DEVELOPMENT AND ANALYSIS OF BAMBOO/COIR FIBRE BASED COMPOSITE USING GUM ARABIC BINDER FOR PARTICLE BOARD PRODUCTION

BY

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ENG1804592

A PROJECT SUBMITTED TO THE

DEPARTMENT OF PRODUCTION ENGINEERING,

(AGRICULTURAL ENGINEERING PROGRAMME)

FACULTY OF ENGINEERING,

UNIVERSITY OF BENIN,

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CERTIFICATION

This is to certify that this project work was carried out, written and submitted by OCHEI GIDEON CHIKWADO of the Department of Agricultural Engineering, University of Benin, Benin City, Edo State, in accordance with the rules and regulations of the University of Benin for the award of the bachelor's degree in production engineering.

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DEDICATION

This project work is dedicated to the almighty God, my parents and all those who have made the work possible and finally a success.

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I remain eternally grateful to God almighty for his ever-abiding grace. He has kept me throughout this research period and offered me guidance on various occasions when I was stuck during the course of this project. May his name be praised forever more.

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ABSTRACT

The increasing demand for sustainable and environmentally friendly materials has spurred significant interest in the development of alternative composite materials. Bamboo, known for its rapid growth and high strength-to-weight ratio, presents a promising candidate for such applications. This project explores the production of bamboo/coir fibre composite boards, leveraging the delignification process to enhance fiber compatibility with gum arabic as a natural binding agent.

The methodology involved multiple steps, starting with an extensive literature review to establish a theoretical framework. Fresh bamboo was subjected to a delignification process using sodium hydroxide (NaOH) to remove lignin, followed by grinding the treated bamboo into fine particles. Central Composite Design (CCD) was employed to plan the experiments systematically, optimizing the variables involved. The ground bamboo particles were then mixed with gum arabic and coconut fiber as reinforcement, and the mixture was molded into boards. These boards were subjected to rigorous testing to determine their modulus of elasticity, tensile strength, water absorption, and thickness swelling.

The results indicated that the delignification process significantly improved the bonding between bamboo fibers and gum arabic, resulting in composite boards with enhanced mechanical properties. The modulus of elasticity and tensile strength of the boards met industry standards, demonstrating their potential as a viable alternative to traditional wood-based materials. Using Response Surface Methodology (RSM), the optimal composite formulation was identified, highlighting the potential of bamboo composite boards for sustainable and eco-friendly applications.

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List Of Abbreviations

ABNT: Brazilian Association of Technical Norms

ANOVA:Analysis of Variance

ANSI: American National Standards Institute

ASTM :American Society for Testing and Materials

B: Bamboo

BP: Bamboo Particles

BPB: Bamboo Particle Boards

BZB: Bamboo zephyr boards

CCD: Central Composite Design

DIFFITS: Difference in Fits

DMF: Dimethylformamide

DOE: Design of Experiment

EN: Norme Européenne

FRIM: Forest Research Institute of Malaysia

FRP: Fiber-reinforced polymer

IB: Internal bond

IS: International standard

JIS:Japanese Industrial Standard

LE: Linear Expansion

MDF:Medium-Density Fibreboard

MDI: Diphenylmethane Diisocyanate

MDP: Medium Density Particleboard

MOE: Modulus of Elasticity

MOR: Modulus of Rupture

NBR: Nitrile Butadiene Rubber

OSB:Oriental Strand Board

PBR: Polystyrene Based Resin

PRESS: Predictive Residual Sum of Squares

RCBD:Randomized Complete Block Design

RSM: Response Surface Methodology

RW: Rubberwood

TDI:Toluene Diisocyanate

TS: Thickness Swelling

UF: Urea Formaldehyde

UPR: Unsaturated Polyester Resin

UTM: Universal Testing Machines

WA: Water Absorption

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Bamboo is a fast growing, renewable and simple-to-cultivate resource. It is a type of grass that grows from its roots, and when it is cut, it quickly grows back, with most species maturing in 3-5 years. There are over a thousand species of bamboo spread across both tropical and temperate environments. Bamboo is very hardy, and doesn’t need pesticides or herbicides to grow well. It is also a well-established fact that bamboo rarely needs replanting and also produces more oxygen than trees, therefore playing an important role in the balance of oxygen and carbon dioxide in the atmosphere.

It is an extremely versatile material that can be used for a plethora of purposes such as clothes, fuel, furniture and construction.In the aspect of houses, schools and buildings, over one billion people in the world live in bamboo houses. This is due to the fact that bamboo provides more than enough material to build houses without need for felling of trees from already diminishing forests

For this project, a composite board will be created using bamboo as the main constituent. Now there are several reasonsto use bamboo rather than the conventional wood processed from trees. They include

i. Rapid Rate of Deforestation: Deforestation is caused by many reasons, ranging from agricultural expansion, urbanization, mining activities, climate change, fire etc.Most notably, one of the major reasons why deforestation occurs is due to the activities involved in producing furniture from wood,gotten from felled trees. There has grown an increased demand for provision of wooden furniture in offices, residential areas etc. This demand doesn't take into consideration the effect logging has on the environment, and so to curb this issue, we've decided to use bamboo as a better alternative as the felling of bamboo doesn't lead to deforestation due to bamboo's special properties.

ii. Time Taken for Felled Trees to Regrow: For trees like Mahogany, Maple & Oak etc. once felled, they can take over 30-50 years to regrow. This is unsustainable and will eventually become an unreliable source for furniture production. This is in contrast to Bamboo whose regrowth rate is about 3-5 years maximum.

1.2 Statement of Problem

This research will serve as an attemptto curb the use of wood from timber for furniture, and propose a eco-friendly alternative to be used -bamboo.This is because the world is facing timber shortage; our forests no longer offer enough wood. This is due to deforestation and time taken to regrow felled trees.

The challenge faced is the fact that there's no standard process for creating composite boards using Bamboo,a binding agent(Gum Arabic), and coconut fiber serving as reinforcement.

1.3 Aims and Objectives:

The aim of this project is to develop and analyze a bamboo/coir fibre composite using gum arabic binder for its suitability in the production of particle board. To accomplish this goal, the project will pursue the following specific objectives:

i. Conduction of extensive literature review.

ii. Acquisition of materials for the experiment.

iii. Extraction of lignin from bamboo.

iv. Grinding bamboo into small, fine particles.

v. Employing “MixtureDesign” to strategize the experimental process.

vi. Fabrication of experimental samples.

vii. Assessment of the mechanical and physical attributes of experimental samples.

viii. Utilization of Response Surface Methodology (RSM) to analyze the experimental findings.

ix. Attaining the optimal composite formulation.

1.4 Scope of Study

The scope of this project is to produce a composite board with desirables properties in regards to the following criteria; Tensile stress, modulus of elasticity, thickness swelling, water absorption etc.

1.5 Significance of Study

Regarding sustainability, this project's significance lies in promoting eco-friendly alternatives to traditional wood-based materials, contributing to conservation efforts and mitigating deforestation since bamboo is a rapidly renewable resource.

This project's significance extends to the innovation in manufacturing processes. Creating composite boards from bamboo involves experimenting with different treatments, binding agents, and different processing techniques, inadvertently contributing to advancements in sustainable material science. It is also worth noting that bamboo composite boards offer versatility and adaptability in various industries. The project's significance also lies in demonstrating the potential applications of these boards, from construction and furniture to other innovative uses, showcasing bamboo's flexibility as a material.

CHAPTER TWO

LITERATURE REVIEW

2.1 Composite Materials

According to Hashin (1983) composite materials are made up of two or more distinct materials that are typically bound together securely at the interface and create regions substantial enough to be considered continuous. This is the case for a wide range of materials, both natural and man-made, including polycrystalline aggregates (metals), filled polymers, concrete and mortar alloys, porous and cracked media, and aligned and chopped fibre composites.

In the field of materials science and engineering, composite materials are described as the adept amalgamation of two or more separate parts to generate a single structure with qualities that outperform those of its individual components. These materials are designed to take use of each constituent's inherent strengths while reducing their limitations. The resulting composite has modified qualities, making it appropriate for a wide range of applications across several industries.

2.2 Composite Boards

A composite board is made by blending a cellulosic filler which has a high extractablecontent, with an expandable thermoplastic polymer. A tacifier agent is added during the blending process to create a pre-blown mixture. The mixture is then heated in a mold to a temperature above the polymer's glass transition temperature for enough time to expand the beads and bond them with the cellulosic filler. The board can be laminated with a solvent-based adhesive or a thermal insult coating to create hard macro-voids between the laminate and composite board surface.

2.3 History and Innovation of Composite Materials

As natural resources become scarcer, synthetic composite boards have emerged as a cost-effective replacement to traditional wood boards. Synthetic prefabricated boards offer unique properties such as strength, density, acoustic and fire resistance that are not found in traditional forest products. (Tock, 1989).

Dating back to the industrial revolution of the 18th and 19th centuries, advancement in use and development of composite materials was spurred by the need for durable, lightweight, and cost-effective replacements of conventional building materials.

During this time, manufacturers experimented with different reinforcement fibres, such as cotton, jute, and sisal, embedded in resin matrices to create early composite boards and laminates.

The introduction of synthetic resins, such as phenolic and polyester resins, increased the capabilities of composite boards by improving strength, durability, and resistance to environmental influences.

The mid-20th century then marked a period of accelerated innovation in composite board technology, spurred by advancements in aerospace, automotive, and construction industries.

In the aerospace sector, composite materials gained prominence for their exceptional strength-to-weight ratios, corrosion resistance, and fatigue properties. Aircraft components, such as fuselages, wings, and engine enclosures, increasingly incorporated composite boards and laminates to reduce weight and enhance performance.

The automotive industry embraced composite materials for their potential to reduce vehicle weight, improve fuel efficiency, and enhance crashworthiness. Composite boards found applications in automotive body panels, chassis components, and interior trim, contributing to advancements in vehicle design and performance.

In the construction sector, composite boards gained traction as sustainable alternatives to traditional building materials. Fiber-reinforced polymer (FRP) composites offered architects and builders versatility in design, durability, and resistance to moisture, chemicals, and corrosion.

2.4 Composition of Composite Boards

A composite board typically consists of two main components: a matrix material and reinforcement materials. Here's a breakdown of the typical composition of a composite board:

a) Matrix Material:

The matrix material serves as the bulk component of the composite board, providing cohesion, structural support, and durability. Common matrix materials include: polymer resins, metal alloys, ceramics.

b) Reinforcement Materials:Reinforcement materials are incorporated into the matrix to enhance specific properties such as strength, stiffness, impact resistance, and dimensional stability. Common reinforcement materials includefibers, particulates, laminates.

2.5 Concept of Bamboo Composite Boards

The study of bamboo composite boards reveals a promising future for sustainable construction and engineered wood products. Bamboo, pertaining especially to this study, is the foundational material for these composite boards, which are meticulously manufactured.At the heart of composite board production is the transformation of raw bamboo into refined fibres or particles suitable for manufacturing. This initial phase is gathering bamboo culms and subjecting them to specific processes designed to remove fibres or particles suitable for composite board production.

Following extraction, bamboo fibres are treated to improve their quality and bonding capabilities. Delignification, a critical component of this process, is the removal of lignin and contaminants from fibres, which is frequently accomplished using chemical agents such as sodium hydroxide.

After delignification, the bamboo fibres are mixed with binding chemicals, which play an important role in keeping the composite material together. These binding agents, which can include synthetic resins and natural adhesives, promote cohesion within the composite matrix, assuring structural integrity and dimensional stability.

The composite mixture of delignified bamboo fibres and binding chemicals is then moulded or extruded into boards. During this stage, the composite material is subjected to controlled temperatures and pressures, resulting in the formation of bamboo composite boards with the necessary dimensions and qualities.

The resulting boards have a number of desirable properties, including as modulus of rupture, modulus of elasticity, tensile stress, thickness swelling, and water absorption, making them appropriate for a wide range of applications in building, furniture, and interior design.

Bamboo composite boards have a wide range of applications, from structural parts in construction to interior components in the automotive and transportation industries. Furthermore, they infiltrate consumer products and packaging, providing lightweight and environmentally responsible alternatives.

In conclusion, bamboo composite boards reflect a successful combination of innovation and sustainability in materials engineering. As research continues and industry adoption grows, these boards have the potential to transform the landscape of sustainable building and engineered wood products, ushering in a new era of environmentally conscious design and manufacture.

2.6 Review ofPast Literatureon Composite Boards

Nugroho and Ando (2000) carried out a study to investigate the suitability of zephyr strands from moso bamboo for the production of structural composite board but the main focus here is the method through which their composite board was created. Bamboo zephyr boards (BZB) measuring 1.8×40×40cm were made with four different zephyr strand diameters (1.5, 2.8,4.7 and 9.5mm) and target densities (0.6, 0.7, 0.8, and 0.9g/cm^3).

In this study, a three-year-old moso bamboo from Kagoshima prefecture in Japan was chosen as raw material. Bamboo clumps were cut to about 40cm in length, and then sliced into quarters. The cut-up bamboo was then crushed by a roll press, leading to the production of Bamboo Zephyr strands. All bamboo zephyr strands were then air-dried to a moisture content of 8-12% before further processing. The air-dried density of moso bamboo (weighing about 0.74 g/cm^3 with an average thickness of 9-15 cm) was mixed with an adhesive - emulsion methyl di isocyanate (E4vIDI)resin (PB-1605) formulated by OshikaSinko Co.

Under controlled conditions, 32 sample boards were produced in the laboratory.

In order to properly evaluate the mechanical and physical properties, the bamboo zephyr boards were conditioned at 20-65% relative humidity (RH) for at least2 weeks. The boards were tested based on Japanese Industrial Standard for Particleboard (JIS A-5908, 1994). All the boards were trimmed and cut into various test specimens as follows:

i. 32 cm for static bending;
ii. 5 cm for internal bond (IB) strength;
iii. 5cm for thickness swelling (TS) and water absorption (WA) tests, and
iv. 10cm for linear expansion (LE) determination.

The results from this study indicated that bamboo zephyr boards exhibit superior strength properties when compared to the commercial products.

Also, the size of the zephyr strand and its level of target density had a significant effect on the elastic and rupture modulus, internal bond strength, water absorption, and thickness swelling, but it did not have a substantial effect on linear expansion. When physical properties were considered, bamboo zephyr board exhibited less thickness swelling and exhibited good dimensional stability under dry-wet conditioning cycles.

Martijanti *et al.*,(2021)embarked on a project was to create composites made of bamboo particles reinforced polymers to replace particleboard products, which relied on wood as a raw material. The technique of creating composites was adjusted by adjusting the powder sizes (50, 100, and 250 mesh), the volume fractions (10, 20, and 30%) of each mesh, the matrix types (polypropylene and polyester), and the reinforcements (Tali bamboo and HaurHejo bamboo). The parameters of the composite synthesis process were also adjusted accordingly. In accordance with JIS A 5908-2003, particleboard products underwent tests for density, moisture content, thickness expansion following immersion in water, flexural strength in both wet and dry conditions, bending Young's modulus, and wood screw holding power. Results show that, polymer composites reinforced with 250 mesh Tali bamboo and a 30% volume fraction had the highest values of flexural and tensile strength, which were

91.03 MPa and 30.85 MPa, respectively. According to JIS A 5908-2003, the particleboard composed of polypropylene and polyester reinforced Tali Bamboo with a particle size of 250 mesh and a volume proportion of 30% composites was acceptable

Khalil *et al*., (2012)also embarked on a similar project with much emphasis placed on the use of bamboo fibres as reinforcement in composite materials, due to a worldwide demand for developing biodegradable and recyclable materials that wouldn't lead to harmful destruction of the eco-system. For the different types of composites that were produced, alkaline treatment and steam explosion technique were the most prominent methods used. The flexural properties of bamboo and biodegradable resin-based bio-based polymer composites were assessed and contrasted with those of kenaf composites. Additionally, they computed flexural modulus using Cox's model, which takes into account the effect of fibre compression, and the findings of the experiments agreed well with this model.

