PRODUCT DEVELOPMENT OF STOOL USING NATURAL FIBER COMPOSITE

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PROJECT WORK

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

ABSTRACT

The study of materials explores the development of a sustainable and eco-friendly stool utilizing natural fiber composite materials. With the growing concern for environmental sustainability and the need for alternative materials, natural fibers offer a promising solution due to their renewable and biodegradable nature. The research investigates the mechanical properties, durability, and aesthetic appeal of natural fiber composites in comparison to traditional materials used in stool production. Through a combination of material testing, design iterations, and manufacturing processes, a prototype stool is developed, aiming to meet both functional and aesthetic requirements while minimizing environmental impact. The study also considers the feasibility of large-scale production and potential market acceptance of natural fiber composite stools. The findings contribute to the advancement of sustainable product design and provide insights into the utilization of natural materials in furniture manufacturing, fostering a more environmentally conscious approach to product development.

Keywords: Product Development, Natural Fiber Composite, Sustainability, Eco-friendly Materials, Renewable Resources, Mechanical Properties, Durability, Aesthetic Appeal, Environmental Impact, Prototype Design, Manufacturing Processes, Sustainable Product Design.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The increasing global awareness of environmental sustainability and the necessity to minimize ecological footprints have prompted industries to seek alternatives to conventional materials. This project report delves into the product development process of a stool made from natural fiber composite, an innovative material that harmoniously blends functionality with environmental consciousness. Traditional furniture manufacturing often relies on non-renewable resources, such as plastics and metals, which contribute significantly to environmental degradation. Natural fiber composites (NFCs) offer a promising alternative, utilizing renewable resources like plant fibers embedded in a biodegradable or recyclable matrix. These materials not only reduce the reliance on finite resources but also offer unique aesthetic and mechanical properties that can be tailored for specific applications. The primary objective of this project is to design, develop, and evaluate a stool constructed from natural fiber composite materials. This endeavor aims to create a product that is not only environmentally sustainable but also meets the functional and aesthetic standards of modern furniture. The development of a stool using Agave Americana fiber represents a pioneering approach in the realm of sustainable furniture design. Agave Americana, commonly known as century plant, is a versatile and robust natural fiber source. This project leverages its unique properties to create an eco-friendly, durable, and aesthetically pleasing stool. Fiber stools made with agave americana fiber could hold significance for society in a few ways. Firstly, agave americana is a renewable resource, making the stools a more sustainable furniture option compared to those using traditional materials. Additionally, these stools could offer a unique aesthetic, incorporating the natural texture of the agave fibers. Furthermore, depending on the chosen matrix, the stools could be lightweight and strong, making them suitable for various uses. Overall, agave americana fiber stools could represent a blend of eco-friendliness, design appeal, and functionality, potentially carving a niche in the furniture market.

The manufacturing process of fiber stools can be done through various new technologies, but here in our project we have done through hand molding. It breathes life into fiber stools, transforming raw materials into functional furniture through a meticulous, artisanal process. Here, skilled crafters layer the chosen natural fibers, like agave americana, with a resin binder, all within a pre-built mold. This hands-on approach allows for customization of each stool, ensuring no two are exactly alike. While time-consuming compared to mass production, hand molding offers a unique opportunity to express design intent through the visible fiber textures and potentially even colored resins, imbuing each stool with a personal touch and a connection to the maker's skill.

In summary, The project focuses on the development of a stool made from natural fiber composite, a sustainable material that combines functionality with environmental consciousness. Traditional furniture manufacturing often uses non-renewable resources like plastics and metals, contributing to environmental degradation. Natural fiber composites (NFCs) offer a promising alternative, utilizing plant fibers embedded in a biodegradable or recyclable matrix. This project aims to design, develop, and evaluate a stool made from Agave Americana fiber, a versatile and robust natural fiber source. The stool is designed to be eco-friendly, durable, and aesthetically pleasing, offering a unique aesthetic and being lightweight and strong depending on the chosen matrix. The manufacturing process of fiber stools is done through hand molding, a meticulous, artisanal process where skilled crafters layer natural fibers with a resin binder within a pre-built mold. This hands-on approach allows for customization of each stool, ensuring no two are exactly alike. Hand molding offers a unique opportunity to express design intent through visible fiber textures and potentially colored resins, imbuing each stool with a personal touch and connection to the maker's skill.

1.2. Benefits of Fiber Stools

Sustainability: Agave Americana is a renewable resource, making the stools a more eco-friendly choice compared to furniture using traditional materials like plastics or metals.

Durability: Agave Americana fibers are known for their strength and resilience, potentially creating stools that can last for a long time.

Unique Aesthetics: The natural texture of the agave fibers can add a distinct and visually appealing element to the stool's design.

Strength: When properly processed and combined with a suitable matrix, the agave fibers can provide surprising strength for the stool's structure.

Potential for Customization: Hand moulding, allows customization and uniqueness in the product's shape, size, design, and colored resins.

Biodegradable Matrix: The resin binder used is biodegradable, the stool can decompose naturally at the end of its lifespan.

Reduced Ecological Footprint: Reduces reliance on non-renewable resources like metals and plastics, leading to a lower environmental impact during production. It mainly reduces carbon emissions to the environment.

CHAPTER 2

DESIGN THINIKING

The furniture industry, a constant dance between style and function, grapples with the environmental impact of traditional materials. Reliance on non-renewable resources like metals and plastics has spurred designers and manufacturers to seek sustainable alternatives. Natural fiber composites (NFCs) have emerged as a promising solution, and design thinking offers a human-centered approach to harness their potential. This methodology, emphasizing empathy, creative exploration, and iterative refinement, guides us in creating a stool that is not only environmentally responsible but also meets the needs of modern users.

This project utilizes design thinking to develop a stool crafted from natural fibers. We begin by understanding user needs through surveys and focus groups, identifying their desired functionality, aesthetics, and level of environmental consciousness. Next, brainstorming unlocks a plethora of design ideas, exploring stool shape, fiber integration methods, and sustainable matrix options. Prototypes, constructed from readily available materials, are then created and tested with users, allowing for iterative refinement of comfort, aesthetics, and environmental impact. Finally, considering factors like production scale and user preferences for customization, we choose a manufacturing process that adheres to the principles of sustainability, bringing the eco-friendly and user-centric stool to life. This design thinking approach ensures the final product not only meets user needs but also embodies environmental responsibility, creating a stool that's both beautiful and sustainable.

This project delves into the application of design thinking in developing a sustainable Agave Americana fiber stool. The process begins with empathy. Through surveys, focus groups, and observational studies, we delve into the target user's world. Understanding their requirements allows for a tailored design is an important part of design thinking process.

Once a range of ideas is established, we move on to creating prototypes. These low-fidelity models allow for quick iteration and testing with users. The prototypes are evaluated for functionality, aesthetics, and sustainability based on user feedback. This iterative process allows us to refine the design until it effectively balances user needs, aesthetics, and environmental responsibility.

