Optimization of the matrix system itself is recommended. While polyester resin exhibits good mechanical properties and is cost-effective, blending it with tougher resins can enhance ductility and fracture resistance, providing a better balance between strength and toughness. For fiber-reinforced composites, surface modification of natural jute fibers or chemical treatments improve fiber-to-matrix adhesion, which is critical. Hybrid composites, particularly those combining glass and jute, have demonstrated a clear advantage in mechanical performance, but optimizing stacking sequences and fiber orientations could open up even more possibilities. Strategically distributing stronger fibers in areas of higher expected stress, or using woven structures, could enhance tensile strength and toughness.

In conclusion, while current composite systems have mechanical properties that make them suitable for a wide range of applications, these composites, by incorporating improved dispersion techniques, matrix modifications, fiber processing, and hybrid reinforcement designs, can evolve into high-performance, lightweight, and environmentally friendly alternatives that meet the needs of modern engineering. To enhance the practicality of these composites, future efforts should focus on improving fiber-matrix interactions.

General Conclusion

Natural fibers are increasingly appreciated for various industrial and emerging applications and are considered a sustainable alternative to synthetic fibers due to their availability at lower cost, cultivability, and environmentally friendly nature. Additionally, natural fiber composites often exhibit superior physical, chemical, and mechanical properties. It is noteworthy that composite technology is one of the advanced materials used in modern industries for its high mechanical strength and resistance.

Furthermore, natural fibers are emerging as competitive materials, capable of rivaling glass fiber and carbon fiber in mechanical industries, especially when used in combination with other fibers.

The aim of this project is to study the hybridization effects of glass fibers and metal networks on natural fibers to enhance their mechanical properties. The composite laminates were fabricated using the hand lay-up technique.

Tests were conducted to evaluate the physical and mechanical behavior of three types of composites. The results indicate that natural fiber composites can be effectively used in the mechanical repair of pipelines with small defects or localized damage. Based on the findings, it can be concluded that this project provides valuable insights into the use of natural jute fiber reinforced with metal wires as patches for repairing corroded mechanical systems such as piping.

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