Abdulkareem and Adeniyi (2017) carried out a study that entailed the production of particle boards using bamboo and resinous material gotten from polystyrene wastes. The production process entailed mixing the bamboo fibres and polystyrene based resin (PBR), and then the application of a flat press process to convert this mixture to a particle board. Physical parameters were then measured in accordance with ASTM D-1037 standard, using both standard and oven curing procedures, and the samples' thickness swelling (TS) was measured after they were submerged in water for twenty-six hours at a temperature of 25 °C. The physical characteristics of particleboards with 20%, 30%, and 40% PBR content were discovered to be in conformity with the American National Standards Institute's (ANSI) low density particleboard categorization. As the matrix's PBR content dropped, TS rose. The qualities obtained provide strong evidence of the synthesized resinous polystyrene's improved bonding capacity compared to well-known industrial adhesives commonly employed in the manufacturing of particleboards.

Alam *et al*., (2015) examined the characteristics of single layer particleboard made from leftover bamboo debris and branches in their research.15% urea formaldehyde (UF) resin was used in the production of three different types of single layer particleboard: branch-waste mixed particleboard (WBPB), bamboo branch particleboard (BPB), and bamboo wastes (shavings collected during the planning operation of bamboo) particleboard (WPB). The ASTM D-1037 standard was used to assess the manufactured particleboards' mechanical and physical qualities. The bamboo branch-waste mixed particleboard (WBPB) outperformed bamboo branch and waste particle board (BPB) in terms of both mechanical and physical properties, including density, moisture content (MC), water absorption (WA), thickness swelling (TS), linear expansion (LE), and modulus of elasticity (MOE).

Papadopoulos *etal*., (2004) in their study proved the feasibility of making a one-layer experimental particleboard from bamboo chips bonded with urea formaldehyde (UF) resin. The bamboo chips used had higher length to thickness, and length to width ratios, coupled with lower bulk density in comparison to industrial wood chip particles. The results gotten from this study showed that bamboo chips can be successfully used as an alternative lignocellulosic raw material, to manufacture particle boards, once again showing how bamboo particle boards are more useful compared to other alternatives.

Brito *etal*., (2020) focused mainly on the technological properties of particle boards manufactured from sugarcane and bamboo particles. They produced these boards by first of all, acquiring bamboo culms with average diameter, internode length and height dimensions were selected and then cutting them into little splits. A thickening planer was then used to remove the inner and outer layers of the cut-out strips and then they were converted into chips. The chips then underwent a drying process in a forced circulation oven before being grinded and converted to particle board using a flat press process.

Kasim *etal*., (2001) in this body of work, acquired 40 bamboo culms each from 1–3year-old Malaysian bamboos which were obtained from the Forest Research Institute of Malaysia (FRIM), Kepong, Selangor. The branches of the 40 culms were removed and split longitudinally. The split bamboo culms were then fed into a pallman drum chipper. The chips produced from this Pallman drum clipper were then flaked in a Pallman knife-ring flaker and the particles produced were screened into small sizes ranging from 0.5-2.0mm before they underwent oven drying process at a temperature of 60°C to moisture content of 5%. The dryed particles were then laid in a wooden mould and prepressed at 3.5MPa for about 30 seconds. Then it was pressed again for 6 minutes at 160°C in a Taihei hot-press at 120kg/cm^2. The final products were single layer boards and three-layer boards of 12mm thickness and dimensions 340x 340mm. The strength and dimensional properties,viz. thickness swelling (TS), water absorption(WA), modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) were tested according to the British Standard: BS EN(1993). In terms of strength properties, all the bamboo particles from all age group of G. schortehiniiare were suitable for particleboard manufacture. However, the high values obtained for 24-hour thickness swell would require further studies before this species could be used for particleboard production.

Karlinasari *et al*., (2021) in their research carried out the production of single layer homogenous particle boards, constructed using particles best described as fine and coarse particles. These particles were bonded using Diphenylmethane diisocyanate resin and then air dried to a moisture content of about 9%. After production, it was then coated with polyurethane and tested for acoustic and surface characteristics.

Yang *et al*., (2014) in their study used the moso specie of bamboo with initial moisture content of around 21%. They cut bamboo culms length wise into several splits using a radial splitting machine, and each slat was shaped into a regular strip so that it could be stacked smoothly through two processes – the removal of outer skin using a two-side planning machine, and the generation of a rectangular strip using a four-side planning machine. The adhesives were then sprayed before the air-drying process commenced. A hot-pressed process was then used to press the mixture and form the corrugated particle boards.

Karlinasari *et al*.,(2021) carried out a study made to evaluate the physical and mechanical properties of particle boards made from Asian giant bamboo. In the early stages of particle board production, 3-year-oldbetung bamboo culms were gathered and cut manually into sections before being converted into chips using a chipper. These chips were then dried and reduced into particles. These particles were then dried in an oven at a temperature of about 70°C for an interval of 2 days to reach an air-dry moisture content 3-5%. The particles were then mixed with Isocyanate resin of diphenyl methanedissocyanate. The particles and the binder were then mixed in a rotary drum mixer in a sealed environment. The mixture of particles and adhesive was then spread manually in a 300 × 300 mm wooden frame. Compressing of the mats were carried out in laboratory press at a temperature of 150 °C using a pressure of 2.5 N/mm2 for 10 min. Pressed panels were conditioned in room temperature (25 °C) and

65% relative humidity for 2 weeks. The physical properties were then carried out on the panel based on Japan Industrial Standard.

Nurhazwani *et al*., (2016) carried out a study aimed at observing the physical and mechanical properties of hybrid particleboards made from bamboo(B), veneer waste and rubberwood (RW). 3-4year old bamboo culms were felled and the wastes from the bamboo peeling process were gathered as they would be the main components of the bamboo particle board. The bamboo wastes were reduced in size with a fibre cutter and processed by a crushing machine to produce particles. The particles were screened and then dried till they were at 5% moisture content. These particles were then mixed with the resin in a blender which was coupled with a spray gun attachment. After mixing, the particles were arranged in a haphazard manner onto a wooden mold. After this the particles were pre-pressed at 3.5MPa for thirty seconds, and then the compressed mat was pressed for 6 minutes at 160°C and 120kg/cm^2 pressure. All hybrid particleboard panels, with the exception of the tests for thickness swelling and water absorption, passed and met the minimal standards. However, only boards made of 50B:50RW and 30B:70RW survived the thickness swelling test and met the minimal TS requirements of British Standard EN 317 (1993).

Iswanto (2018) in his research studied the effect of particle length on physical and mechanical properties of oriented particle boards. The materials employed in this study were isocyanate, bamboo tali, and urea formaldehyde (UF) resin. A 25 by 25 cm2 Oriental Particle Board was created, with a target thickness and density of 0.75 gcm^3 and 1cm, respectively. In order to combine the particle with UF/Isocyanate (70/30%w/w) at a 12% level, a rotary bending machine was used. The particle was then put into the mat former. The procedure of hot pressing, which takes 10 minutes at 160ºC and 30 kgcm^{-2} of pressure, comes next. Following a week of board conditioning, OPB underwent an evaluation that is referenced in JIS A 5908 (2003).

Kshirsagar *et al.*,(2012)conducted research on the suitability of bamboo for preparation of particle board. In the events of this research, freshly felled culms of bamboo were procured and cross cut into small pieces about 15cm long in the round form, and then transformed into even smaller sizes through the use of Combi-planner machine. The chips then obtained were the sun dried for week in order to reduce moisture content from 30-40%. The chips were then passed down through the wood grinder to obtain particles used in preparing the particle boards. The dried particles were then mixed with phenol formaldehyde resin and a wooden mould was kept over this mixture to form a mat. The mat was then pressed in a hydraulic hot press at specific pressure of about 300lbs/inch, and 150°C for about 12 minutes and the particle board was made.

Srichan and Raongjant (2020) investigated the mechanical, thermal, and physical characteristics of single-layer particleboard made from the sheaths of bamboo shoots. They made particleboards using sheaths of bamboo shoots which were grinded and mixed proportionally with a binding agent called diphenylmethane diisocyanate (MDI). This mixture was then made to undergo the hot-press method to produce 3 single layer particleboards at 400, 600, and 800kg/m^3 densities. The JIS standard was then applied to the particleboards in order to determine board density, water absorption, thickness swelling, modulus of elasticity, modulus of rupture in bending, and internal bonding. The findings demonstrated the particleboard's exceptional performance in terms of low heat conductivity and tensile strength perpendicular to the surface (internal bonding).However, compared to standard criteria, their characteristics showed some weaknesses, such as low modulus of elasticity and rupture modulus, high water absorption and swelling thickness, and low modulus of rupture. Further investigation is required to improve the strength and durability of the particleboard made from bamboo shoot sheaths.

Júniorand Brito(2019) studied the thermal modification of sugarcane waste and bamboo particles for the manufacture of particleboards. This study made use of two materials in the production of particle boards – sugarcane waste and bamboo particles. First of all, sugarcane bagasse was obtained from a local sugar mill at Sao Paulo state, Brazil. The sugarcane bagasse were then air-dried (18%) and further dried again in a greenhouse (70 ± 2 °C) for 3 hours until they reached 10%. The material (sugarcane bagasse) was classified, and 0.50 - 0.85 mm granulometry particles were utilised. On the other hand, the bamboo obtained from the same vicinity had their internal layers transformed into splinters and their external layers cut up into chips through the use of a band saw. They were dried and processed in a similar manner to sugarcane bagasse. After those procedures had been observed, the bamboo and sugarcane particles underwent thermal modifications. The particles were then combined with urea-formaldehyde (UF) adhesive in proportion to their mass. The mixture was homogenized and sprinkled on the particles in a slasher of warp and a paraffin emulsion (1.0% solids) was applied. After being taken out of the box and cold pre-consolidated, the mattress was hot-pressed. The pre-pressed mattress was lined with 1.57 cm thick delimiters placed on its sides to ensure that the pressure applied was evenly distributed throughout the panel area. As per the Brazilian Association of Technical Norms - ABNT (2013), it was subsequently set up in a vertical orientation for cooling and acclimatization before the samples were removed for physical-mechanical and density profile tests.

Wu*et al.*,(2022) were focused mainly on unsaturated polyester resin as a non-formaldehyde adhesive used in bamboo particle boards. Here, the bamboo particle board was produced using bamboo particles (BP) and Unsaturated polyester resin (UPR). To create BPBs, the UPR (10 weight percent of dry BP) was first combined with methyl ethyl ketone peroxide (1.0 weight percent of UPR) and cobalt naphthenate (an accelerator; 1.0 weight percent of UPR). This mixture was then used as the adhesive. Dropwise addition of the TDI (0.3–3% of UPR) was made while stirring continuously. Using a laboratory particle blender the prepared UPR (with and without TDI) was sprayed onto the BPs (8% of moisture content). The BP was mixed with the adhesive and then put into a 350 mm × 350 mm × 10 mm rectangular mould. To create the BPBs (control and TDI-modified samples), the moulded BP was then moved to a hot-press machine (BY302X2/15, Suzhou Xinxieli Machine). The hot-pressing temperature, pressure, and time were 160 °C, 1.0 MPa, and 5 min, respectively.

Hung and Wu(2010) examined the mechanical and interfacial properties of plastic composite panels made from esterified bamboo particles. In this study, dried shavings of 3-year-old kei-chiku bamboo were provided by the local bamboo-processing factory and were chipped to particles without any pretreatment. After that, 1.2 kg of bamboo particles were submerged in a dimethylformamide (DMF) solution that contained potassium carbonate (1.1 mM) as a catalyst and 20 mM either butyric or acetic anhydride. To obtain bamboo materials esterified to varying degrees, the reaction was carried out at 100°C with stirring for a duration of 1-8 hours. Following modification, the esterified bamboo particles were rinsed with acetone and Soxhlet-extracted for six hours using acetone to eliminate any remaining butyric or acetic acid. The esterified bamboo particles were then dried for 12 hours at 105°C.The bamboo particle composites (were manually formed into a mat, and then they were hot pressed into p. After a 24-hour immersion in water, tests were conducted to determine the modulus of rupture (MOR), modulus of elasticity (MOE), thickness swelling (TS), internal bond (IB) strength, and water absorption (WA).

Iswanto *et al*.,(2020)investigated the physical, mechanical, and sound absorption properties of sandwich particleboard. For this study, materials included cornstalk, sugarcane bagasse, sugar palm fibre, and belangke bamboo (Gigantochloa pruriens) and tali bamboo (Gigantochloa Apus).An 8% concentration of isocyanate resin was combined with the bamboo particles. Additionally, a 1:2:1 composition ratio of lingo-cellulose was used as the core layer and bamboo as the surface layer during the mat-forming process. This mixture was introduced into the hot-press machine at 160°C for 5 minutes and 3 N/mm^2 of pressure, respectively. A 25 x 25 cm^2 sandwich particleboard was created, with targets for thickness and density of 10 mm and 0.75 g/cm^3, respectively.

Ndulue *et al*.,(2023) carried out research on the effect of particle sizes on the physio-mechanical properties of bamboo particleboard. In the events of this research, bamboo culms were purchased from the Enugu South Local Government Area's Gariki Timber Market. Using a chipper machine, bamboo culms were cut into strips, and at the Scientific Equipment Development Institution in Awkuke, Enugu state, hammer mills were used to reduce the strips into chips of various sizes. Wood chips were converted, then sieved and divided into two sizes: coarse, 2.00 mm, and fine, 1.00 mm. A uniform moisture content was achieved by oven drying wood particles for approximately 24 hours at 60±2°C. The adhesive used was a 70% solid content sodium silicate solution, also referred to as water glass. A laboratory ring-type flaker was used to produce boards by reducing the waste to the necessary sizes. Before applying adhesive, every particle was first screened and then dried to a moisture content of less than 10% in an oven set at 60°C. Each board was made using 1 kg of each particle size and 60 cl of sodium silicate adhesive.370 x 370 mm randomly oriented homogeneous boards with a thickness of 1.0 inch were created at various densities, from 0.49 to 0.81 g/cm^3. Applying a 70% solid content sodium silicate solution to the board was done with a pressurized spray gun in a box-style blender. Wax or any other additives were not used. Mats that were hand-formed were manually pressed using a hard board and sun-dried for 24 hours. At the Frederick Research Centre in Agbani, Enugu state, tests were done on the board's mechanical and physical qualities. Following that, the edges of each board were cut to create 370 mm x 370 mm rectangles that were all the same size. The board density, moisture content, and weight were determined in compliance with the relevant Japanese Industrial Standard, while the Shimadzu Universal Testing Machine was used to measure the internal bond, modulus of elasticity (MOE), and modulus of rupture (MOR) for mechanical properties.

Widyorini *et al.*, (2017) researched on the effect of starch addition on properties of citric acid-bonded particleboard made from bamboo. Petung bamboo particles were gathered and screened from the Indonesian province area, Yogyakarta. These bamboo particles were screened, by passing them through a 10-mesh, and only those who passed through were selected as test materials. The selected particles were then air dried to a moisture content - 12%. A warm mixed solution of citric acid and starch was used as an adhesive, and they were then combined with the bamboo particles at 30 weight% resin content based on the weight of the dried particles. The particles were then oven dried through the night at a temperature of 80^{o}C to reduce the moisture content to 5%. These particles were then hand formed into a mat using a forming box. After that, they were hot-pressed at 180°C for about 10 minutes under applied pressure of 3 MPa. The particle board was then produced, and tests were carried out for physical and mechanical properties of the particle board.

Widyorini *et al*., (2013) investigated the characteristic of bamboo particleboard bonded with citric acid, wood research journal. Petung bamboo particles (Dendrocalamus asper Backer) were used in this research. Citric acid concentrations ranged between 10% and 20% depending on dried particles. The target density was 0.9 g/cm^3, and the boards measured 25 x 25 x 0.7 cm. Particleboards were hot pressed for ten and fifteen minutes at 200 and 220°C.The Japanese Industrial Standard A 5908 for particleboard was then used to evaluate the mechanical and physical characteristics of those particleboards. The findings demonstrated that adding the citric acid considerably enhanced the boards' mechanical and physical qualities. The resulting bamboo particleboards had good qualities; at the ideal conditions of 20% weighted citric acid content and 200°C hot press, the specific IB, specific MOR, and specific MOE values were, respectively, 0.44 MPa, 15.1 MPa, and 4.6 GPa. Citric acid-bonded bamboo particleboards were reported to exhibit excellent mechanical performance and good dimensional stability.