With a well-tested and refined design, we can move towards production. The chosen manufacturing method, hand molding for instance, can showcase the natural beauty of the fibers and potentially offer customizable options, aligning with the principles established through design thinking. However, design thinking also necessitates flexibility. If large-scale production is desired, alternative methods like compression molding could be explored. The key is to ensure the chosen method upholds sustainability and aligns with the desired production scale.

By embracing design thinking, this project paves the way for the creation of a natural fiber stool that offers a compelling combination of functionality, aesthetics, and environmental responsibility. Throughout the process, user needs remain paramount, ensuring the final product resonates with the target audience and offers a stylish yet eco-conscious furniture option. The natural beauty of Agave Americana fibers, combined with their inherent sustainability, paves the way for a future of furniture that is both beautiful and responsible.

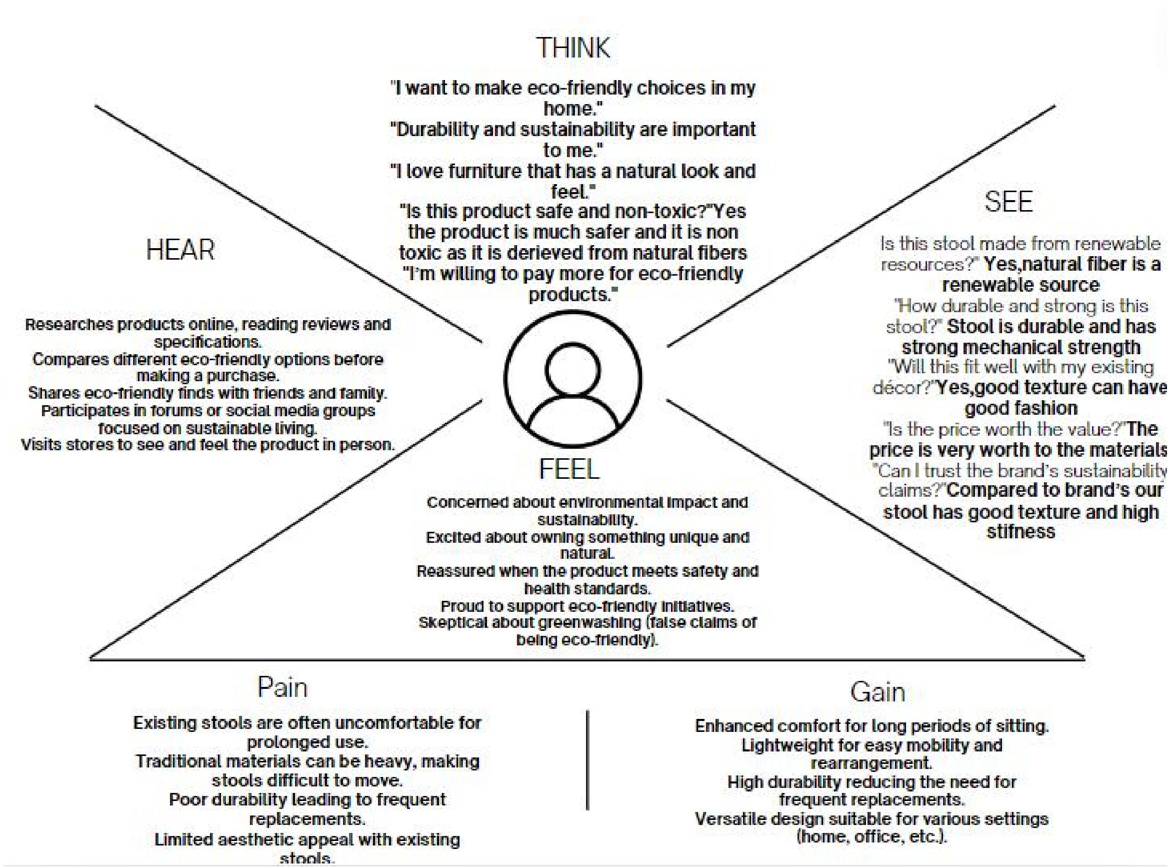

Fig 2.1 Empathy Map

CHAPTER 3

STAGES OF APPROACH

Approach 1: Understanding the Needs - Empathy in Action

The journey begins with understanding the target user. Through surveys, focus groups, and even observing how people use stools in different settings, we gain valuable insights. Who are we designing for? Are they homeowners seeking stylish additions, or do they represent commercial spaces with specific needs for durability and stackability? Understanding the target audience allows us to tailor the design. We delve into user needs, both functional and aesthetic. What are the essential functions – occasional use, long periods of sitting requiring ergonomic considerations, or a simple footrest? User preferences for aesthetics are also explored – minimalist, rustic, or a desire for the natural beauty of the fibers themselves? Perhaps most importantly, we assess user attitudes towards sustainability. Is environmental consciousness a priority for the target user? Are they open to embracing a natural fiber material? By gathering this data, we build a strong foundation for user-centric design.

Approach 2: Defining the Challenge - From Insights to Opportunity

With a clear understanding of user needs, we define the design challenge. This concise statement encapsulates the project's objective: "Design a stool made from natural fibers that is sustainable, functional, and aesthetically pleasing for [target user]." This guiding principle ensures all design decisions remain focused on user needs and environmental responsibility.

Approach 3: Ideation

Design thinking thrives on unleashing creativity. This is the brainstorming stage where we generate a multitude of ideas for the stool's design. Here, we explore the stool's shape and size, considering ergonomics and user comfort. What type of natural fibers will we utilize? Will they be woven for texture, arranged in a specific pattern for strength, or left exposed for a natural aesthetic? The resin binder, a crucial element, is carefully considered – factors like strength, water resistance, and biodegradability (if a sustainable option is desired) are all weighed.

Approach 4: Prototyping

Design thinking encourages exploration of customization options – can the design allow for variations in fiber patterns or colors to cater to individual preferences? Prototypes, often low-fidelity models, are then created. These prototypes are used to test functionality, aesthetics, and sustainability with user feedback guiding further refinement.

Approach 5: Implementation - Bringing the Stool to Life

With a well-tested and refined design, we can move towards production. The chosen method needs to be considered. For a project focused on sustainability and potentially customizable options, hand molding could be a suitable approach. However, design thinking requires flexibility, and alternative methods like compression molding or injection molding could be explored for larger-scale production. The key here is to ensure the chosen method upholds the principles of sustainability and aligns with the desired production scale.

This design thinking project fosters a sustainable stool that balances functionality, aesthetics, and environmental responsibility. Throughout the process, user needs remain paramount, ensuring the final product not only complements different environments but also resonates with the target audience's desire for eco-conscious furniture.

