Design and Optimization of Bamboo/Glass Fiber Reinforced Epoxy Composites for Sustainable Wall Panel Application

Masters of Science in Product Design and Development

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THESIS ACCEPTANCE APPROVAL FORM

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ABSTRACT

The increasing demand for sustainable construction materials has driven interest in natural fiber-reinforced composites as eco-friendly alternatives to conventional materials. This study focuses on the design and optimization of bamboo/glass fiber-reinforced epoxy composites for application in sustainable wall panels, aiming to achieve a balance between mechanical performances, weight reduction, improve water resistance and sustainability**.** Different stacking sequences (B-G-B, G-B-G, G-G-B, and B-B-B) of bamboo and glass fibers were fabricated using the hand lay-up technique, preparation of 40% fiber and 60% of epoxy matrix incorporating alkali-treated bamboo fibers to improve interfacial bonding. The mechanical and physical properties of the fabricated composites were experimentally determined according to ASTM standards. A multi-criteria decision-making approach, using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), was employed to identify the optimal composite configuration. And it tells that G-B-G, characterized by a stacking sequence comprising 30% Bamboo, 10% glass, 60% epoxy, stands out as the optimal choice. The structural behavior of the optimized wall panel design was analyzed using Classical Lamination Theory. The optimization process, incorporating a genetic algorithm in MATLAB, aimed to minimizing weight and the constraint function is Tsai-Wu failure criterion. It results weight of the composite is 23.04kg, which reduced weight of the plywood weight by 15%, gypsum board by 5.8% and concrete panel by 38.4% and brick by 36%. Using literature review optimization, the water absorption of composite is 2.98% which reduced water absorption of the plywood by 7.11% of the gypsum board dry well is 9.11%, and concrete panel 2.11%, brick panel reduce by 8%. The optimized results were validated using ABAQUS of FEA. The maximum stress obtained from Genetic algorithm is 4.466Mpa and the maximum Von Mises stress is 8.511Mpa. The maximum deformation of the composite laminate is 12.2mm. This is less than the ultimate strength, proving the composite wall panel is safe and shows the safety factor is 2.5 against failure. The results of this study contribute to the development of sustainable and high-performance wall panels using locally available bamboo resources.

Keywords: wall panels, TOPSIS, ABAQUS, FEA, Genetic Algorithm, and Classic laminate theory, Hybrid bamboo/glass and epoxy.

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LIST OF ABBREVIATIONS AND ACRONYMS

G	Glass fiber
B	Bamboo fiber
e	Epoxy
[A]	Membrane stiffness of a laminate;
[B]	Bending-extension coupling stiffness of a laminate
[D]	Bending stiffness of a laminate;
[Q]	Reduced material stiffness matrix
ASCE	American Society of Civil Engineers
BCs	Boundary constraints
CLT	Classical Laminate Theory
CPT	Classical Plate Theory
E1, E2	Lamina longitudinal and transverse moduli composite
W	Weight (kg)
Fi	Impact force (N)
P	Load (N)
DD	Dead load
FEA	Finite element analysis
G12	In-plane shear modulus
GPa	Giga Pascal
Mx, My	bending moments per unit length at the mid-surface of a shell

Mpa	Mega Pascal
Nx, Ny, Nxy	Membrane forces per unit length at the mid surface of a shell
TOPSIS	Technique for Ordering Preference by Similarity to Ideal Solution
U	Displacement
V12	In-plane Poisson’s ratio
xt, xc	Tensile and compression strength in the fiber direction
yt, yc	Tensile and compression strength in the transverse direction
θ	Angle between the global x-axis and material direction local-axis
σ	Tensile stress (MPa).
$\sigma 1$	principal stress in plane 1.
$\sigma 2$	principal stress in plane 2.
$\tau 12$	Shear stress in 1-2plan
GA	Genetic algorithm