Arruda *et al*.,(2011) carried out a research on the lignocellulosic composites from brazilian giant bamboo (guadua magna) properties of resin bonded particleboards. Bamboo culms were sourced from the state of Goiás in the Midwest, while 21-year-old Pinus taeda logs were gathered in Arapoti in the South. The materials were kept at (22 ± 2)°C and (60 ± 2)% relative humidity in an environmentally controlled room. For a week, the culms were submerged in water to reduce the amount of starch, sugar, and soluble materials. This process was required to lessen biodegradation and facilitate cutting. After that, the culms were divided into 20-cm-long slices and put through a rotary disc flaker. The wood was chipped into flakes after being cut into blocks that measured 19 cm x 20 cm x 3.5 cm along the grain. The wood and bamboo flakes were then separately ground into particles in a hammer mill using a mesh wire with a 5 mm opening. The three sieves used to screen the particles were as follows: 3.0 mm, 1.5 mm, and1.0 mm. Particleboard was made from the particles that made it through the 3.0 mm sieve and were held in the 1.0 mm and 1.5 mm sieves. Following screening, the wood and bamboo particles were dried at 70°C until they contained 5% moisture. Weighing only the bamboo particles allowed us to confirm the processing yield. On the other hand, both species' particle dimensions were established. A rotary blender was used to combine the pre-weighed furnish (approximately 760g) with urea-formaldehyde (labelled as BB/UF) and phenol-formaldehyde (labelled as BB/PF) resins, which had respective solid contents of 61% and 46.5%. A hardener of 2% ammonium chloride was used, taking into account the solids content of the UF. Based on the dry weight of the particles, 8% of either resin was used in the manufacturing of each board. After the mixture was homogenised, it was manually formed into 300 mm by 300 mm mats, which were then hot pressed for 10 minutes at 170°C under a nominal pressure of 4.0 N/mm^2. For every type of board, three duplicates, or panels, were made. The boards were conditioned at (22 ± 2)°C and (60 ± 2)% relative humidity after manufacturing. Target board thickness was set at 13.0 mm, and target board density was 0.65 g/cm^3.

Araújo*et al.*,(2011) investigated the lignocellulosic composites from brazilian giant bamboo (guadua magna and the properties of cement and gypsum bonded particleboards. The bamboo culms were sourced from the Central-Western region of Brazil, specifically the state of Goiás. According to Arruda et al. (2011), they were first pretreated in cold water at room temperature for a week to get rid of inhibitory substances (starch and sugar). After that, they were processed into particles. Based on the dry weight of the cement in the mixture, three $CaCl_2$ concentrations—0%, 2%, and 4%—were tested to create bamboo-cement boards. Since the hydration test showed that the addition of bamboo had no effect on the gypsum's hydration, $CaCl_2$was not added to the bamboo-gypsum boards. For every treatment, three copies were produced, yielding a total of twelve boards measuring 300 x 300 x 12.5 mm. The ratios of water to cement or gypsum was 1:2.5 and bamboo to cement or gypsum was 1:2.75. A density of 1.25 g/cm^3 was the goal. The inorganic materials, such as gypsum or cement, were added after the particles had been wetted with a solution of additive and water. A hydraulic press was used to press the mat at 3.0 N/mm^2 for a full day at room temperature. After that, the boards were conditioned for 28 days at (22±2)°C and (60±2)% relative humidity to allow the cement and gypsum to fully set.

Bazzetto *et al*., (2019) studied the effect of particle size on bamboo particle board properties. Bamboo was gathered at the Tatuí/SP-based Agronomic Institute of Campinas (IAC) Research and Development Unit (UPD). Using a chainsaw, stems from bamboo plants that were three to four years old were chopped. Cutting the stem into sections yielded 2.00m long culms. A circular saw was used to cut the stalks lengthwise to create slats. After that, the slats were run through a planer to remove the external (bark) and internal (rich in starch) layers. Lastly, a band saw was used to turn the slats into chips. Samples of bamboo chips were chosen in order to assess the basic density using NBR 11941 standard operating procedures. After the chips were exposed to air drying until they contained 15–18% moisture, they were ground into particles using a Wiley mill. A vibrating machine and sieves with a mesh size of 35 mesh (0.500 mm), 40 mesh (0.420 mm), 48 mesh (0.297 mm), 60 mesh (0.250 mm), and 65 mesh (0.210 mm) were used to classify the obtained particles. Based on particle mass and 0% moisture, 10% resin solids of urea-formaldehyde (UF) resin were applied. The adhesive was combined with a 5% solids solution of ammonium sulphate. In a rotary drum-style gluer, dried particles with 3% to 5% moisture content were coated with a mixture of catalyst and adhesive that had been previously prepared using a compressed air cannon. Then, with the exception of the air gun, paraffin emulsion at a level of 1% solids was applied using the same tools as the adhesive. To create the mattress, a manually applied adhesive and paraffin-impregnated particle mass was placed inside a 40 cm x 40 cm wooden box. The mattress was then cold pre-pressed for air removal and pre-consolidation in a manual hydraulic press. After that, the mattress was hot-pressed in a hydraulic press that was motorised and had automatic temperature, pressure, and plate closure and opening timing controls. The following were the pressing cycle parameters: A total of 10 minutes will pass—01 minutes for closing and reaching the maximum pressure, 8 minutes for operating at the maximum pressure, and 1 minute for opening—with 35 kgf/cm^2 of pressure and 180°C of temperature. The particleboard was then produced.

Widyorini, (2020), evaluated the physical and mechanical properties of particleboard made from petung bamboo using sucrose-based adhesive. Particles of bamboo petung were gathered from the Yogyakarta province of Indonesia's bamboo-sawing industry. After that, the particles were filtered through a 10-mesh screen, retaining the particles that made it through. Particle size distributions showed that 10.1% passed through 60 mesh, 14.8% (40 to 60 mesh), and 75.1% passed through 10 mesh and were retained at 40 mesh (10 to 40 mesh).The particles were stored until they air-dried, which occurred at 12.3% ± 0.34 percent, following screening. Without additional purification, sucrose (Meade-King, Robinson & Co. Ltd., Liverpool, UK) and ammonium dihydrogen phosphate (Merck, Darmstadt, Germany) were utilized.

Distilled water was used to dissolve the sucrose and ADP at different compositions. The solution's concentration was set at 50% weight percent. The sucrose to ADP mixture ratios were set at 100 weight percent to 0%, 95 weight percent to 5%, 90 weight percent to 10%, 85 weight percent to 15%, and 80 weight percent to 20%. Based on dry-weight particles, the adhesive load was 20 weight percent. The target dimensions of the board were 25 cm × 25 cm × 1 cm, and the weight of the particles was computed using the particleboard's target density of 0.8 g/cm^3.After spraying the particles with the adhesive solution, they were oven-dried for four hours at 80 °C to lower their moisture content. After being oven-dried, the moisture content of the sprayed particles dropped to 5% ± 0.34% from 26% ± 0.33%.

The particles were manually shaped into mats measuring 25 cm by 25 cm. They were then hot-pressed at 3 MPa specific pressure using a three-step cycle (PCL-700, Riken Seiki Co., Ltd., Ojiya, Japan), following the methodology described by Widyorini *et al*. (2018). A target thickness of 10 mm was established. The mat was heated for five minutes, then for one minute during the breathing stage, and then for five more minutes, totaling ten minutes of pressing. 160°C, 180°C, and 200°C were used for pressing. Following about a week of conditioning at room temperature, the particleboards' mechanical and physical qualities were assessed in accordance with the Japanese Industrial Standard for Particleboard.

Sotannde *et al*.,(2012)evaluated cement-bonded particle boards produced from afzeliaafricana wood residues. Green sawdust and wood flakes of Afzeliaafricana were collected from the Baga road timber market in Maiduguri, Borno state, northeastern Nigeria. The materials were stored at a constant room temperature for four months in the Forestry and Wildlife Department's wood utilisation laboratory at the University of Maiduguri. This allowed for the breakdown and degradation of wood components like glucose, lignin, and cellulose prior to treatment. The materials were extracted in hot water at 85○C to break down inhibitory sugar compounds. The extracted materials were air dried in a controlled environment for two weeks to achieve a moisture content of around 12% before use. To make each board, sawdust and flakes were dry-mixed with cement at the specified w/c ratio. Chemical additives ($CaCl_2$, $MgCl_2$, and $AlCl_3$) were dissolved in water at 2% by weight of cement, sprinkled on the wood-cement composite, and mixed to form a uniform lump. The stock was hand-formed in a 30 cm × 30 cm wooden mould, then placed on a metal plate and covered with polythene sheet. The mat was then secured with four 1 cm stoppers at the edges and pre-pressed with a wooden press. The pre-pressed mat was covered with another polythene sheet, followed by the upper metal plate. Five replications were prepared for each production batch. The mats were then cold pressed in a 5-ton hydraulic jack press for 24 hours. After pressing, the boards were demolded and cured at room temperature for one month. The production batches were replicated five times based on wood particle type, chemical additives, and w/c mixing ratios. The boards were trimmed, cut into 20×20cm specimens, and tested following ASTM D 1037-93. The board density, thickness swelling (TS), and percentage of water absorption (WA) were measured manually. The internal bonding strength (IBS), modulus of rupture (MOR), and compressive strength (CS) of the boards were tested using the Otto Wolpert-Werke GMBH D-6700 universal testing machine.

Poonia *et al*., (2018) carried out a comparison of the physical and mechanical properties of particle boards of bamboos bonded with urea formaldehyde resin. The raw materials used were Dendrocalamusstrictus and Bambusa polymorpha, which were harvested from the Forest Research Institute (located at 300 19'N and 78 0 04'E), Dehradun.

Urea formaldehyde (UF) resin, was used as a binding material in the board-making process, and was the raw material utilised as a chemical at a 35% solid content. With the aid of a condux mill, the air-dried bamboo culms were reduced to small chips or particles. To achieve uniformly sized particles by eliminating dust, the D. strictus and B. polymorpha particles were filtered through a 20-mesh screen. To get the accepted particles' moisture content down to 6–8%, they were dried in an oven set at 50–60°C.Before being evaluated for their properties, these particle boards were conditioned for 24 hours at room temperature and humidity after being hot-pressed. According to IS: 2380 (Anon., 1977) and IS: 3087 (Anon., 1985), the physical and mechanical characteristics of the particleboard, including thickness variation, density, moisture content, water absorption, thickness swelling, swelling resulting from surface absorption, modulus of rupture, Internal bonding (IB), and screw withdrawal strength, were measured.

Grubert *et al.*, (2019) investigated the technological properties of particleboards produced using mixture of pines and bamboo. The Pinus spp. particles utilised in the panel particleboard production process were gathered from the MDP production industrial process at Bonet Madeiras e PapéisLtda Company, situated in Santa Cecília, Santa Catarina. Without making a distinction between the species, the company used eight-year-old P. taeda and P. elliottii logs from the thinning process. The P. edulis was gathered in Santa Catarina's Frei Rogério. Three-year-old bamboo splints were reduced to fragments using a mill hammer. Bamboo and Pinus spp. were sorted using oscillating screens and dried in an oven with forced air circulation at 80°C until their moisture content reached 4%. 500 particles of Pinus spp. and P. edulis were separated prior to the panels' production in order to measure their length, width, and thickness using a digital calliper. By measuring these dimensions, it was possible to calculate the flatness ratio using the relationship between width and thickness and the slenderness ratio using the ratio between length and particle thickness.

2.7 Design of Experiment

The design of any task that attempts to characterize and explain the variance of data under circumstances that are thought to represent the variation is known as the design of experiments (DOE or DOX), sometimes known as experiment design or experimental design.

It enables the manipulation of several input parameters to ascertain how they affect the intended output (response). Through simultaneous manipulation of several inputs, DOE is able to reveal significant interactions that could go unnoticed when examining one element at a time. Either the complete set of combinations (full factorial) or just a subset of them (fractional factorial) can be examined.

CHAPTER THREE

METHODOLOGY

3.1 Procedure

3.1.1 Acquisition of Materials

Fresh bamboo sticks and coconut fiber were obtained from the general market of Uselu, Benin City, while the gum arabic powder was purchased from a local chemical store within the campus of the University of Benin, Benin City. Gum Arabic content was varied from 30-35% at 16 different intervals as a a total of 48 composite samples were produced in the laboratory. The coconut fiber varied in content between 21-28%, while the grinded bamboo particles varied from 40-45%.

Plate3.1Fresh Bamboo Sticks

3.1.2 Delignification of Bamboo

Delignification is an essential process used to remove lignin, a complex polymer found in the cell walls of plant fibers like bamboo. This process is essential as lignin can interfere with the adhesion between fibers and the matrix, hindering the overall performance of the composite.

Before delignification, the bamboo was cut into smaller pieces to facilitate the delignification process. A delignification bath was prepared by dissolving 0.1 mol of sodium hydroxide (NaOH) in distilled water. The cut bamboo fiber was immersed and soaked in the delignification bath for seventy-two hours (72 hours).

Over the span of 72 hours when the bamboo fibers were immersed in the delignification bath, the delignifying agent reacted with the lignin present in the bamboo. This reaction broke down the lignin polymer chains, causing them to solubilize or disperse into the solution, while leaving the cellulose and hemicellulose components of the plant fibers largely intact.

After 72 hours had elapsed, the delignification process became complete, the delignified bamboo fiber was removed from the delignification bath and rinsed thoroughly with distilled water to remove any residual chemicals or impurities.

The delignified bamboo fiber was then air dried to remove excess moisture and then finally oven dried at a temperature of 60 degree Celsius till moisture content was reduced to about five percent.

Plate 3.2 Bamboo Soaked in Delignification Bath

3.1.3 Preparation of Materials

The oven dried bamboo was grinded into a finely grounded powder through the use of a grinding machine. Congealed gum-arabic powder was then broken up and grounded. The grounded powder was then diluted with water to form a resin adhesive -liquid in nature- in a ratio 3:1 by weight. The coconut fiber was also ground into smaller particles.

3.1.4 Mixing and Forming

The resin adhesive was then mixed with the grounded bamboo fiber and coconut fiber, according to desired viscosity and bonding power. This mix was then transferred into a 151 x 23 x 15 mm mold made from wood. The matrix content varied from 30-35% while the reinforcement varied from 20-28% for the experimental samples. As stated above, these percentages were gotten through the use of design software -Design of Experiment- which determined that sixteen runs were needed to determine the best sample.

3.1.5 Compression and Compaction

Pressure was applied to the mold using varying distributed force, to compact the composite mixture and remove air pockets, to ensure uniform density and consolidation of the material. This pressure was applied over a duration of 2 hours at room temperature.

3.1.6 Curing and Drying

The molded composite board was allowed to cure and dry at room temperature and room humidity, facilitating the crosslinking of the gum arabic matrix, resulting in a fairly strong and cohesive structure.

Plate3.3 Drying of Composite Board

3.1.7 Testing and Evaluation

The dried particle boards were evaluated in terms of modulus of elasticity, tensile stress, water absorption and thickness swelling.

3.1.7.1 Modulus of Elasticity Test

A static loading test was conducted to determine the modulus of elasticity. Holes were punched into the ends of the samples and the load was gradually increased until samples fractured. After acquiring the load at failure, modulus of elasticity was determined using the formula

$$E = \frac{\sigma}{\mathcal{E}}$$

where E is the modulus of elasticity in N/mm, $\mathcal{E}$ is strain, and σ is stress.

3.1.7.2 Water Absorption Test

Each experimental sample's weight was measured and then these samples were immersed in water at room temperature over a duration of 24 hours. After that time had elapsed, these samples were extracted from water and re-weighed. Water absorption percentage was determined by

$$WA\% = \frac{(W_W - W_D)}{W_D} * 100$$

Where WA% is the water absorption percentage, W_W is the wet weight after 24 hours and W_D is the dry weight or initial weight.