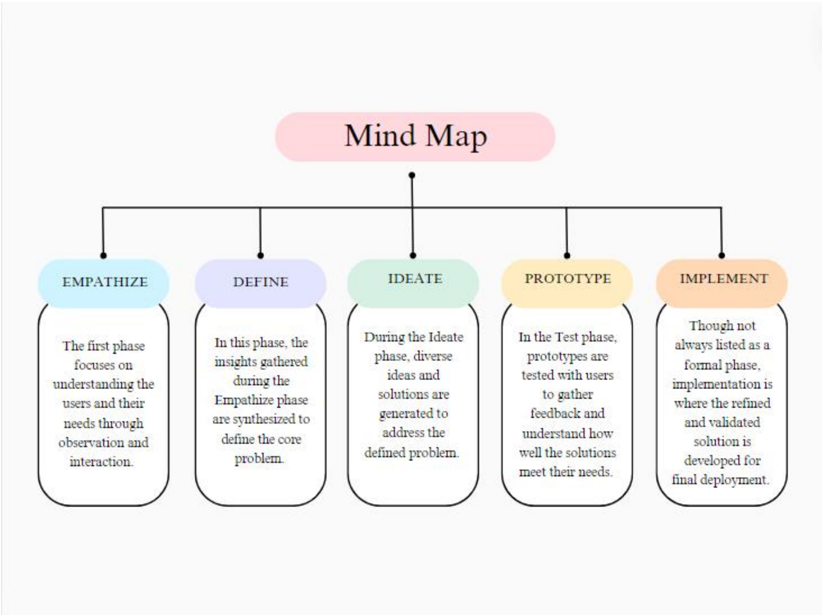

Fig 3.1 Mind Map

CHAPTER 4

PROBLEM STATEMENT

4.1 The Problem with Plastic and Metal Stools

The furniture industry sits at a crossroads. While constantly evolving in terms of design and function, it grapples with the environmental impact of traditional materials like plastic and metal. These materials, while offering certain advantages, come with a significant ecological footprint that can no longer be ignored. This section delves into the specific problems associated with plastic and metal stools, highlighting the need for a more sustainable alternative. It then explores the potential of natural fiber stools as a solution, paving the way for a future of furniture that is both stylish and environmentally responsible.

4.2 Plastic Stools Demerits

Plastic stools have become a ubiquitous presence, offering low prices, lightweight construction, and seemingly effortless maintenance. However, this convenience comes at a hidden environmental cost. The very foundation of plastic stools – fossil fuel-based production – contributes significantly to greenhouse gas emissions, intensifying climate change. Furthermore, plastic production often releases pollutants into the air and water, harming ecosystems and human health alike.

The problem doesn't end with production. The limited lifespan of cheaply made plastic stools leads to frequent replacements, creating a growing mountain of plastic waste. Disposal is a major concern. While some facilities offer plastic recycling, the process is often inefficient, and a significant portion ends up in landfills or leaks into the environment. Landfill plastic takes hundreds of years to decompose, releasing harmful chemicals into the soil and potentially contaminating water sources. Marine plastic pollution is another alarming consequence, with plastic fragments disrupting marine ecosystems and entering the food chain. The environmental cost of plastic stools extends beyond production and disposal. Dyes and other additives used in manufacturing can further contribute to environmental pollution.

4.3 Metal Stool Demerits

Metal stools have traditionally been a popular choice for their durability and aesthetic appeal. However, the environmental impact of metal production and use cannot be overlooked.

Resource Depletion: Metal production relies on the extraction of finite resources like iron, aluminum, or steel. This extraction process can be destructive to landscapes, creating deforestation and soil erosion.

Energy Consumption and Pollution: Metal refining involves significant energy consumption, often relying on fossil fuels. This contributes to greenhouse gas emissions and air pollution. Additionally, the smelting process can generate wastewater containing harmful chemicals, polluting waterways if not properly treated.

End-of-Life Concerns: While metal stools can be more durable than plastic options, they eventually reach the end of their lifespan. Discarded metal requires proper recycling to prevent environmental harm. However, recycling infrastructure can be limited, and improperly disposed-of metal ends up in landfills, taking up valuable space and potentially leaching harmful chemicals into the soil.

While metal stools offer some advantages over plastic, their environmental impact remains a significant concern. The depletion of finite resources, energy consumption, and potential for pollution necessitate exploring more sustainable alternatives for furniture design.

4.4 Alternative Solution

The limitations of plastic and metal stools, from resource depletion to pollution, necessitate a shift towards more sustainable furniture solutions. Natural fiber stools present a compelling alternative, offering a multitude of benefits that address the environmental shortcomings of traditional materials.

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CHAPTER 5

EXTRACTION OF FIBERS

5.1 Overview on Agave Americana Fiber

Synthetic fibers like aramid, glass, and carbon are commonly used in engineering composites, but they are nonrenewable and pose health risks. Natural fibers, on the other hand, are lightweight, biorenewable, and locally available, with comparable strength. However, they are primarily used in low-performance industries like automotive and construction. Understanding the micro-mechanical behavior of natural fibers is crucial for durable applications in high-performance areas like aerospace, marine, and hostile environments. Agave fibers have high variability in physico-chemical and mechanical properties, even within the same leaf. They are susceptible to variations from origin, climate, soil, leaf maturity, and extraction techniques. Technical materials' properties depend on constituent fiber characteristics. Agave fibers are hygroscopic, exhibiting high affinity towards moisture and water, which can hinder their scope, versatility, and multidisciplinary applications.

5.2 Extraction of Agave Fibers

To extract fiber, mature Agave Americana plant leaves are collected from the field. Using a sharp cutting instrument, all lower leaves that are angled more than 45° toward the vertical are removed from the plant. The leaves are taken to a factory to be processed into fiber once they are harvested. Thorns on the leaf margins and the spine at the apex of the leaf are removed prior to extraction. The techniques utilized to remove sisal fibers from plant leaves are comparable to those used to extract fibers from Agave Americana. Agave Americana, known for its spiky leaves, holds a hidden treasure within - strong, versatile fibers. Extracting these fibers involves a multi-step process. First, mature leaves are harvested, with the lower angled ones being ideal. Those nasty thorns and the tip spine are then carefully removed to prevent injury. Here, the method splits into three main paths: mechanical, chemical, and retting.

The method which is mainly used for fiber extraction is water retting. It generally involves use of microorganisms in water to break down the non-fibrous materials that bind the strong agave fibers together Water retting is a method used for fiber extraction in agave plants, where microorganisms in water break down non-fibrous materials that bind strong fibers together. Boiling is a chemical process that removes non-cellulosic material attached to fibers, releasing individual fibers. Agave atroverance plant leaves are immersed in water and boiled for 4-5 hours, softening pectinous substances that bind fiber with other plant tissues. After harvesting, flax straw is spread evenly in the field and turned over periodically. The degree of retting is evaluated organoleptically by breaking and removing woody parts of the plant stalk. The straw is collected, dried, and placed in a tank parallel to each other, flooded with water. The retting process takes 72 hours for flax and 144 hours for hemp. The straw is then rinsed and dried in a laboratory dryer at 60 C air temperature for 48-72 hours. Mechanical processing of the degummed straw is carried out using a laboratory scutching unit. Retting is the main challenge in processing bast plants for long fiber production. Traditional methods for separating long bast fibres include dew and water retting, which require 14 to 28 days to degrade pectic materials, hemicellulose, and lignin. Although water retting produces high-quality fibers, its long duration and polluted water make it less attractive.