1. Introduction

1.1. Background

With the recent technological advances in engineering material science has assumed a position of utmost importance. The interest in advanced materials is increasing rapidly, both in terms of their research and application. It is a truism that technological development depends on advances in the field of material. Composite materials are widely used in the industry because of their superior mechanical, thermal, and chemical properties, e.g. high stiffness-to-weight and strength-to-weight ratios, corrosive resistance, low thermal expansion, vibration damping. As a further advantage, composite materials offer a great flexibility in design, allowing change of the material system in many ways. Configurations of a laminate, i.e. fiber orientation, ply thickness, material of each ply, stacking sequence, type and volume fraction of reinforcement can be tailored to make a better use of material or attain a desired property like strength, elastic modulus, thermal and electrical conductivity, thermal expansion coefficient. One may thus significantly decrease the weight of a structure by optimizing the design of the composite material itself, or increase its performance using the same amount of material. Composites were a need in the evolution of engineering materials. The simplest combination is that of only two materials, one acting as reinforcement and the other as the matrix [1].

The construction industry is increasingly looking for sustainable materials to reduce environmental impact. Thus, the progress and development of contemporary art are indivisibly linked to materials engineering, which aims to optimize the design of new construction materials and skillful use of existing ones, a rapidly renewable resource offers a promising solution for creating strong, lightweight wall panels. The composite materials have advantage over other conventional materials due to their higher specific properties such as tensile, impact and flexural strengths, stiffness and fatigue characteristics, which enable the structural design to be more versatile. [2].

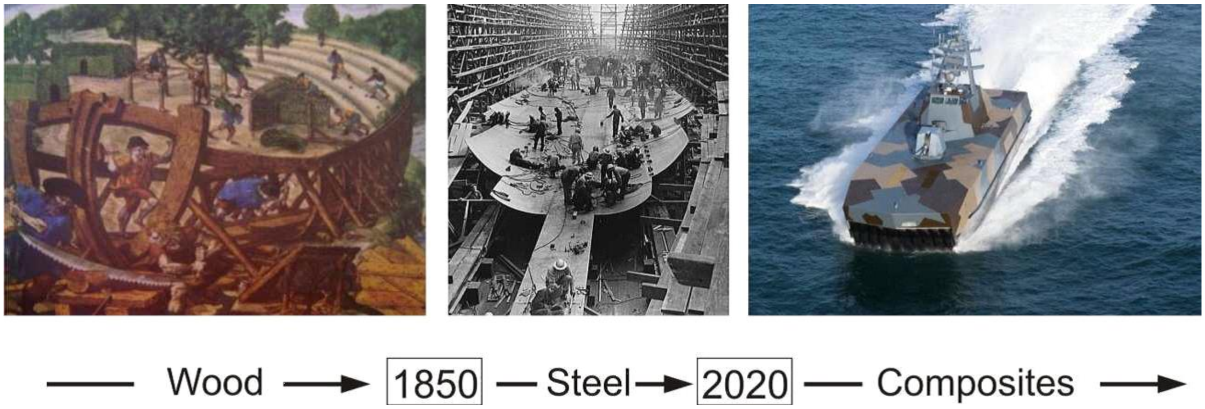


Figure 1-1: Evolution of material in construction

1.2. Definition of Composite Material

Composite materials are material systems that consist of a discreet constituent (the reinforcement) distributed in a continuous phase (the matrix) and that derive their distinguishing characteristics from the properties and behavior, geometry and arrangements of constituents and from the properties of the boundaries between the constituents [3]. A composite material system is composed of two or more physically distinct phases whose combination produces aggregate properties that were different from those of its constituents. Reinforced polymer composites showed advantages in recent decades, due to their superior properties and availability over using traditional monolithic metals such as steel and aluminum. Based on the matrix materials, composites were classified as the metal matrix, ceramic matrix, and polymer matrix. Polymer matrix composites can be used in a wide range of applications due to their low density, good thermal and electrical insulation, and low cost [4]. Steel and cast iron are materials which have been dominating the industries before the introduction of polymer composites. Minimizing weight, improve strength and stiffness, environmentally friendly and easy availability are the attractive characteristics of natural composite materials over metal materials [5] [3]