3.1.7.3 Thickness Swelling Test

Initial thickness of samples were measured, and then the samples were immersed in water over 24 hours. After the span of 24 hours, the samples were extracted and the thickness of immersed samples was measured to ascertain thickness swelling. The thickness swelling percentage was determined by

$$T_S = \frac{(T_2 - T_1)}{T_1} * 100$$

Where Ts is the thickness swelling percentage, T_2 is the final thickness in mm, and T_1 is the initial thickness in mm.

3.1.7.4 Tensile Strength Test

Samples (rectangular in shape) were mounted onto the grips of a tensile testing machine, also known as a universal testing machine (UTM), and held in place for the application of tensile force. The force was applied along the longitudinal axis of the specimen, causing it to elongate or stretch. The tensile test continues until the specimen reaches a predetermined endpoint, such as fracture or a specified level of deformation. At this point, the test is stopped, and the maximum load and corresponding deformation values are recorded.

Tensile test was determined using $T = \frac{F}{A}$

Where F is the maximum applied load in N, and A is the cross sectional area in mm^2

3.1.8 Determination of Optimum Composite Using Response Surface Methodology

Response Surface Methodology (RSM) is a statistical technique used to optimize processes by modeling the relationship between input variables and one or more response variables. First off, the response variables that are most relevant to the project are determined. These included the mechanical properties such as modulus of elasticity (MOE), tensile stress, as well as physical properties such as thickness swelling and water absorption.

The input variables that could influence the response variables are identified and they include the proportions of bamboo particles, binding agent (gum Arabic) etc.

Next up, an experimental plan was designed using RSM technique –Mixture Design. This involved selecting appropriate levels for each input variable and determining the number of experimental runs required to fit the model. The experimental runs determined were sixteen runs

For each experimental run, the values of the response variables obtained from testing and evaluation were recorded

Design-Expert software was used to fit a response surface model to the experimental data. This involved using a regression analysis to determine the relationship between the input variables and response variables.

Once the response surface model was fitted, the combination of input variables that maximizes or minimizes the response variables of interest, was determined and the best composite was identified.

3.2 Brief Description of Materials and Equipment Used

3.2.1 Wooden Mold

A wooden mold is a structure composed mainly of wood that is used to shape and confine materials during the molding or casting process.

Typically, solid wood or engineered wood materials like particleboard or plywood are used to make wooden molds. The wooden mold is constructed by fastening separate wooden components together using screws, nails, or adhesive.

Wooden molds are custom made to match the specified shape, size, and surface finish of the finished object. Surface treatments such as sealing, varnishing, or lining with release agents can be used to aid in mold release and avoid molded material adherence.

Plate3.4 A Wooden Mold

3.2.2 The Universal Testing Machine

A universal testing machine (UTM), also known as a “materials testing machine”, is a versatile and powerful tool for determining the mechanical properties of materials. Universal testing machines work on the concept of applying regulated forces to test specimens and measuring the resulting deformation or displacement. The machine applies loads in tension, compression, bending, and torsion to test the material's mechanical performance under various loading circumstances.

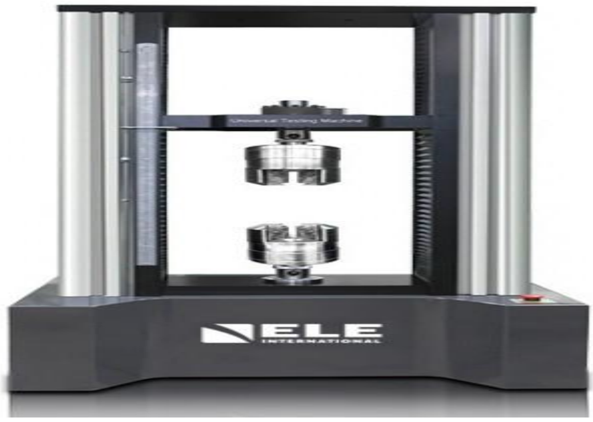


Figure 3.1 Universal Testing Machine

(https://images.app.goo.gl/6rWtiLz76gYsFQNm6, Accessed April 9, 2024)

3.2.3 The Bench Saw

A bench saw, also known as a table saw or a benchtop saw, is a flexible woodworking instrument that can cut various materials, typically wood, into precise and uniform pieces. It comprises of a flat table surface with an adjustable blade projecting from the middle that can be lifted, lowered, and slanted to make various cuts.

The bench saw consists of a several components like the blade assembly, table surface, fence, miter gauge, blade guard and riving knife etc. The table surface of a bench saw serves as a sturdy and flat platform for supporting the workpiece while cutting. The blade assembly includes a circular saw blade mounted on an arbor that is powered by a motor. The fence is a movable guide that runs parallel to the blade, providing for clean, precise cuts. The miter gauge is a tool that guides angled cuts like miter and bevel cuts. Blade guards and riving knives are safety measures that protect the operator from touch with the spinning blade and reduce kickback during cutting operations. They contribute to operator safety and lower the likelihood of accidents.

Figure 3.2Bench Saw

(https://images.app.goo.gl/NTacsB3hihicHHT37, Accessed April 9, 2024)

3.2.4 The Hack Saw

A hack saw is a handheld cutting tool that is primarily used to cut metal, as well as plastic and wood. It comprises of a frame with a detachable blade tensioned between its ends. Hack saws are widely used in workshops, construction sites, and DIY projects to cut metal pipes, rods, bars, and other tiny materials.

Figure 3.3 Hack Saw

(https://images.app.goo.gl/pDrCT825D1wLrZ2L9, Accessed April 9, 2024)

3.2.5 The Vernier Caliper

A vernier caliper, often known as a caliper, is a precision measuring tool used to measure the internal and external dimensions of things with great accuracy. It includes a main scale, a sliding vernier scale, and a movable jaw. The main scale is a graduated scale that is etched or printed along the caliper's fixed beam. It is commonly divided into millimeters (mm) or inches (in) and is used for fundamental measurements. A vernier caliper normally has two sets of jaws, one external and one inside. The external jaw measures the external dimensions of items, such as a rod's diameter or a box's width. The internal jaw, also known as the depth probe or depth rod, is used to determine the internal dimensions of objects, such as the depth of a hole or the internal diameter of a pipe.

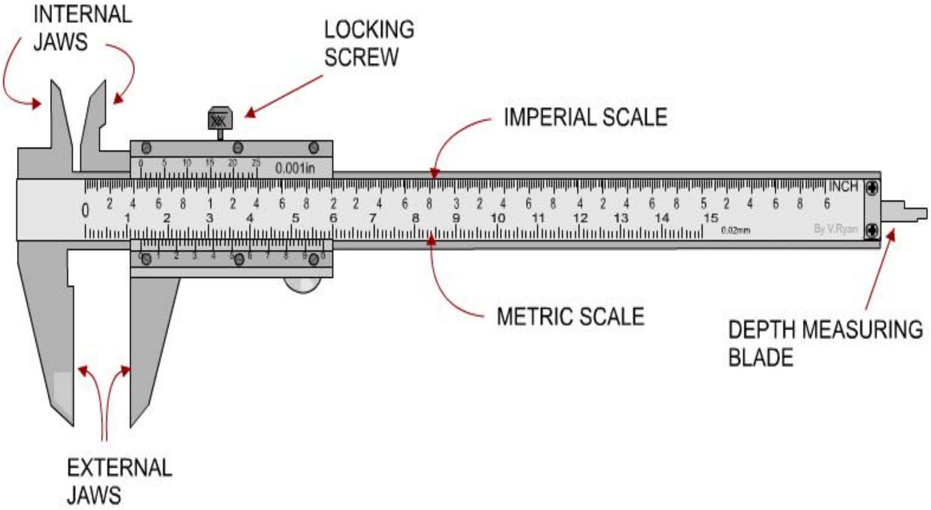


Figure 3.4 The Vernier Caliper

(https://images.app.goo.gl/pTAk18Cak8QoAnH69, Accessed April 9, 2024)

3.2.6 The Grinding Machine

These machines are specifically designed to crush and grind wood, bamboo and even perishable products into a fine powder or paste, which can then be used in various applications.

The grinders are often motorized machines that use electric motors to power the grinding mechanism. The grinding mechanism of the grinder typically consists of rotating blades that crush and grind the bamboo as they pass through the machine. These grinders usually have a hopper where the bamboo particles are loaded before being fed into the grinding mechanism.

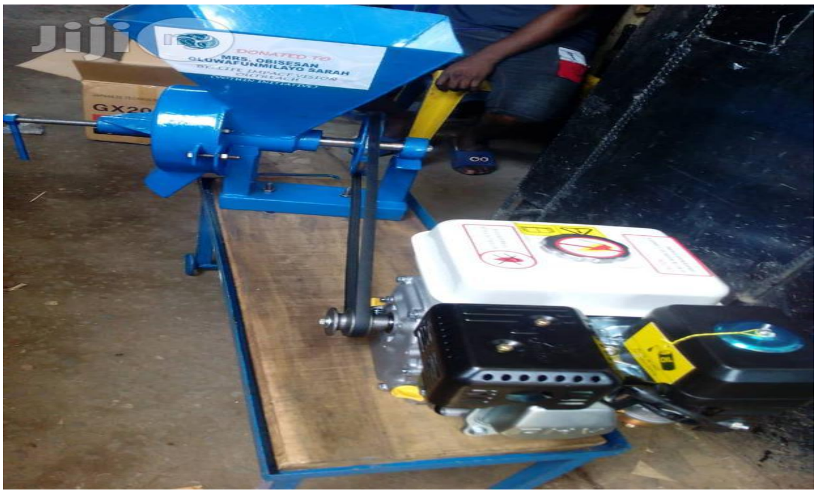


Figure 3.5 The Grinding Machine

(https://images.app.goo.gl/sxaDnMFHP3FVmefm7, Accessed April 9, 2024)

3.2.7 Digital Weight Scale

A digital weight scale, also known as an electronic scale or digital weighing scale, is a device that accurately and precisely measures the weight of objects or substances. Unlike traditional mechanical scales that rely on springs or balances, digital weight scales use electrical sensors and a digital display to deliver quick and accurate weight readings.

Plate 3.5 Digital Weight Scale

3.2.8 The Drying Oven

A drying oven, also known as a drying chamber or drying cabinet, is a specialized piece of equipment used to remove moisture or solvents from samples, materials, or goods using heat.

Drying ovens are designed with an insulated chamber made of stainless steel, aluminum, or mild steel. The insulation promotes equal temperature distribution and reduces heat loss. The chamber may include one or more adjustable shelves or racks to hold samples or materials of varying sizes and forms. The drying oven's door is supplied with seals or gaskets to provide a tight seal and prevent heat loss while in operation.

Drying ovens use heating components, such as electric resistance coils or infrared lamps, that generate heat and raise the temperature inside the chamber. A thermostat, temperature controller, or programmable logic controller (PLC) can be used to control the heating system and keep it at a steady temperature or follow a set temperature profile while drying.

Figure 3.6 The Drying Oven

(https://images.app.goo.gl/CQxFqg4ksMoZ877H9, Accessed April 9, 2024)

3.2.9 Distilled Water

Distilled water is water that has been purified by a process known as distillation. During distillation, water is heated to its boiling point, causing it to evaporate and leave contaminants such as minerals, dissolved particles, and microbes. The resulting steam is then cooled and condensed back into liquid, yielding distilled water. This technique efficiently separates pure water molecules from other things, yielding water free of most contaminants.

3.2.10 Sodium Hydroxide (NaOH)

Sodium hydroxide (NaOH), commonly known as caustic soda or lye, is a powerful alkaline compound used as a delignifying agent in various industrial processes. As a delignifying agent, NaOH plays a crucial role in breaking down lignin, a complex polymer found in the cell walls of plants, particularly in wood fibers.

Sodium hydroxide is highly alkaline, meaning it has a high pH level. When dissolved in water, NaOH dissociates into sodium ions (Na^+) and hydroxide ions (OH^-).The hydroxide ions are reactive and can attack the ester bonds present in lignin molecules, initiating a process known as alkaline hydrolysis or saponification. During alkaline hydrolysis, the hydroxide ions break the bonds between lignin molecules and other constituents of the plant cell wall, such as cellulose and hemicellulose, leading to the dissolution and solubilization of lignin.

Figure 3.8 Sodium Hydroxide

(https://images.app.goo.gl/vNcuoj3Pdrv6Dnxm8, Accessed April 9, 2024)

3.2.11 Plastic Drum

Plastic drums are used as containers or vessels for storing and transporting chemicals used in the delignification process. Plastic drums are often made of high-density polyethylene (HDPE) or other durable plastic materials that are resistant to corrosion and chemical degradation. These drums provide a safe and convenient way to handle and store large quantities of chemicals such as NaOH, which is a commonly used delignifying agent.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Experimental Results

Run	Bamboo fibre	Gum Arabic	Coir Fibre	Tensile Strength (MPa)	Modulus of elasticity (MPa)	Thickness Swelling (%)	Water absorption (%)
1	42.17	30	27.83	8	2422	31.61	51.3
2	41.51	31.88	26.61	48	2782	4.86	28.96
3	42.17	30	27.83	10	2422	31.61	51.3
4	45	31.10	23.90	33	1295	14.77	23.66
5	40	31.44	28.56	35	2765	18.94	22.69
6	40	31.44	28.56	14	2765	18.94	22.89
7	44.75	35	20.25	33	1998	18.44	26.49
8	44.78	33.10	22.13	16	1949	4.42	22.65
9	40.5	35	24.5	16	2442	2.84	23.09
10	45	31.10	23.90	14	1664	27.62	22.99
11	42.57	32.88	24.55	14	2269	9.09	19.24
12	42.57	32.88	24.55	18	2269	9.09	19.24
13	42.57	32.88	24.55	33	2269	9.09	19.24
14	40	33.58	26.42	22	1664	2.76	29.04
15	42.61	35	22.3858	10	1664	2.76	29.04
16	43.48	30.64	25.8805	15	1958	35.05	14.52

Table 4.1: Experimental Results for Bamboo Composites

4.2 Response Surface Modelling (RSM)

4.2.1 Identification of Most Appropriate Model

i) Model Fit Results

Modulusof Elasticity						
Source	**Std. Dev.**	**R²**	**Adjusted R²**	**Predicted R²**	**PRESS**	
Linear	42.22	0.12	-0.04	-0.63	36396.12	
Quadratic	36.37	0.53	0.24	-2.47	77301.82	
Special Cubic	38.21	0.54	0.15	-18.57	4.37E+05	
Cubic	6.74	0.99	0.97		*	Aliased
Special Quartic	**6.74**	**0.99**	**0.97**		*	**Suggested**
Tensile Strength						
Source	**Std. Dev.**	**R²**	**Adjusted R²**	**Predicted R²**	**PRESS**	**Remark**
Linear	0.80	0.02	-0.13	-0.44	12.26	
Quadratic	0.86	0.14	-0.29	-0.88	16.05	
Special	0.90	0.14	-0.43	-1.86	24.35	

Cubic						
Cubic	**0.51**	**0.81**	**0.54**	**-17.56**	**158.20**	**Suggested**
Special Quartic	1.01	0.16	-0.80	-346.55	2962.54	
Quartic	0.11	0.99	0.98		*	Aliased
Thickness Swelling						
Source	**Std. Dev.**	**R²**	**Adjusted R²**	**Predicted R²**	**PRESS**	**Remark**
Linear	6.94	0.62	0.55	0.29	993.64	
Quadratic	**4.57**	**0.88**	**0.81**	**0.63**	**526.35**	**Suggested**
Special Cubic	4.88	0.88	0.78	0.32	952.09	
Cubic	4.06	0.94	0.85		*	Aliased
Special Quartic	4.06	0.94	0.85		*	
Quartic					*	Aliased
Water Absorption						
Source	**Std. Dev.**	**R²**	**Adjusted R²**	**Predicted R²**	**PRESS**	**Remark**
Linear	62.55	0.43	0.33	0.07	70560.29	
Quadratic	**46.45**	**0.77**	**0.63**	**0.18**	**62228.65**	**Suggested**
Special	48.34	0.78	0.60	-1.31	1.75E+05	