Fig 5.1 Water Retting Process

CHAPTER 6

SURFACE TREATMENT ON FIBERS

6.1. Alkaline Treatment

Untreated, dried nettle fibers underwent surface modification by immersing them in solutions of NaOH, NaHCO3, and KOH, LiOH to induce alterations in their surface properties. The concentration of each chemical varied at 3%, 6%, and 9%,12%. The alkali solutions were meticulously prepared by blending specific quantities of NaOH, NaHCO3, and KOH,LiOH with a predetermined volume of water (100 gm).For the 3% alkali solution, 3 gm of each chemical was diluted in 100 gm of water, and a similar procedure was employed for the preparation of 6% and 9%,12% alkali solutions. The nettle fibers were immersed in each alkali solution for a duration of 8 hours, with periodic shaking to ensure uniform treatment. The nettle fiber to alkali solution ratio was maintained at 1:15.

6.2. $NaHCO_3$ Treatment

Agave Americana fibers can also be treated with sodium bicarbonate (NaHCO3), a milder alternative to harsh chemicals. Unlike water retting which relies on bacteria, NaHCO3 treatment modifies the fiber surface physically. This treatment can improve the adhesion between the agave fibers and other materials like resins. The NaHCO3 solution enhances the surface roughness of the fibers, creating a better grip for the resin to lock onto, potentially leading to stronger composite materials. This method is particularly effective at a 10% concentration, although further research is likely ongoing to optimize the process.

Fig 6.1 $NaHCO_3$ Treatment

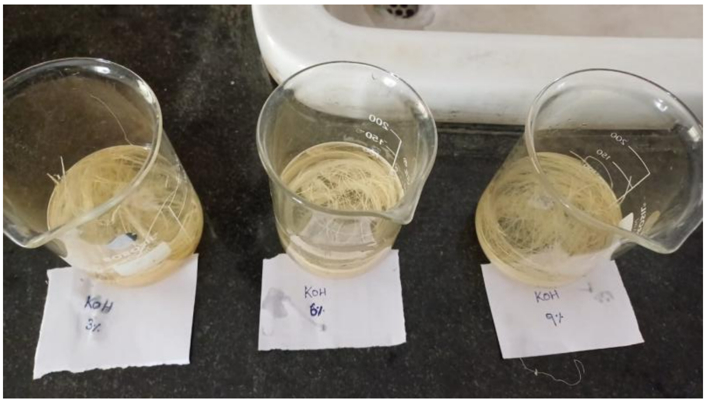

Fig 6.2 KOH Treatment

CHAPTER 7

PHYSICAL CHARACTERISTICS

7.1. Single Fiber Length

The influence of single fiber length on the effectiveness of various chemical treatments for Agave Americana fibers remains an under-explored area. Investigating the aspect ratio (length to diameter) of individual fibers could be crucial in optimizing these treatments. For instance, longer fibers might benefit more from treatments enhancing interfacial adhesion with composites due to increased surface area, while shorter fibers might require a focus on improving their individual strength for optimal reinforcement. Exploring this relationship between fiber length ratio and specific chemical treatments could lead to significant advancements in utilizing Agave Americana fibers in various industrial applications. An agave fiber sample of 10g was selected at random. The number of fibers in the consignment was counted. The length of each fiber was measured at room temperature by a metre scale with an accuracy of ±1mm. During measurement care was taken to make sure that elongation does not take place while stretching the fiber to its full length. Fibers varying in length under 100mm were grouped into one category. The shortest fiber measured was 326mm and the longest fiber was 1576mm. The length of the fiber was skewed towards the longer fibers. Maximum number of fibers were found to be in the range of 10μm to 1200mm.

7.2. Diameter

Fiber diameter significantly impacts properties like tensile strength, flexibility, and water absorption. The Agave Americana fibers appear as in bundles, which contain many ultimate fibers imperfectly held together by some sticky and waxy substances. The thickness of the fiber when determined using projection microscope, it was in the range of 10–150 μm. Agave Americana fibers are relative thick fiber as a result of the numerous cell ultimates that form the fiber bundle.

7.3. Density of Fiber

Agave Americana fibers boast a relatively large diameter compared to other natural fibers, yet they achieve a low overall density (around 1.36 grams per cubic centimeter) due to a hollow core within their oval or irregular cross-section. Agave Americana fibers boast a unique advantage in the natural fiber world: exceptionally low density. Research suggests a density range of 0.475 – 0.497 g/cc, significantly lower than other natural cellulosic fibers and even amorphous materials. This low density, despite the high crystallinity of the fibers, is attributed to the presence of cylindrical voids within the fiber structure.

7.4 Tensile Strength of Fiber

Studies suggest tensile strengths ranging from 240 to 512 MPa (Megapascals), depending on factors like fiber origin, processing methods, and fiber orientation during testing. Agave Americana fiber has a tenacity of 16-41 cN/tex and a elongation of 2%-4% at rupture, making it suitable for use in instantaneous forces during end product use. Its strength is attributed to high cellulose polymerization and crystallization processes, possibly due to years of growth. This makes it suitable for various fabrics, including furnishing fabrics, carpets, floor mats, rugs, upholstery fabrics, nonwovens, and fiber reinforced composites. However, the tensile properties of Agave Americana fiber are not uniform due to its natural growth irregularities. The outer leaf sheaths produce the strongest fibers, while the inner sheaths produce the weakest. Inner fibers have a high fracture strain, while peripheral fibers have lower tensile strength. The outermost fibers have more elongation before breaking than inner fibers, making them rigid and having low elongation. The fiber's lower elongation at break values further contribute to its versatility.

CHAPTER 8

CHEMICAL CHARACTERISTICS

8.1 Alkalization and it's importance

The process of alkalization is based on the same principle as the mercerization process for cotton fibers. The natural fibers are treated with an alkaline solution, such as NaOH, resulting in change of fiber properties . Agave fibers are composed of cellulose (68%), hemicelluloses (15%), lignin (5%), wax (0.26%), and moisture (8%). The effect of the alkali treatment on cellulose fiber is a swelling reaction during which the natural crystalline structure of the cellulose relaxes. The alkali solution influences cellulosic components within the natural fiber and moreover influences non-cellulosic components (hemicellulose, lignin, and wax content). Chemical tests were conducted with various NaOH concentrations of 5% and 10% agave fibers. The cellulose of the fiber did not affect the alkali-treated fiber but resulted in change of other chemical properties. So the alkali-treated fiber had good adhesion properties and improved strength of fiber.