Cubic						
Cubic	3.06	0.99	0.99		*	Aliased
Special Quartic	**3.06**	**0.99**	**0.99**		*	**Suggested**
Quartic					*	Aliased

Table 4.2 Model Fit Results

ii) Lack of Fits Test Results

Modulus of Elasticity						
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-value**	**p-value**	
Linear	19385.30	6	3230.88	71.15	0.0001	
Quadratic	10353.23	3	3451.08	76.00	0.0001	
Special Cubic	9992.56	2	4996.28	110.02	< 0.0001	
Cubic	0.0000	0				Aliased
Special Quartic	**0.0000**	**0**				**Suggested**
Tensile Stress						

Source	**Sum of Squares**	**Df**	**Mean Square**	**F-value**	**p-value**	**Remark**
Linear	8.29	8	1.04	82.07	< 0.0001	
Quadratic	7.28	5	1.46	115.38	< 0.0001	
Special Cubic	7.27	4	1.82	144.08	< 0.0001	
Cubic	**1.51**	**1**	**1.51**	**120.00**	**0.0001**	**Suggested**
Special Quartic	7.10	2	3.55	281.12	< 0.0001	
Quartic	0.0000	0				Aliased
Pure Error	0.0631	5	0.0126			
Thickness Swelling						
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-value**	**p-value**	**Remark**
Linear	446.62	6	74.44	4.51	0.0599	
Quadratic	**84.80**	**3**	**28.27**	**1.71**	**0.2793**	**Suggested**
Special Cubic	84.11	2	42.06	2.55	0.1727	
Cubic	0.0000	0				Aliased
Special Quartic	0.0000	0				
Quartic	0.0000	0				Aliased
Pure Error	82.56	5	16.51			

Water Absorption						
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-value**	**p-value**	**Remark**
Linear	42990.88	6	7165.15	765.93	< 0.0001	
Quadratic	**17215.64**	**3**	**5738.55**	**613.43**	**< 0.0001**	**Suggested**
Special Cubic	16307.53	2	8153.76	871.60	< 0.0001	
Cubic	0.0000	0				
Special Quartic	**0.0000**	**0**				**Suggested**
Quartic	0.0000	0				Aliased
Pure Error	46.77	5	9.35			

Table 4.3 Lack of Fits Result

4.3 Analysis of statistical models

The final model equations that reflect these reactions in terms of the input components, bamboo fibre level (X1), gum arabic level (X2), and Coir fiber level (X3), are provided below.

$$Thickness\ Swelling = 21.9X1 + 52.2X2 + 42.87X1X2 - 1.25X1X3 - 0.6X2X3 - 1.59X1X2X3$$

4.4 Comparison Between Experimental and RSM Predicted Results

Modulus Of Elasticity

Run	Bamboo fibre	Gum Arabic	Coir Fibre	Actual Value	Predicted Value
1	42.17	30	27.83	24.22	22.39
2	41.52	31.88	26.61	27.82	9.74
3	42.17	30	27.83	24.22	22.39
4	45	31.09	23.90	127.95	117.03
5	40	31.44	28.56	27.65	31.19
6	40	31.44	28.56	27.65	31.19
7	44.75	35	20.25	19.98	21.93
8	44.78	33.09	22.13	59.49	52.81
9	40.5	35	24.5	24.42	23.55
10	45	31.09	23.90	106.64	117.03
11	42.57	32.88	24.55	22.69	27.73
12	42.57	32.88	24.55	22.69	27.73
13	42.57	32.88	24.55	22.69	27.73
14	40	33.58	26.42	106.64	106.31
15	42.61	35	22.39	106.64	105.15
16	43.48	30.64	25.88	19.58	27.08
Tensile Strength					
Run	**Bamboo fibre**	**Gum Arabic**	**Coir Fibre**	**Actual Value**	**Predicted Value**
1	42.17	30	27.83	0.08	0.09
2	41.52	31.88	26.61	0.48	-0.09
3	42.17	30	27.83	0.02	0.09

4	45	31.09	23.90	0.33	0.35
5	40	31.44	28.56	0.36	0.35
6	40	31.44	28.56	0.14	0.35
7	44.75	35	20.25	0.33	0.59
8	44.78	33.09	22.13	0.16	-0.32
9	40.5	35	24.5	0.16	0.44
10	45	31.09	23.90	0.14	0.35
11	42.57	32.88	24.55	0.14	0.57
12	42.57	32.88	24.55	0.18	0.57
13	42.57	32.88	24.55	0.33	0.57
14	40	33.58	26.42	0.22	-0.07
15	42.61	35	22.39	1.77	1.28
16	43.48	30.64	25.88	2.87	2.63
Thickness Swelling					
Run	**Bamboo fibre**	**Gum Arabic**	**Coir Fibre**	**Actual Value**	**Predicted Value**
1	42.17	30	27.83	31.61	34.22
2	41.52	31.88	26.61	4.86	12.18
3	42.17	30	27.83	31.61	34.22
4	45	31.10	23.90	14.77	22.19
5	40	31.44	28.56	18.94	17.50
6	40	31.44	28.56	18.94	17.50
7	44.75	35	20.25	18.44	14.17
8	44.78	33.09	22.13	4.42	10.72

9	40.5	35	24.5	2.84	2.53
10	45	31.10	23.90	27.62	22.19
11	42.57	32.88	24.55	9.09	6.64
12	42.57	32.88	24.55	9.09	6.64
13	42.57	32.88	24.55	9.09	6.64
14	40	33.58	26.42	2.76	2.36
15	42.61	35	22.39	2.76	6.83
16	43.48	30.64	25.88	35.05	25.36

Water Absorption

Run	Bamboo fibre	Gum Arabic	Coir Fibre	Actual Value	Predicted Value
1	42.17	30	27.83	51.30	64.10
2	41.52	31.88	26.61	283.96	216.43
3	42.17	30	27.83	51.30	64.10
4	45	31.10	23.90	233.66	236.04
5	40	31.44	28.56	226.69	230.45
6	40	31.44	28.56	226.89	230.45
7	44.75	35	20.25	266.49	277.00
8	44.78	33.09	22.13	226.65	201.51
9	40.5	35	24.5	233.09	236.61
10	45	31.10	23.90	223.99	236.04
11	42.57	32.88	24.55	191.24	219.36
12	42.57	32.88	24.55	191.24	219.36
13	42.57	32.88	24.55	191.24	219.36

14	40	33.58	26.42	294.04	297.16
15	42.61	35	22.39	294.04	268.84
16	43.48	30.64	25.88	142.52	111.51

Table 4.4 Comparison of Experimental and RSM Predicted Results

4.5 Model Diagnostics

Diagnosis of the models developed to predict the responses for the composites was also carried out to assess their accuracy and indeed adequacy for the intended purpose

4.5.1 Normal Probability Plot

The normal probability plot is used to evaluate whether or not a dataset is approximately normally distributed

i)Modulus of Elasticity

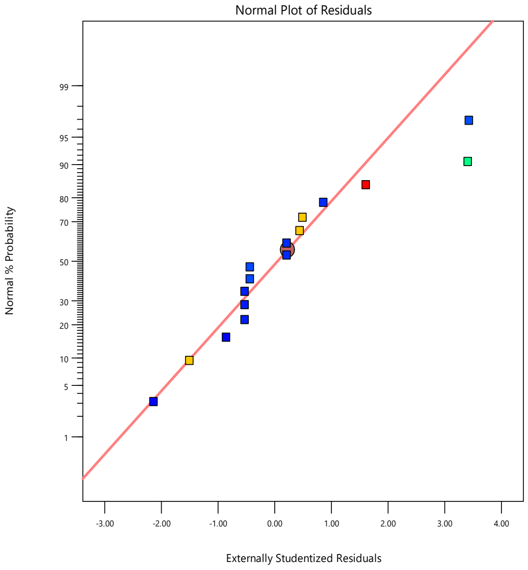


Figure 4.1 Normal probability plot for Modulus of Elasticity

ii)Tensile Strength

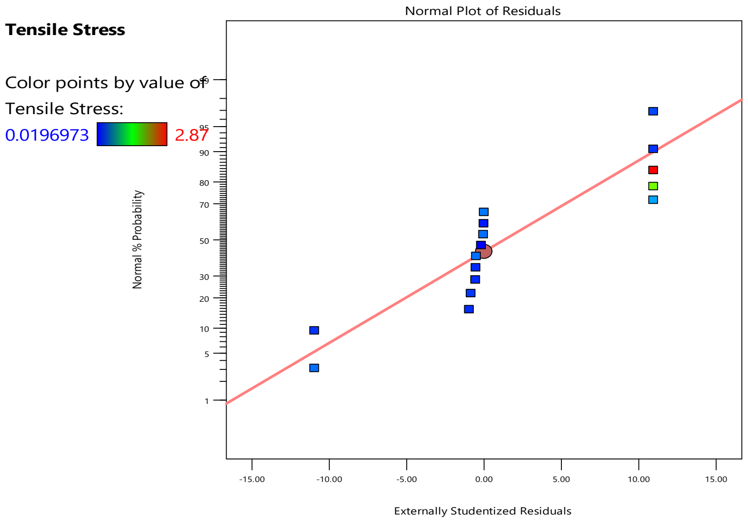


Figure 4.2 Normal probability plot for Tensile Strength

iii) Thickness Swelling

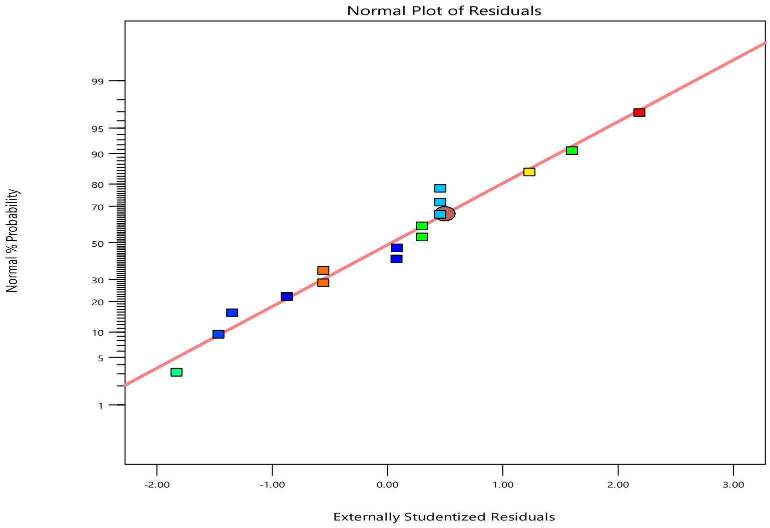


Figure 4.3 Normal probability plot for Thickness Swelling

iv) Water Absorption

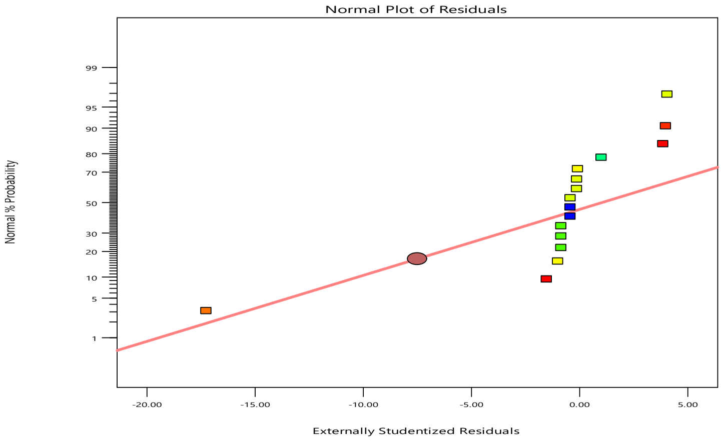


Figure 4.4 Normal probability plot for Water Absorption

4.5.2 Cook’s Distance

The plot of Cook’s distance is used to determine the presence of outliers.