8.2 Surface Morphology of Fibers

The surface morphology of raw and treated agave fibers using SEM were carried out. The microscopic image of raw fiber showed the presence of irregular cell wall features and also the presence of some extra cellular non-fibrous impurities. The alkali treatment (5%, 10%, and 15% NaOH) was found to give a uniform smoothness to the fiber surface and also to have leavened away the impurities that were found in raw fibers.

CHAPTER 9

TESTING AND VALIDATION

9.1. SEM Test Analysis

Scanning Electron Microscopy (SEM) testing plays a crucial role in analyzing the surface morphology and elemental composition of Agave Americana fibers, providing valuable insights for optimizing their utilization in various applications. By examining Agave Americana fibers with an SEM, we can observe longitudinal streaks which are characteristics of long vegetable fibers. The fiber has a composite structure. Ultimate fibers are held together by sticky and waxy substances such as lignin, pectin and hemicelluloses. The fiber surface is also covered with these substances. Due to this natural coating, Agave Americana fibers present a high resistance when they are exposed to the influence of some external factors like weak chemical agents such as acids and alkalis, as well as to UV (108 h). Agave Americana fibers occur as a technical fiber, having oval and irregular sections with a large lumen and appears as a helical structure of square shape spires. These fibers can be characterized by two parameters: the average length of a spiral side which is about 10.1µm and the average diameter which is equal to 10.1µm. The average diameter is very small compared to other natural fibers such as flax, sisal and alfa. This particular structure will be used to explain the mechanical behavior of the technical fibers .

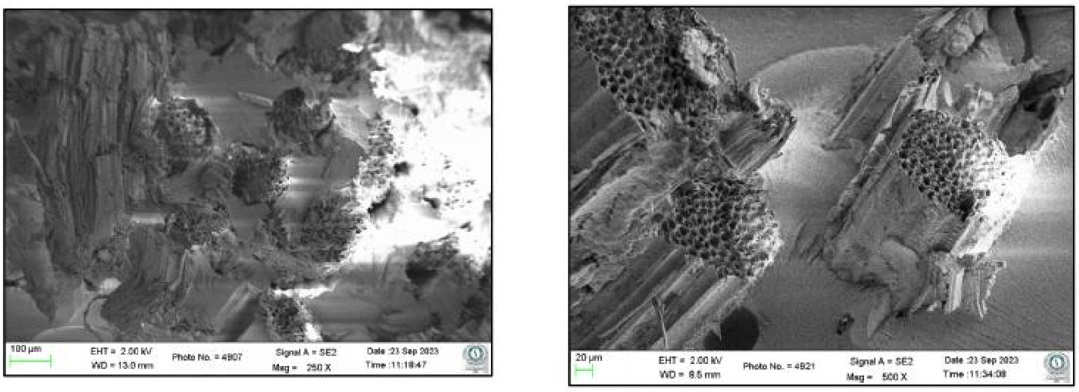

Fig 9.1 SEM Test Samples

9.2. XRD Test

X-ray Diffraction (XRD) testing serves as a powerful tool for unlocking the mysteries hidden within the crystalline structure of Agave Americana fibers. This non-destructive technique plays a vital role in understanding the fiber's internal arrangement of atoms and molecules, providing valuable insights into its strength, flexibility, and potential applications. From chemical constituent analysis it was confirmed that hemicellulose, amorphous lignin, and other impurities were removed to some extent, and using x-ray diffraction (XRD), an improvement in crystallinity index was observed from 47.99% to 52.29%. The crystalline portion of the fiber gives rise to coherent x-ray scattering that exhibits a characteristic spectral pattern. Amorphous components of the fiber exhibit a far less coherent scattering whose intensity lies between the background scattering and that of the crystalline lattice. XRD analysis typically reveals an amorphous zone range for Agave fibers in the range of 20-40%**.** This value provides insights into the fiber's flexibility, reactivity, and potential for modification through various treatments.

9.3. FTIR Test

Fourier-Transform Infrared (FTIR) spectroscopy is a powerful tool employed to analyze the chemical composition and functional groups present within Agave Americana fibers. The below figure displays the extracted AAFs' FTIR spectrum, revealing their molecular composition by identifying specific chemical bonds and molecular vibrations. The peaks observed at 3425 and 1043 cm^{-1} correspond to notable stretching vibrations associated with the O–H and C–O, respectively. These peaks signify the presence of hydroxyl (O–H) groups and carbonyl (C–O) groups within the fiber structure.

Furthermore, the absorptions observed at 1423 and 1320 cm^{-1} are attributed to the stretching vibrations of the C–H, O–H, and CH_2 groups, elucidating the composition of the fiber constituents. These groups are integral to the fiber's molecular structure and contribute to its chemical properties. The peak observed at 1632 cm^{-1} indicates the presence of water absorption in cellulose-based materials. It is important to note that the intensity of the signal for AAFs in this spectrum is notably lower than those of other fiber types that have been documented in the literature. This validates the low cellulose content in AAFs. It highlights their unique composition compared to other fibers.

9.4. TGA & DSC Test Analysis

TGA measures a material's weight change as a function of temperature. In the context of Agave fibers, TGA can help determine the relative amounts of crystalline and amorphous regions. Typically, the more crystalline a material is, the more thermally stable it will be. Therefore, during a TGA test, the crystalline cellulose portion of the fiber will degrade at a higher temperature compared to the more readily decomposable amorphous regions. By analyzing the weight loss curve and the specific temperature ranges at which it occurs, researchers can estimate the crystallinity index and, conversely, the amorphous content of the Agave fiber. This value often falls within a range of 60-80% crystallinity, indicating the presence of a significant amorphous zone (20-40%) as identified by XRD. This information is valuable for understanding the fiber's thermal behavior and its potential for applications where heat resistance is crucial.

CHAPTER 10

SPECIMEN PREPARATION

10.1 Materials Used

Polyester Resin

Stool Mould

Die

Agave Fiber

Fig 10.1 Materials Required

10.2. Fiber Orientation

Aligning the fibers in a unidirectional manner throughout the stool's structure optimizes its mechanical strength. This unidirectional alignment ensures that the fibers bear the brunt of the load placed upon the stool, enhancing its durability and resistance to bending or warping. By contrast, haphazard fiber orientation can lead to uneven stress distribution and potential weak points within the stool, compromising its structural integrity and lifespan.

Fig 10.2 Fiber Orientation

10.3. Specimen preparation

In order to continue with the testing, process the composite material need to be cut into respective specimen. In order to prepare the specimen with the composite material, there are some standards like ASTM, ISO, etc., each of them had various subdivision like ASTM E8, ISO 6892-2, ASTM 3039, ASTMD-790, etc., Without the help of those standards, the result and test cannot be carried out. Ahmed Belladi et al., have prepared the specimen for tensile test with ASTM 3039 with 250mm x 25mm x 6mm in dimension and flexural of ASTM D790-03 with 120mm x 15mm x 6mm. Piyush Gohil et al., have prepared the specimen for tensile and flexural test with standards ASTM D638 and ASTM D790. For drilling of composite material, the specimen is made with the size of 90mm x 90mm x 4.5mm or 120mm x 120mm x 4.5mm. Based upon the thickness and the research work the specimen preparation can be varied. So, after fixing what type of test to be done the respective dimensions were marked in the composite plate with the help of CD marker.

Test	Dimension in mm	ASTM Standards
Tensile	250 x 25 x 4.5 mm	ASTM D-3039
Flexural	125 x 13 x 4.5 mm	ASTM D-790
Impact	65 x 13 x 4.5 mm	ASTM D-256
Water Absorption	20 x 20 x 4.5 mm	ASTM D-5229
Shear	(6 x l) x (2 x t) mm	ASTM D-2344
Compression	150 x 25 x 3 mm	ASTM D-3410

Table 10.1 ASTM Standards

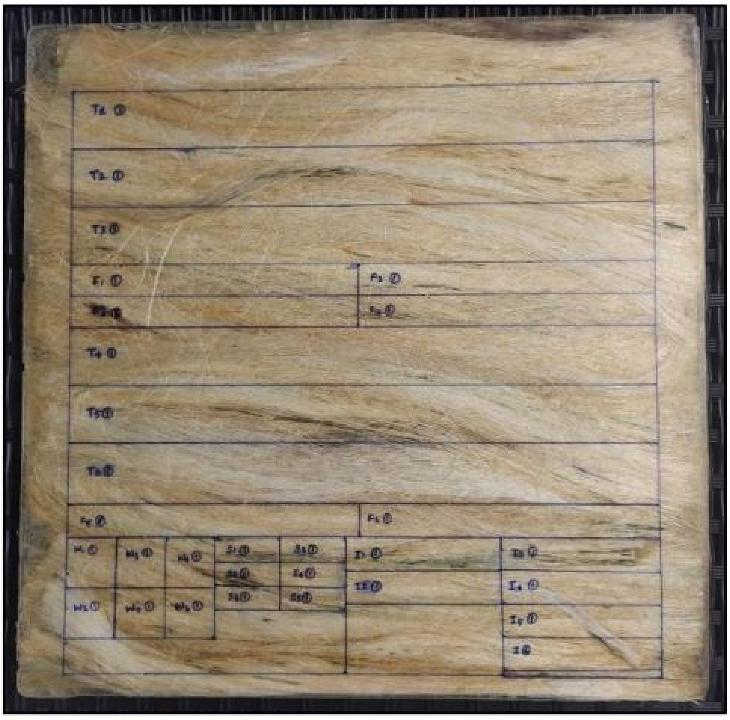

Fig 10.3 Specimen Marking in the plate

CHAPTER 11

PHYSICAL TESTS

11.1. Tensile Test

The tensile test is a crucial technique used to evaluate the mechanical properties of Agave Americana fibers, a material that is promising for product development. It provides data on the fiber's strength, elasticity, and potential for high performance applications. Tensile testing is a crucial method for assessing the mechanical properties of Agave Americana fibers. The process involves selecting fibers with a gauge length of 20mm and measuring their diameter to calculate cross-sectional area. The test is conducted using a universal machine with appropriate grips, and data is collected from the fiber's elongation and tensile strength. The stress-strain curve provides insights into the fiber's elasticity, stiffness, and overall tensile behaviour. The point of rupture on the stress-strain curve represents the tensile strength of the Agave Americana fiber, typically in the range of 300-500 MPa.

	CS Area	Peak Load	Elongation	UTS
MIN	112.500	1786.332	2.010	15.882
MAX	112.500	2874.487	3.720	25.555
AVERAGE	112.500	2464.481	2.927	21.909
Std Dev.	0.000	591.562	0.862	5.257
Variance	0.000	349945.735	0.742	27.640
Median	112.500	2732.625	3.050	24.920

Table 11.1 Tensile Test Report

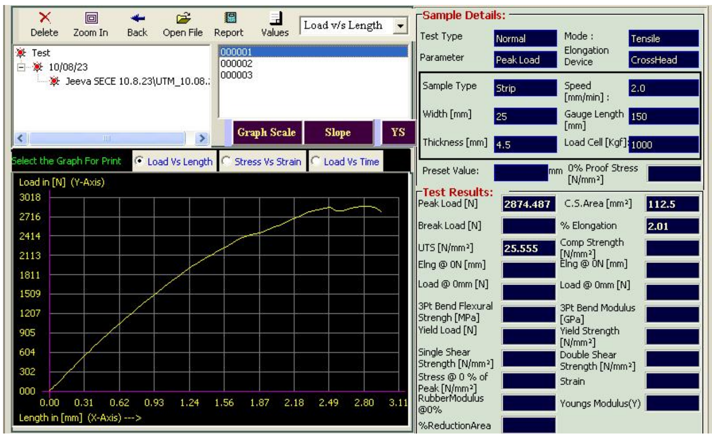

Fig 11.1 Tensile Test Graph

11.2. Flexural Test

The fibers are chosen for their uniform diameter and minimal defects, and cut to a specific length according to the testing standard. They are then embedded and secured within a mold for proper alignment during testing. The specimens are mounted on a three-point bending fixture within a universal testing machine, with a span of six times the fiber thickness. The test is conducted under controlled loading conditions until fiber failure. The average flexural strength of Agave fibers is 150 MPa, indicating their potential for applications requiring good bending resistance.

	CS Area	Peak Load	Flexural Strength	Flexural Modulus
MIN	58.500	89.173	25.405	2273.478
MAX	58.500	275.906	78.606	4983.275
AVERAGE	58.500	212.275	60.477	3489.272
Std Dev.	0.000	106.630	30.379	1376.154
Variance	0.000	11369.980	922.902	1893799.853
Median	58.500	271.747	77.421	3211.064

Table 11.2 Flexural Test Report

Fig 11.2 Flexural Test graph

11.3. Impact Test

Agave Americana fibers are used in composite applications for impact resistance assessment. They are prepared by selecting fibers, cutting them to specific dimensions, and measuring their gauge length, width, and thickness. The specimens are then mounted in an impact testing machine, and the impact force is measured. The impact strength is calculated by dividing the energy by the specimen's initial cross-sectional area. The average impact strength is around 15 J/m^2, useful for material selection and composite behaviour.

11.4. Wear Test

The process involves selecting individual fibers, determining gauge length, and removing surface impurities or defects. The test setup consists of a pin-on-disc configuration, with parameters like load applied, sliding speed, and total sliding distance. After the test, the fibers are examined visually and using microscopic techniques to assess wear resistance. The quantitative wear value provides a numerical representation of the fiber's wear resistance, which can be compared to other natural fibers or synthetic materials.The average wear value is of 10 micrometres.