i) Modulus of Elasticity

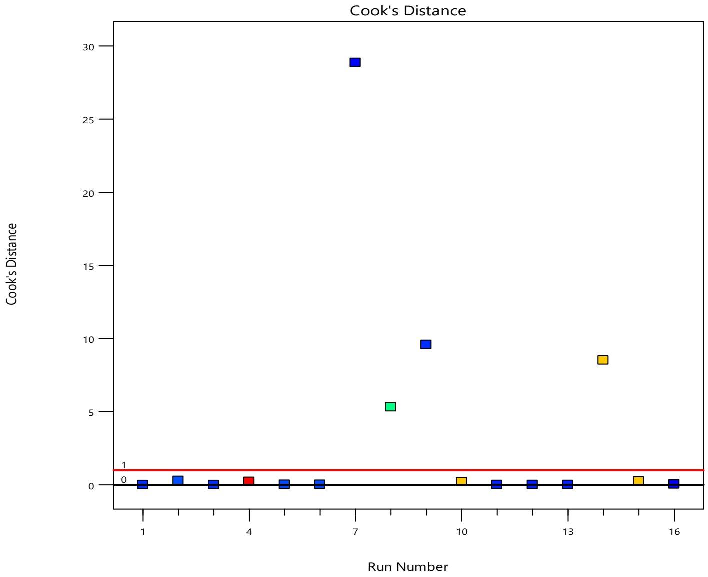


Figure 4.5 Cook Distance Plot for Modulus of Elasticity

ii) Tensile Strength

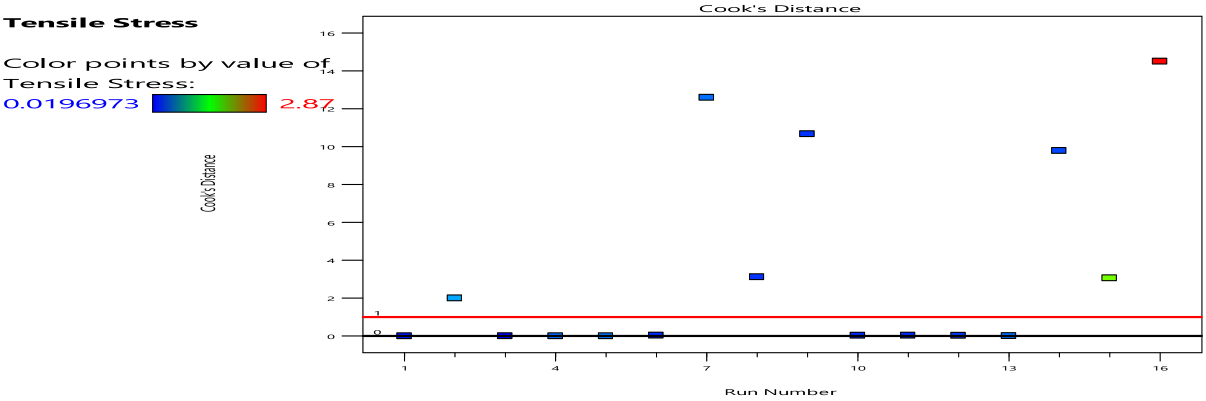


Figure 4.6 Cook Distance Plot for Tensile Strength

iii) Thickness Swelling

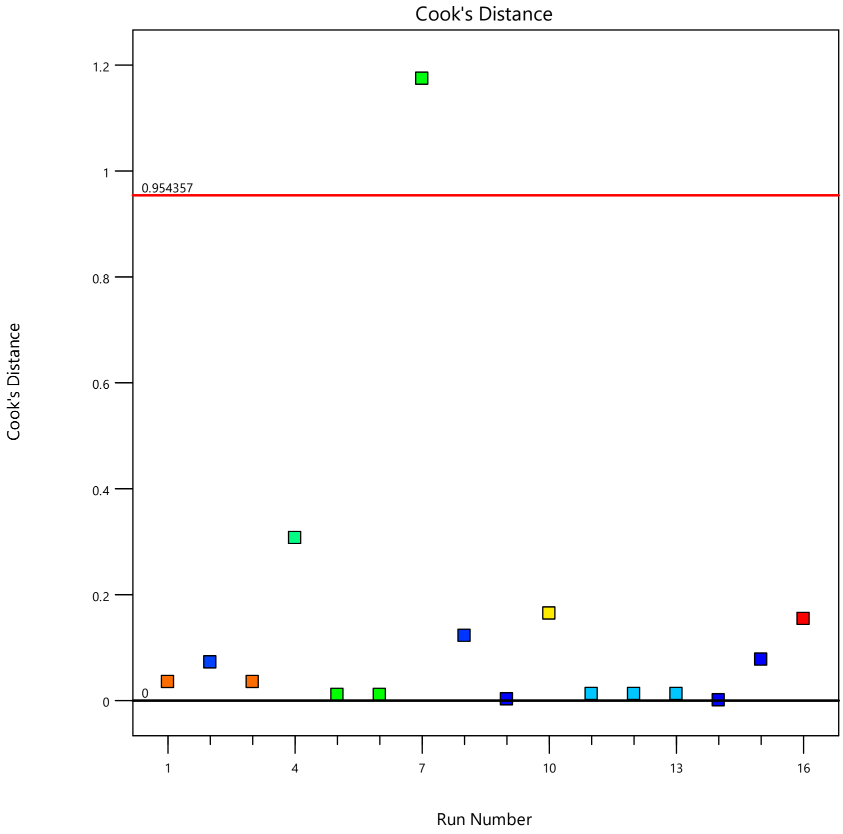


Figure 4.7 Cook Distance Plot for Thickness Swelling

iv) Water Absorption

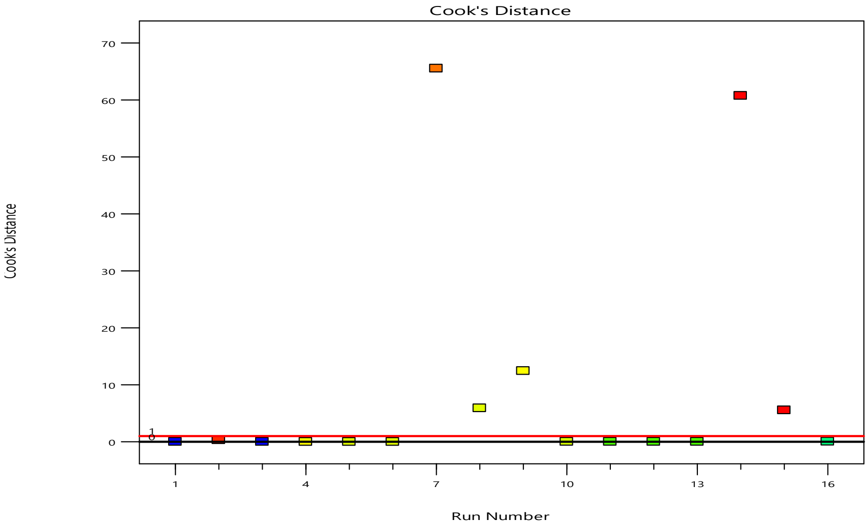


Figure 4.8 Cook Distance Plot for Water Absorption

4.5.3 Residual vs Run

The plot of externally studentized residuals versus experimental runs checks for lurking variables that may have influenced the response during the experiment

i) Modulus of Elasticity

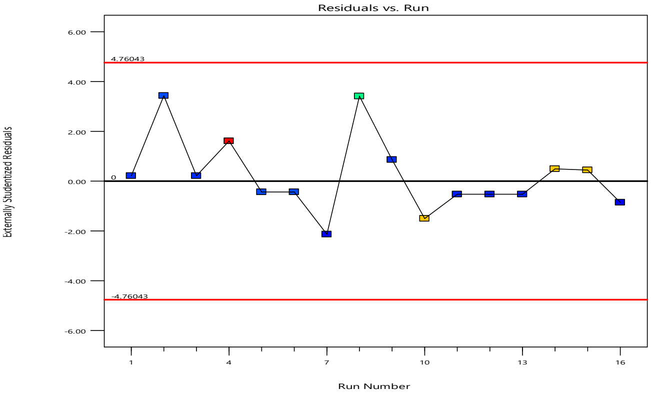


Figure 4.9: Plot of Residuals Versus Experimental Run for Model Representing Modulus of Elasticity

ii) Tensile Strength

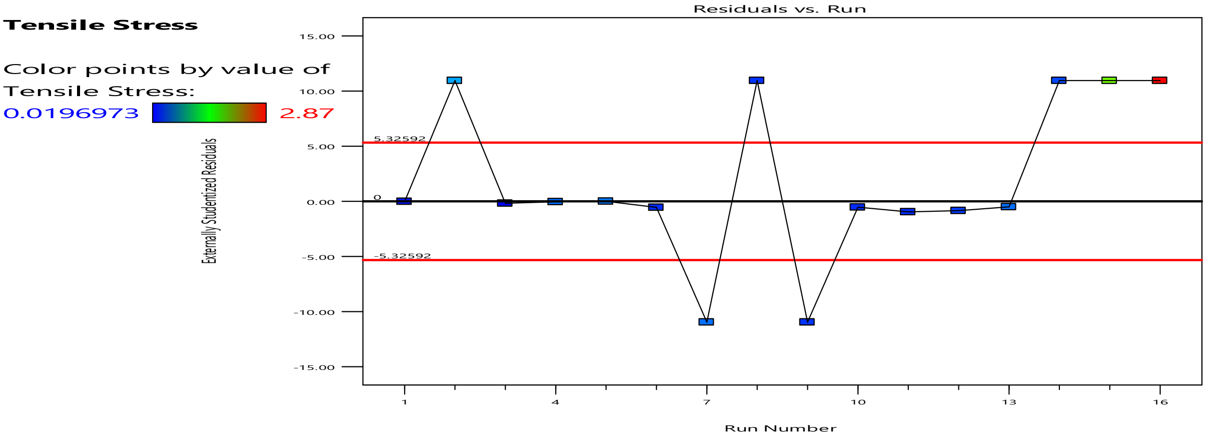


Figure 4.10: Plot of Residuals Versus Experimental Run for Model Representing Tensile Strength

iii) Thickness Swelling

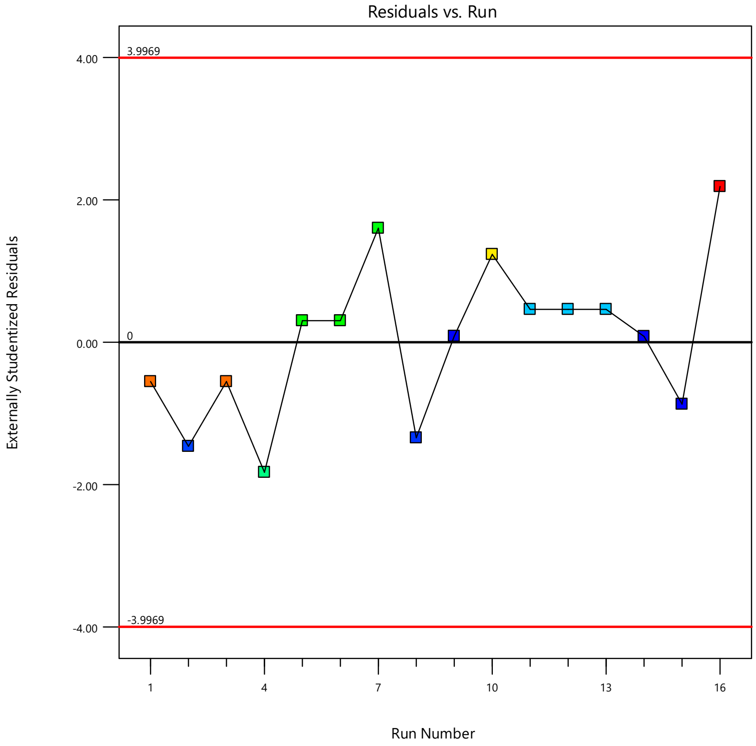


Figure 4.11: Plot of Residuals Versus Experimental Run for Model Representing Thickness Swelling

iv) Water Absorption

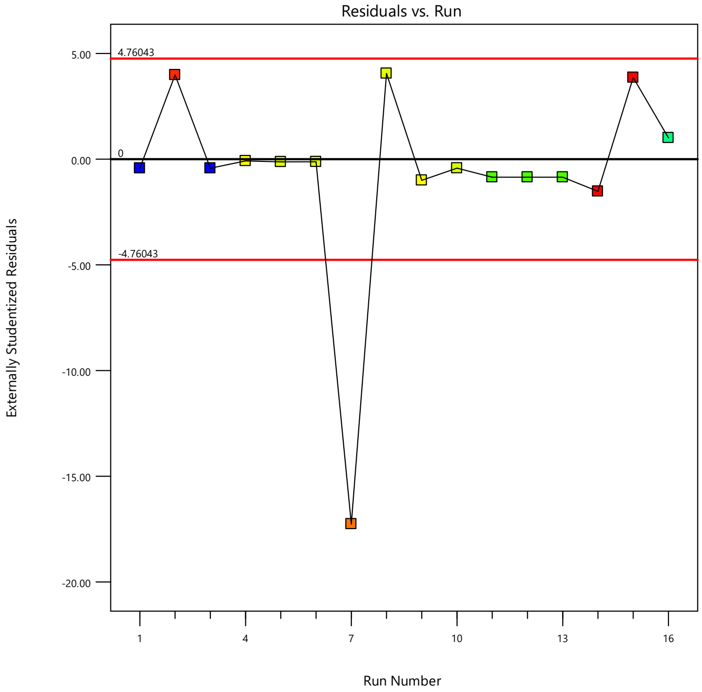


Figure 4.12: Plot of Residuals Versus Experimental Run for Model Representing Water Absorption

4.5.4 Difference in Fits (DFFITS)

The DIFFTS tells whether a particular experimental observation will influence the prediction model.

i) Modulus of Elasticity

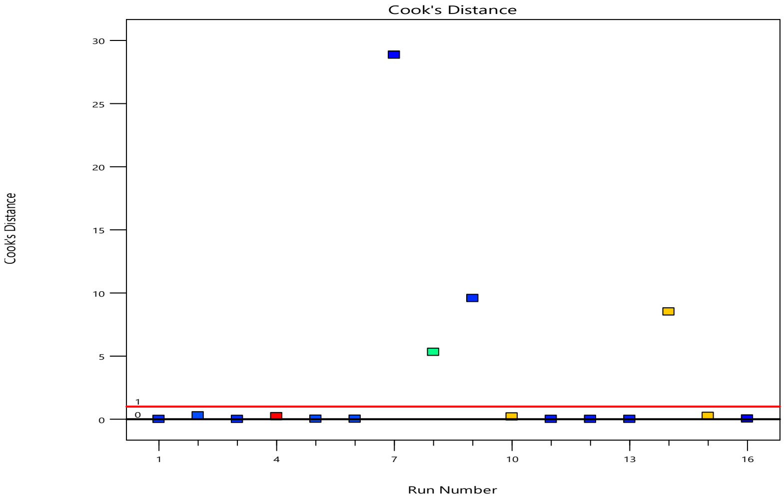


Figure 4.13: Plot of DFFITS Versus Experimental Run for Model Representing Modulus of Elasticity

ii) Tensile Strength

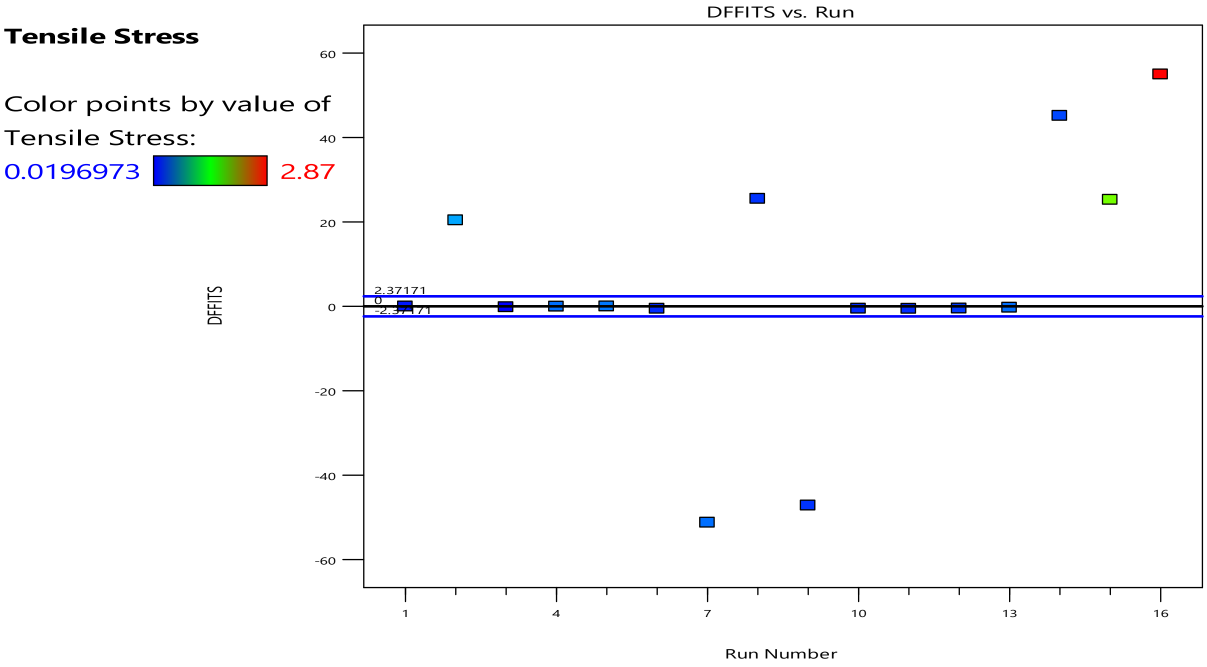


Figure 4.14: Plot of DFFITS Versus Experimental Run for Model Representing Tensile Strength

iii) Thickness Swelling

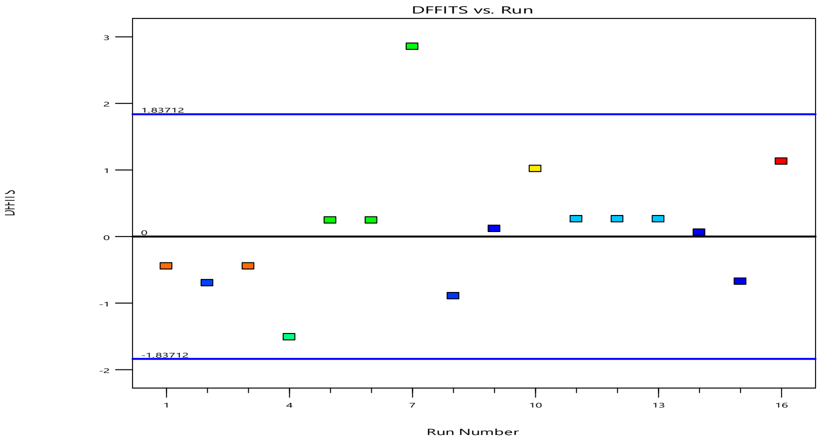


Figure 4.15: Plot of DFFITS Versus Experimental Run for Model Representing Thickness Swelling

iv) Water Absorption

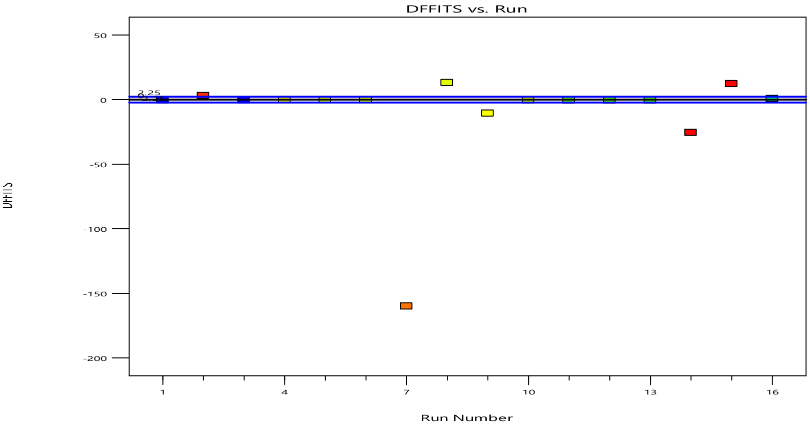


Figure 4.16: Plot of DFFITS Versus Experimental Run for Model Representing Water Absorption