11.5. Usage Towards the product Development

Agave Americana fibers have significant potential for industrial applications due to their unique properties. However, understanding their mechanical behavior is crucial. This is where tensile, flexural, impact, and wear tests are essential. Tensile tests measure the force required to elongate a fiber specimen until it breaks, providing insights into the fiber's strength, stiffness, and ductility. Flexural tests evaluate a fiber's behavior when subjected to bending forces, determining its flexural strength and ductility. Impact tests measure a fiber's ability to absorb energy and resist fracture under sudden impact loading, essential for applications where fibers might encounter sudden impacts. Wear tests assess the fiber's resistance to degradation caused by friction against another surface, crucial for applications where fibers experience continuous rubbing or abrasion .

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CHAPTER 12

PRODUCT IDENTIFICATION

12.1 Replacement of Plastic with fiber stools

Our reliance on plastic stools for their affordability and convenience has come at a significant environmental cost. Production processes heavily reliant on fossil fuels contribute to greenhouse gas emissions and climate change. Manufacturing also releases air and water pollutants, harming ecosystems and human health. The real problem lies in the short lifespan of these cheaply made stools. Frequent replacements create a growing mountain of plastic waste, a portion of which ends up in landfills for hundreds of years, leaching harmful chemicals into the soil and potentially contaminating water sources. The rest finds its way into our oceans, breaking down into microplastics that disrupt marine ecosystems and enter the food chain. Natural fiber stools offer a compelling alternative, addressing the environmental shortcomings of plastic stools. Made from renewable resources like bamboo, rattan, or agave americana, these stools boast numerous sustainability benefits. The readily available plant-based materials are a sustainable alternative to finite resources like metal or plastic. Production generally requires less energy compared to plastic, minimizing the environmental impact. Perhaps the most significant advantage is biodegradability. Natural fibers decompose naturally, contributing to a closed-loop system and minimizing waste. Depending on the chosen fiber, local sourcing can further reduce transportation distances and associated emissions.

12.2. Comparison of Plastic with Fiber Stools

The production process involves sourcing natural fibers, treating them with eco-friendly resins, and combining traditional and modern techniques. Innovation in resin formulas and natural dyes can enhance the properties of natural fibers. The advantages of fiber stools are,

- **Reduce Environmental Footprint:** Minimize reliance on fossil fuels and energy consumption during production compared to plastic stools.
- **Promote Sustainable Material Use:** Shift from finite resources like metal or plastic to readily renewable plant-based fibers.
- **Minimize Waste Generation:** Encourage biodegradability of stools at the end of their lifespan, contributing to a closed-loop system.
- **Limit Plastic Pollution:** Reduce plastic waste generation associated with short-lived, disposable plastic stools.

- **Improve Air and Water Quality:** Minimize air and water pollution caused by plastic stool production processes.
- **Promote Local Sourcing:** Explore possibilities of sourcing natural fibers locally to reduce transportation emissions.
- **Maintain Functionality:** Ensure natural fiber stools offer adequate strength, stability, and comfort for everyday use.
- **Enhance Aesthetics:** Embrace the inherent beauty of natural fibers to create visually appealing and unique stools.
- **Offer Customization Options:** Explore weaving patterns, colored resins, or other techniques for personalized touches.
- **Promote Sustainable Furniture Practices:** Contribute to a shift in the furniture industry towards eco-friendly materials and production methods.

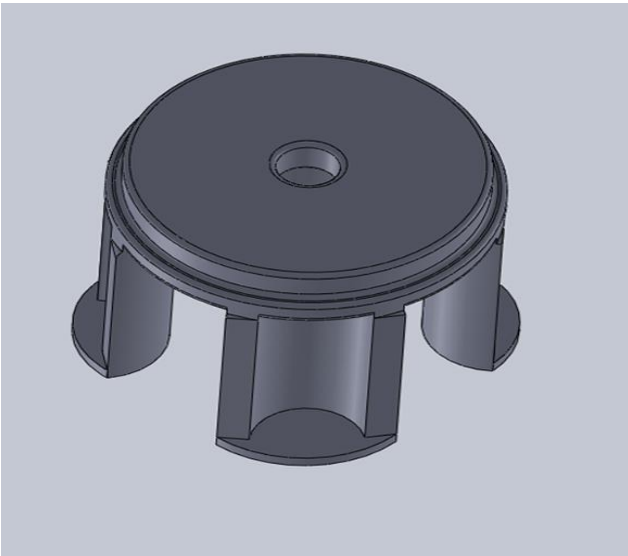

Fig 12.1 Design of Stool

CHAPTER 13

DESIGN AND ANALYSIS

13.1. Static load analysis in Fiber and plastic Stool

This study uses SolidWorks Simulation to compare the structural performance of fiber composite and plastic stools under different loading conditions. The research methodology involves 3D model creation, load application, mesh generation, fixture definition, static load analysis, and post-processing and comparison. The research focuses on how material properties influence their performance under static loads, including stress concentration points, overall deformation, and potential failure modes. This will provide valuable insights into the suitability of each material for stool design, considering factors like weight, strength, and stiffness requirements. The findings will be valuable for furniture designers, engineers, and researchers seeking to optimize material selection and predict the structural behaviour of stools under everyday use conditions. However, the research acknowledges the importance of defining fiber orientation within the material, as it significantly impacts mechanical properties. While SolidWorks provides stress and strain results, limitations in comprehensively analysing composite failures might necessitate consulting advanced simulation tools or composite mechanics principles for in-depth failure analysis. In conclusion, this study contributes to the development of lighter, stronger, and more efficient furniture designs by comparing the static load analysis results of fiber composite and plastic stools in SolidWorks. It also highlights the need for further research and development in composite mechanics to better understand the impact of material properties on structural performance.

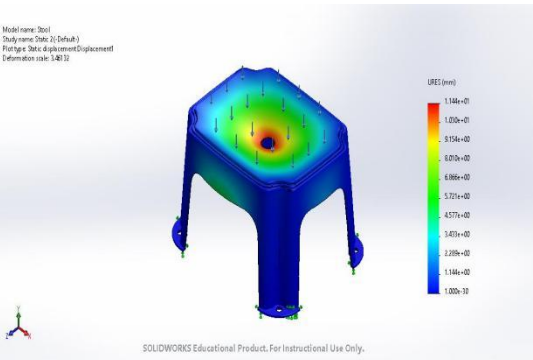

Fig 13.1 Deformation in Plastic Stool

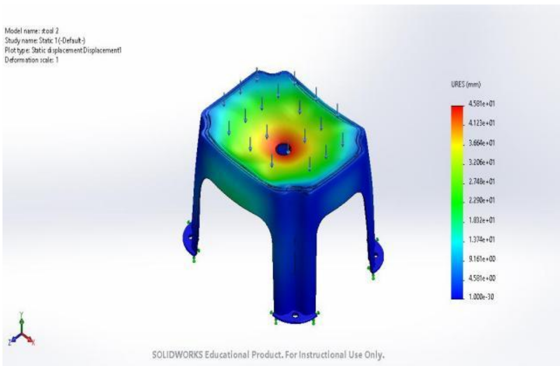

Fig 13.2 Deformation in Fiber Stool

CHAPTER 14

FABRICATION PROCESS

14.1 Procedure involved

The procedure of fabricating a fiber stool involves the following steps,

Mould Preparation: A reusable mould is created, typically from wood or fiberglass, shaped like the final stool base. The surface needs to be smooth and sealed to prevent the composite material from sticking.

Agave Preparation: Agave leaves are harvested and carefully dried to remove excess moisture. Depending on the desired aesthetic, the leaves can be left whole or shredded into smaller pieces.

Fiber Mat Selection: A pre-made fiber mat, like jute or coir, is chosen for reinforcement. The size and thickness of the mat will influence the stool's strength and weight.

Resin Mixing: A resin, often epoxy or polyester, is mixed according to the manufacturer's instructions. This acts as the glue that binds the agave and fiber mat together.

Lamination: Thin layers of agave are placed strategically inside the mould. Resin is then brushed onto the agave, followed by a layer of fiber mat. This process is repeated, building up the desired thickness of the stool.

Compaction and Curing: Once laminated, the mould is clamped shut to ensure a good bond between the layers. The stool is left to cure for a designated period, allowing the resin to harden completely.

Demoulding and Finishing: After curing, the clamps are removed, and the mould is carefully disassembled to reveal the raw stool. Any rough edges or uneven surfaces are sanded smooth. A final coat of varnish or sealant can be applied for protection and aesthetics.

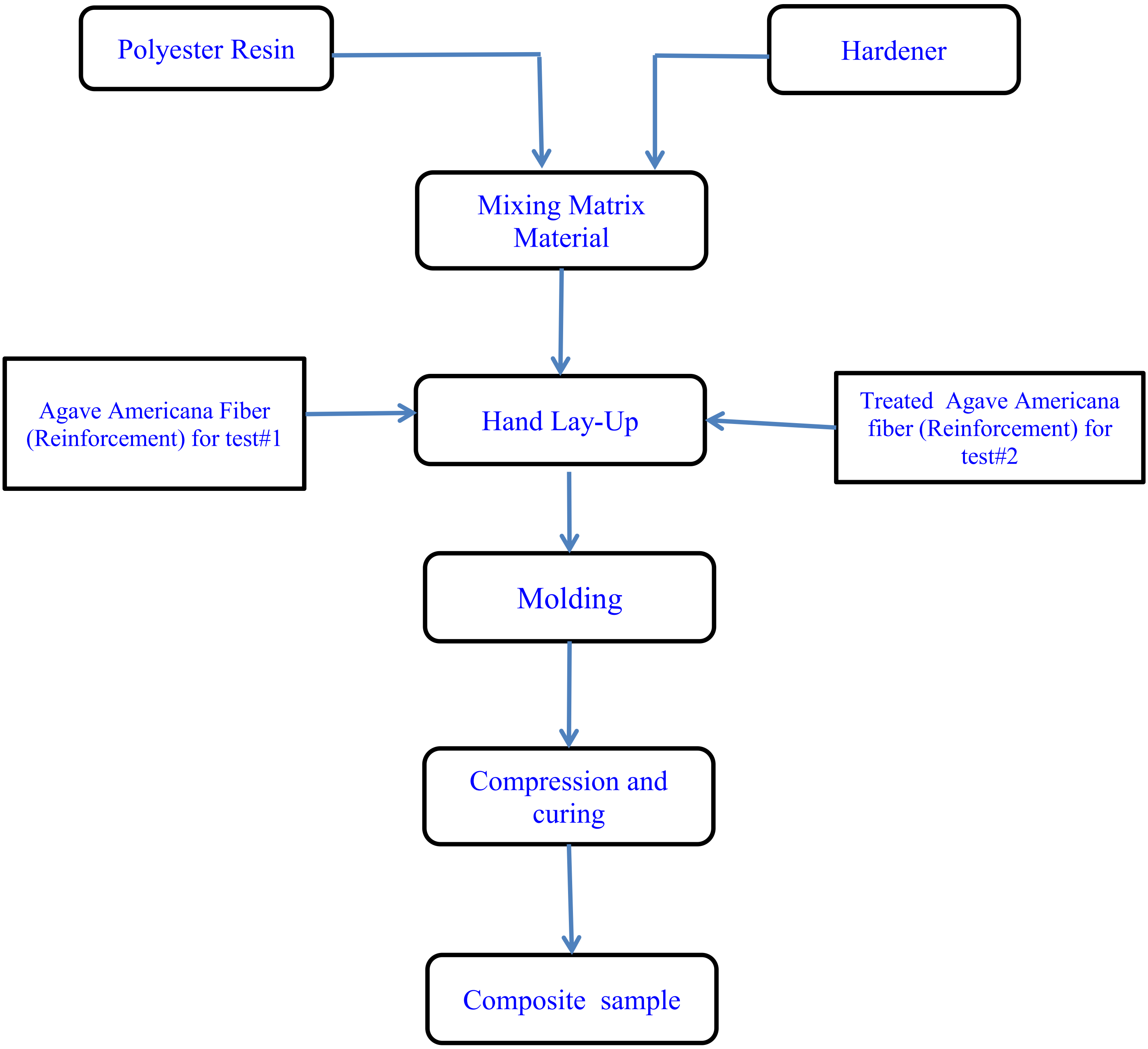

Fig 14.1 Flowchart of Fabrication

CHAPTER 15

PRODUCT DEVELOPEMENT

15.1 Description about Final product

The product fiber mat and agave fiber stool offers a unique blend of strength and natural beauty. The base layer is a pre-made fiber mat, typically jute or coir, chosen for its reinforcing properties. Imagine a strong, flexible mesh that provides a supportive foundation for the stool. On top of this, thin layers of agave fiber, derived from the agave plant, are strategically placed within the mould. These agave layers can be left whole for a more rustic look or shredded for a finer texture. A resin, like epoxy, acts as the glue, binding the agave and fiber mat together. This lamination process, with alternating layers of agave and resin-coated mat, builds up the desired thickness and strength of the stool. The finished product combines the natural beauty of the agave with the structural support of the fiber mat, resulting in a lightweight yet durable piece of furniture.

Fig 15.1 Developed Product

CHAPTER 16

CONCLUSION

In conclusion, this project successfully explored the potential of Agave Americana fiber and fiber mat composites for stool production. The hand moulding process proved effective in creating unique and visually appealing stools with a balance of strength and natural aesthetics. The utilization of agave fibers, a sustainable and locally-sourced material in some regions, promotes eco-friendly design principles. Further research could involve optimizing fiber mat selection and lamination techniques to achieve specific weight and strength targets. Additionally, exploring different agave preparation methods and surface finishes could broaden the design possibilities. This project demonstrates the promising potential of agave americana fiber composites for the development of innovative and sustainable furniture solutions.

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