4.5.5 Analysis of Variance (ANOVA)

i) Modulus of Elasticity

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	22506.89	8	2813.36	25.59	0.0002	significant
(1)Linear Mixture	2414.37	2	1207.18	10.98	0.0069	
AB	431.10	1	431.10	3.92	0.0882	
AC	5875.66	1	5875.66	53.44	0.0002	
BC	8022.92	1	8022.92	72.97	< 0.0001	

A^2BC	7578.59	1	7578.59	68.93	< 0.0001	
AB^2C	8565.76	1	8565.76	77.91	< 0.0001	
ABC^2	8603.88	1	8603.88	78.26	< 0.0001	
Residual	769.61	7	109.94			
Lack of Fit	542.55	2	271.28	5.97	0.0473	significant
Pure Error	227.06	5	45.41			
Cor Total	23276.50	15				

Table 4.5: Analysis of Variance for Modulus of Elasticity

ii) Tensile Strength

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	6.95	9	0.77	2.94	0.1015	not significant
(1)Linear Mixture	0.18	2	0.09	0.33	0.7285	
AB	0.63	1	0.63	2.41	0.1718	
AC	3.87	1	3.87	14.72	0.0086	
BC	1.32	1	1.32	5.01	0.0665	
ABC	0.58	1	0.58	2.19	0.1895	
AB(A-B)	1.79	1	1.79	6.79	0.0403	
AC(A-C)	3.51	1	3.51	13.34	0.0107	
BC(B-C)	1.51	1	1.51	5.73	0.0538	
Residual	1.58	6	0.26			

Lack of Fit	1.51	1	1.51	120.00	0.0001	significant
Pure Error	0.06	5	0.01			

Table 4.6: Analysis of Variance for Tensile Stress

iii) Thickness Swelling

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1580.30	5	316.06	9.23	0.0017	significant
(1)Linear Mixture	1177.31	2	588.66	17.19	0.0006	
AB	82.90	1	82.90	2.42	0.1508	
AC	12.92	1	12.92	0.37	0.5529	
BC	352.55	1	352.55	10.29	0.0094	
Residual	342.50	10	34.25			
Lack of Fit	259.94	5	51.99	3.15	0.1169	not significant
Pure Error	82.56	5	16.51			
Cor Total	1922.80	15				
Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	1580.30	5	316.06	9.23	0.0017	significant
(1)Linear Mixture	1177.31	2	588.66	17.19	0.0006	

Table 4.7: Analysis of Variance for Thickness Swelling

iv) Water Absorption

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	71034.32	8	8879.29	6.34	0.0124	significant
(1)Linear Mixture	37592.35	2	18796.17	13.43	0.0040	
AB	31.23	1	31.23	0.02	0.8855	
AC	14265.62	1	14265.62	10.19	0.0152	
BC	7726.89	1	7726.89	5.52	0.0511	
A^2BC	8490.98	1	8490.98	6.06	0.0433	
AB^2C	8346.06	1	8346.06	5.96	0.0447	
ABC^2	2404.21	1	2404.21	1.72	0.2314	
Residual	9800.13	7	1400.02			
Lack of Fit	9753.36	2	4876.68	521.30	< 0.0001	significant
Pure Error	46.77	5	9.35			
Cor Total	80834.46	15				

Table 4.8: Analysis of Variance for Water Absorption

4.6 Goodness Fit Statistics

Parameter	Modulus of Rupture	Tensile Strength	Thickness Swelling	Water Absorption

R^2	0.97	0.81	0.82	0.88
Adjusted R^2	0.93	0.54	0.73	0.74
Mean	48.19	0.48	15.12	208.02
Standard Deviation	10.48	0.51	5.85	37.42
CV	21.76	106.04	38.71	17.99
Adequate Precision	13.64	7.28	8.89	8.30

Table 4.9 Goodness of Fit Statistics

4.7 3D Response Surface Plot

4.7.1 Effect of Input Factors on all Tests (Contour & Surface Plots)

i) Modulus of Elasticity

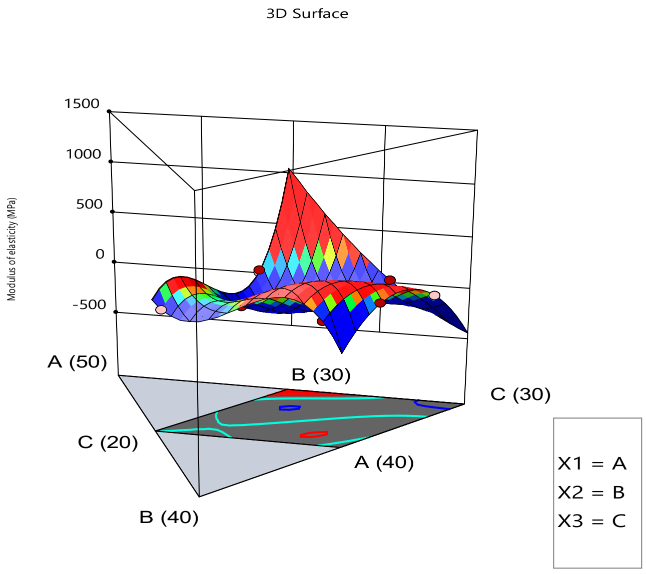


Figure 4.17 Surface Plots For Modulus of Elasticity

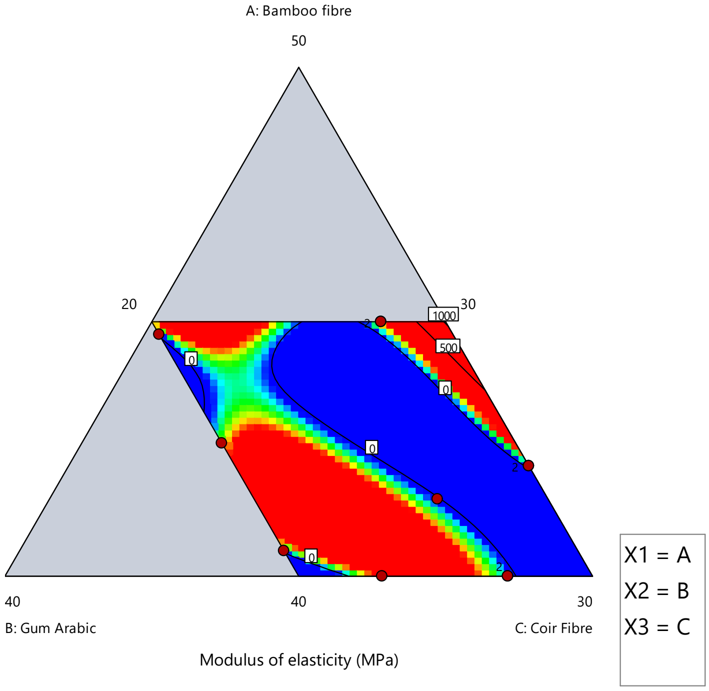


Figure 4.18: Contour Plot for Modulus of Elasticity

ii) Tensile Stress

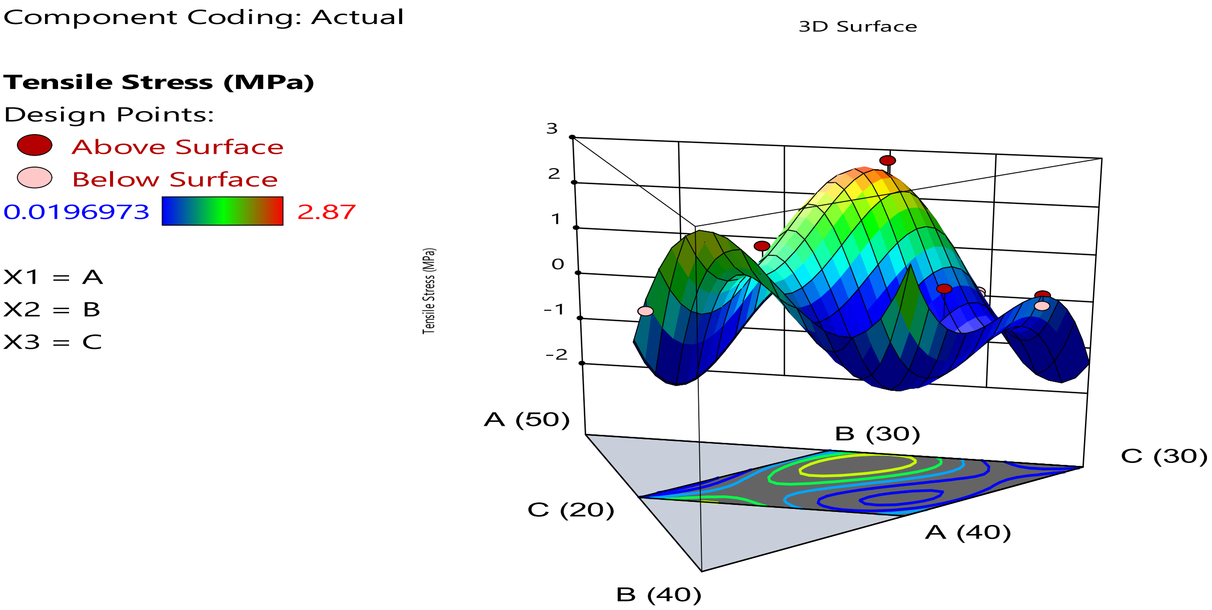


Figure 4.19: Surface Plot for Tensile Stress

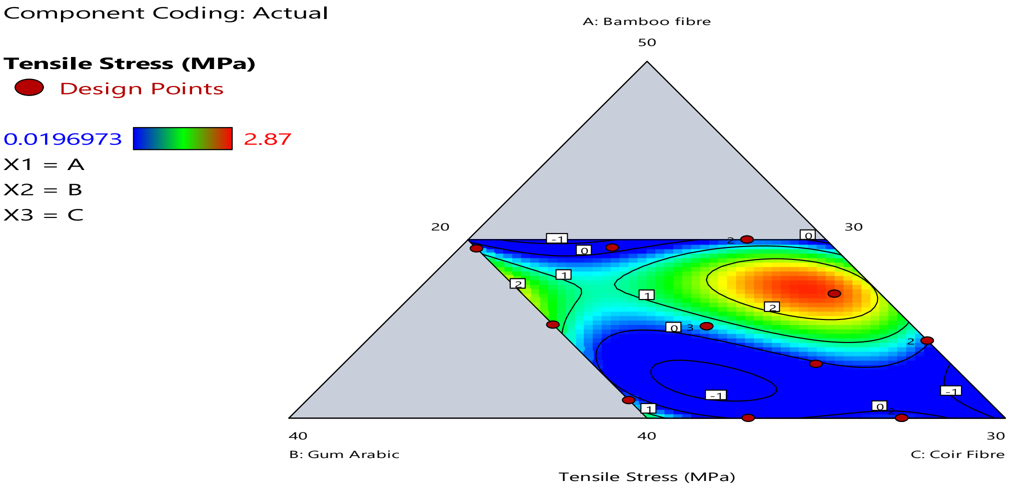


Figure 4.20 Contour Plot forTensile Stress

iii) Thickness Swelling:

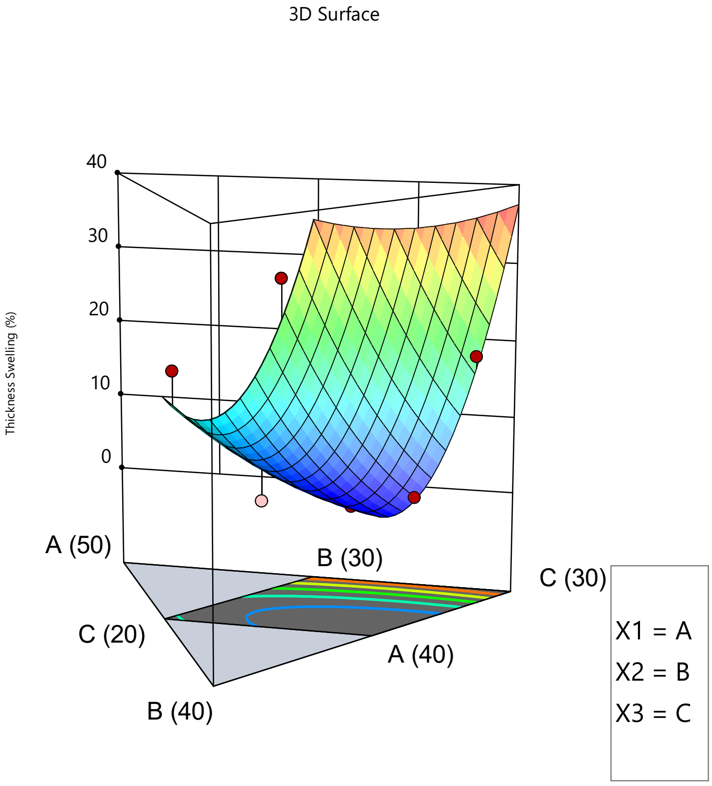


Figure 4.21 Surface Plot for Thickness Swelling

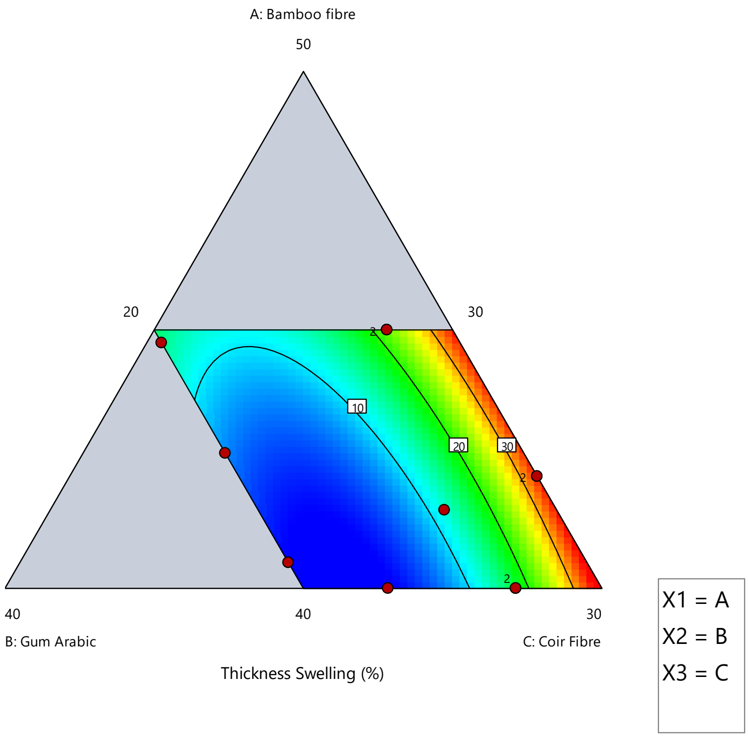


Figure 4.22 Contour Plot for Thickness Swelling

iv) Water Absorption

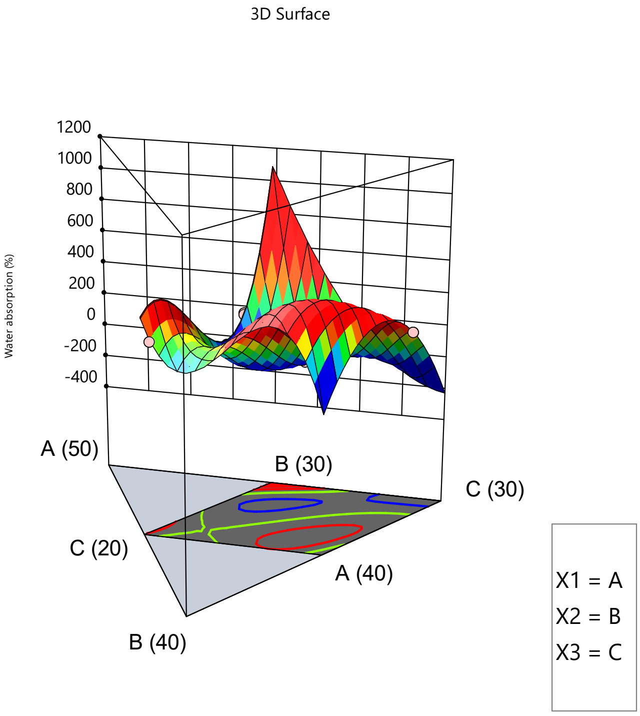


Figure 4.23: Surface Plot for Water Absorption

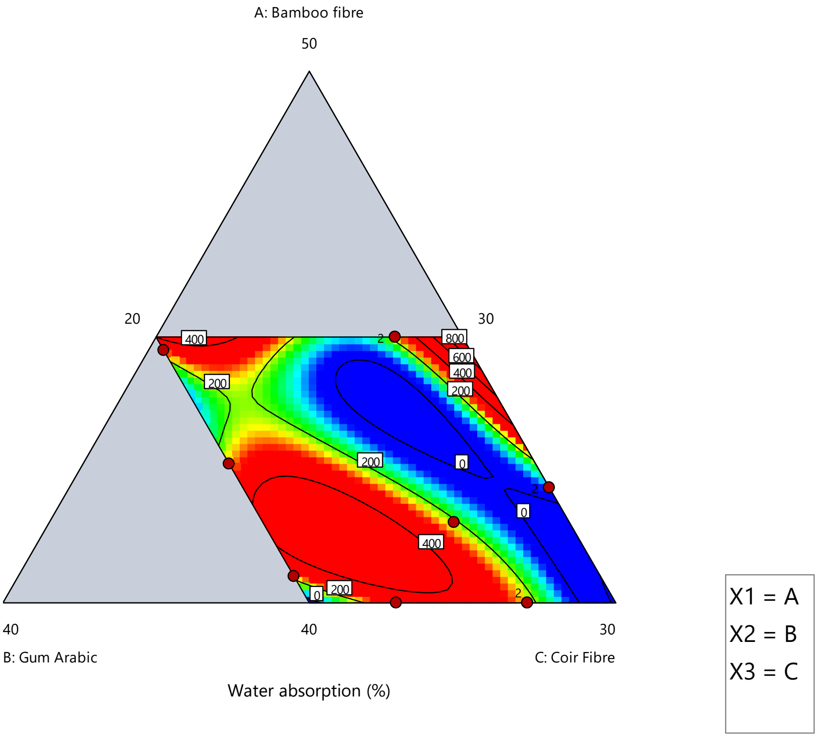


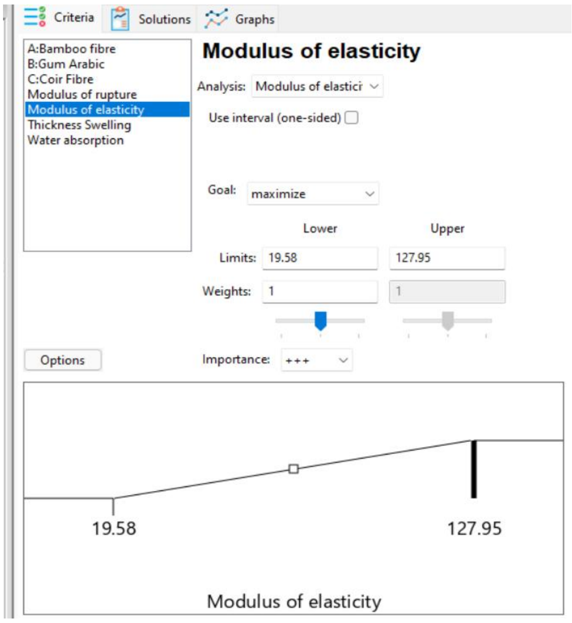
Figure 4.24: Contour Plot for Water Absorption

4.8 Optimization of Input Factors and Responses

Constraints for Numerical Optimization

Name	**Goal**	**Lower Limit**	**Upper Limit**	**Lower Weight**	**Upper Weight**	**Importance**
A:Bamboo fibre	is in range	40	45	1	1	3
B:Gum Arabic	is in range	30	35	1	1	3
C:Coir Fibre	is in range	20	30	1	1	3
Modulus of elasticity	maximize	19.58	127.95	1	1	3
Tensile Strength	maximize	0.02	2.87	1	1	3
Thickness Swelling	minimize	2.76	35.05	1	1	3
Water absorption	minimize	51.3	294.04	1	1	3

4.10 Table of Constraints for Numerical Optimization



Modulus of elasticity

Analysis: Modulus of elastici

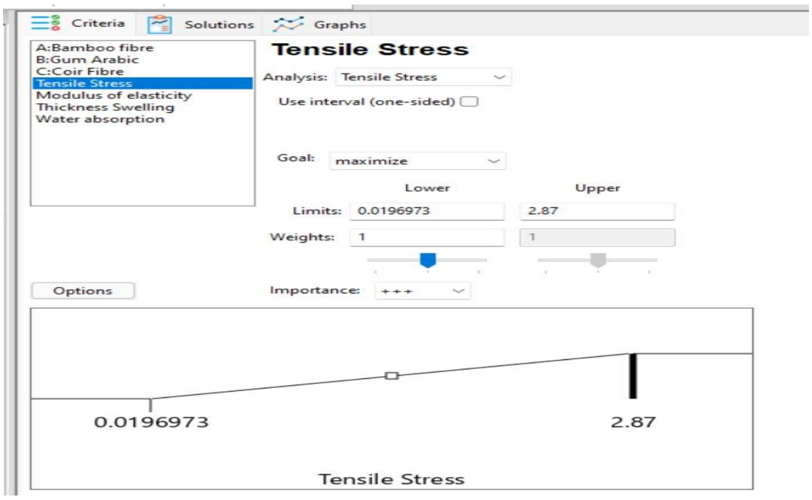
Use interval (one-sided) ☐

Goal: maximize

	Lower	Upper
Limits:	19.58	127.95
Weights:	1	1

Importance: +++

Figure 4.25: Optimization step for Modulus of Elasticity



Tensile Stress

Analysis: Tensile Stress

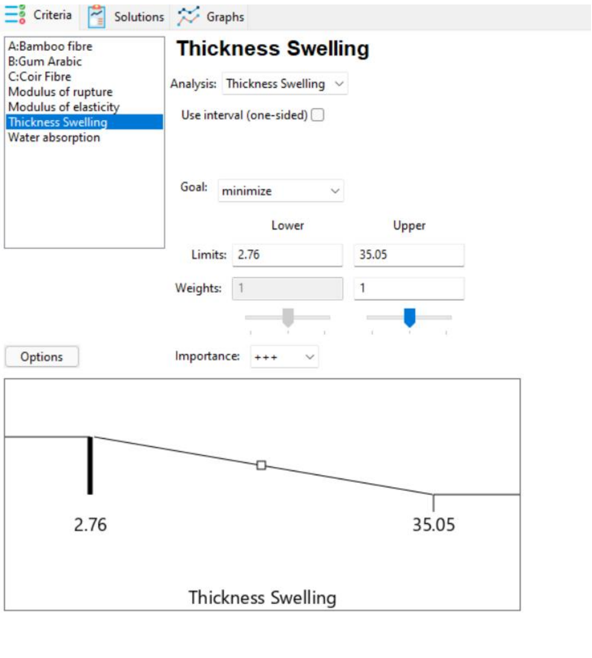
Use interval (one-sided) ☐

Goal: maximize

	Lower	Upper
Limits:	0.0196973	2.87
Weights:	1	1

Importance: +++

Figure 4.26: Optimization step for Tensile Strength



Thickness Swelling

Analysis: Thickness Swelling

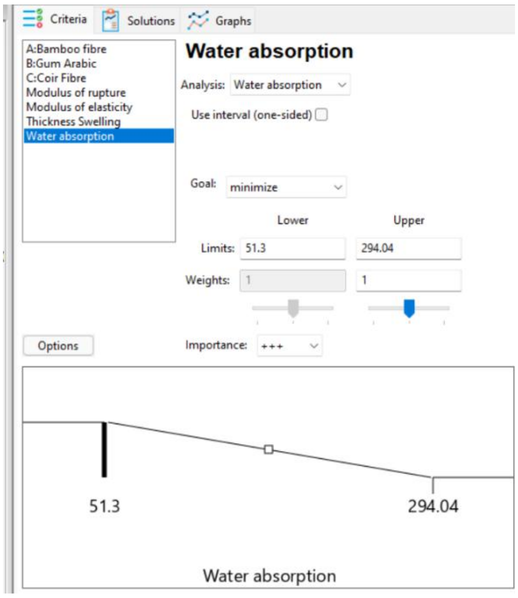
Use interval (one-sided) ☐

Goal: minimize

	Lower	Upper
Limits:	2.76	35.05
Weights:	1	1

Importance: +++

Figure 4.27: Optimization step for Thickness Swelling



Water absorption

Analysis: Water absorption

Use interval (one-sided) ☐

Goal: minimize

	Lower	Upper
Limits:	51.3	294.04
Weights:	1	1

Importance: +++

Figure 4.28: Optimization step for Water Absorption

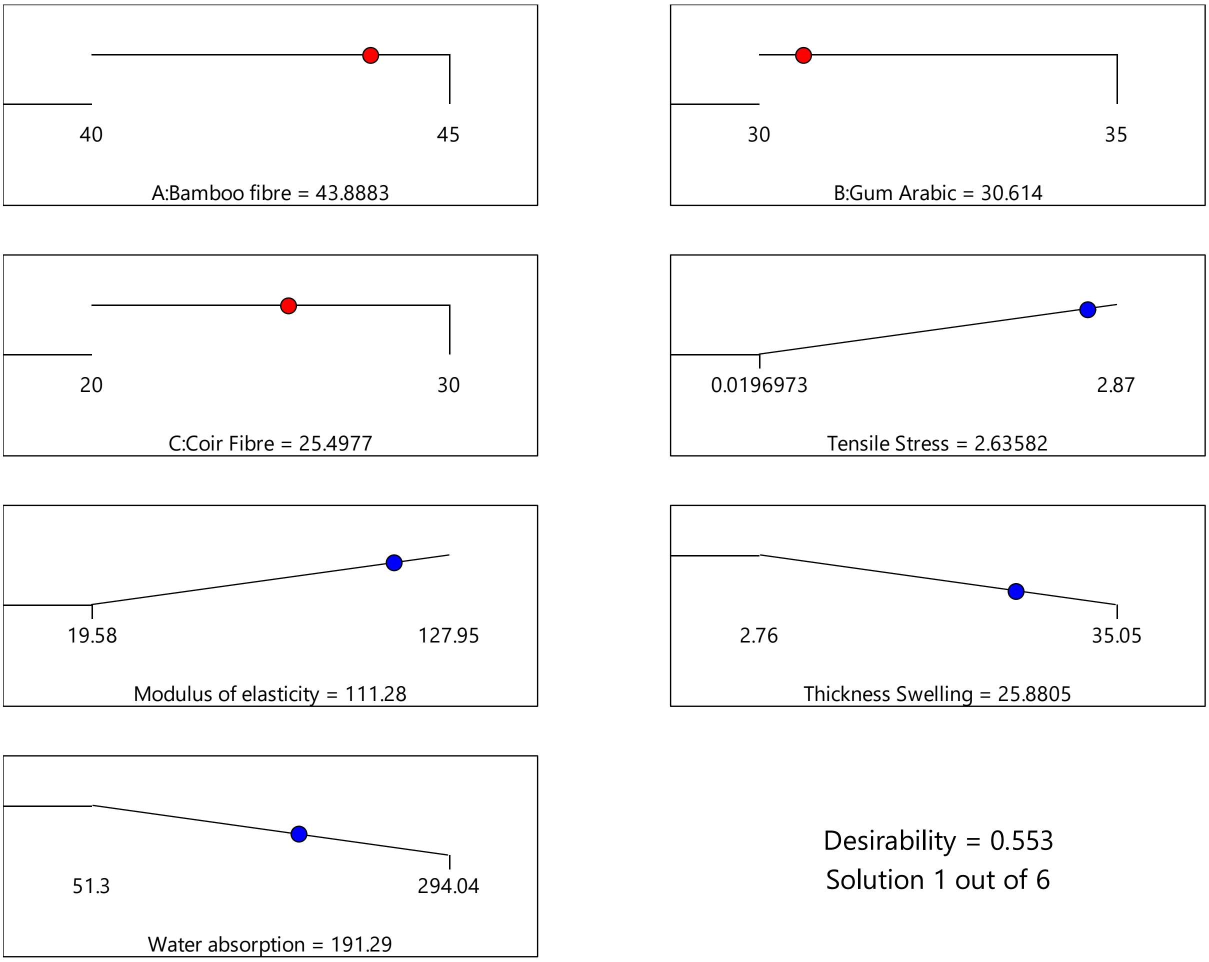


Figure 4.26: Solution to Optimization Problem

Variable	**Value**
Bamboo fibre	42.879
Gum Arabic	35.000
Coir fibre	22.121
Tensile Strength	4.55
Modulus of elasticity	111.28
Thickness swelling	25.88
Water Absorption	191.29

Desirability	0.499
Ss	**Selected**

Table 4.11: Optimization Results for Composites

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This paper presents a report on the production of a composite board from the combination of bamboo powder and grinded coir fibre, binded with gum-arabic as the resin adhesive. The following conclusions can be drawn;

1. Firstly, an extensive literature review was conducted to understand the existing research landscape and identify key factors influencing the production of bamboo composite materials. This provided a solid foundation for designing the experimental framework.
2. The delignification process using sodium hydroxide effectively removes lignin from bamboo fibers, leading to improved compatibility and bonding with the binding agent
3. The bamboo fibers were then ground into small particles to facilitate uniform distribution within the composite matrix, ensuring enhanced mechanical properties and dimensional stability.
4. Central Composite Design (CCD) was employed to plan the experiment, allowing for systematic exploration of the effects of process parameters on the mechanical and physical properties of the composite boards.
5. Experimental samples were produced according to the designed experimental plan, and their mechanical and physical properties were determined through rigorous testing and evaluation.
6. Utilizing Response Surface Methodology (RSM), the experimental results were analyzed to identify the optimal composite formulation that maximizes desired

properties such as modulus of rupture, modulus of elasticity, tensile stress, thickness swelling, and water absorption.

Finally, it’s worth noting that theThe ASTM D1037-12 (2020) standard were used to compare the experimental results.

The values of the modulus of elasticityof the developed particle boardsobtained were within the range of 1295-2782MPa. For tensile strength, the values obtained were within the range of 10-48MPa. As for water absorption, the values obtained were within the range 14.52-29.04%, while the values recorded for thickness swelling ranged from 2.76-35.05.

While the ASTM standard does not specify exact numerical values for these properties, it outlines testing methods and acceptance criteria that can be used to assess the performance of materials and compare experimental results. The acceptance criteria for modulus of elasticity values can range from around 1,000 MPa to 10,000 MPa or higher, depending on factors such as material density, resin content, and manufacturing process. For tensile strength, values can range from approximately 10 MPa to 50 MPa or higher, depending on factors such as adhesive type, panel density, and fiber orientation.For water absorption, acceptable values may range from 5% to 15% or lower. For thickness swelling, values can range from approximately 5% to 15% or lower.

Based on comparison of experimental results with these ranges, we can conclude that the bamboo/coir fibre composite with gum arabic as binder satisfiedthe ASTM standard for modulus of elasticity and tensile strength. However, for water absorption and thickness swelling, some experimental runs exceeded the acceptable range.

In summary, the performance characteristic of these composites are enhanced as the gum Arabic content by weight is increased, excluding the water absorption capacity and thickness swelling.

5.2 Recommendations

From the results obtained, the following recommendationsmade are;

1. Explore alternative binding agents or additives to improve the bonding between bamboo fibers and enhance the overall performance of the composite boards.
2. Investigate the effect of post-processing treatments, such as heat curing or surface modification, on the properties of the bamboo composite boards to further enhance their performance and durability.
3. Conduct long-term durability testing and accelerated aging studies to assess the resistance of the composite boards to environmental factors such as moisture, temperature, and UV exposure.
4. Explore sustainable sourcing and production practices for bamboo materials to ensure the environmental sustainability and eco-friendliness of the composite board manufacturing process.
5. Collaborate with industry partners and stakeholders to scale up production and commercialize the bamboo composite boards for widespread use in various sectors, contributing to the development of sustainable and environmentally friendly materials.

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