1.3. Classification of composite

1.3.1. Classification of Composites based on matrix

The following types of matrices are most commonly used:

1. *Metal Matrix Composites*: Metal matrices are generally used up to 1000°C. They have improved thermal resistance as compared to pure metals and alloys. They also have high ductility, strength and fracture toughness. They have superior electrical, thermal conductivity and magnetic properties. Due to a low thermal expansion coefficient, they also possess a high dimensional stability. High density, complicated fabrication processes and high cost of production are the disadvantages of Metal matrices.

2 *Ceramic Matrix Composites*: Ceramics are used to refer to a wide variety of nonmetallic inorganic materials. They are generally processed at high temperatures. Most notable properties of CMCs include high resistance to heat, chemical abrasion and wear. Due to these reasons, it is also difficult to fabricate them economically. CMCs can be used up to temperatures of 1500℃. The main objective of using CMCs is to get increased toughness.

3 *Polymer matrix Composites*: This is the most widely used group of matrices. A polymer is a long chain molecule having one or more repeating units of atoms joined together by strong covalent bonds. In solid state, the polymer the polymer molecules may be visualized as being frozen in space. They may either be oriented in a random fashion (amorphous polymers) or in a mixture of random fashion and orderly fashion (as found in semi-crystalline polymers). They have extremely good properties such as high stiffness and fracture toughness, good corrosion and abrasion resistance. Polymer matrix composites are the subject of growing interest in recent times due to the immense versatility in their applications. They can further be classified into the following two types:

Thermosetting Resins: The most commonly used resins are Epoxy, Unsaturated Polyester and Vinyl Ester. The liquid resin is generally converted into a hard solid by mechanical properties of various resins depend on the molecular units making up the networks. They also depend on the length and density of the cross links. The most notable property of the thermosetting resins is they have lower strains to failure. These may be essentially considered to be brittle materials.

Thermoplastics: These polymers do not have a cross-linked structure. They derive their strength and stiffness characteristics from the properties of the individual monomer units as well as the very high molecular weight. The advantage of thermoplastics is that in amorphous thermoplastics, there is a high concentration of molecular entanglements. These act like cross-links. Although a degree of molecular order and alignment can be seen in semi crystalline materials. Heating of thermoplastics leads to the disentanglement of molecules and thus it turns from solid to a slightly liquid (viscous) state. An amorphous Viscous liquid is formed on heating the crystalline materials. These materials have anisotropic properties. They have good chemical resistance and good thermal stability. Many thermoplastics are also resistant to water absorption.

The most common property is that all thermoplastics undergo large deformation before the final fracture. Commonly used thermoplastics are Nylon, polypropylene, acrylics, etc.

1.3.2. Classification based on reinforcement

1. Particulate Composites (PCs): - are composed of particles in flakes or powder form distributed in a matrix body. Concrete, Fly Ash and wood particle boards are some examples of this category.

2. Structural composites (SCs): - grouped into 2: laminated and sandwiched panel composites. Laminated Composites are composed of layers of materials held together by a matrix. Sandwich structures fall under this type.

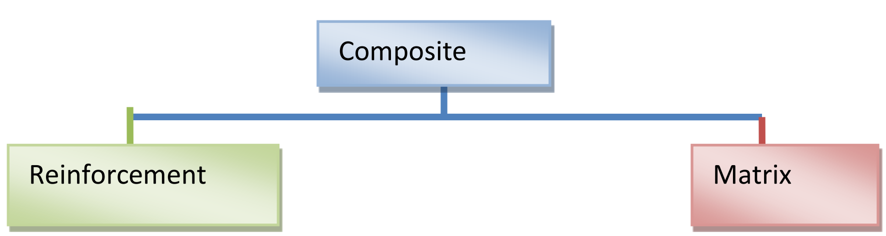
3. Fiber Reinforced composites (FRC): - Fiber reinforced composites are the most widely used class of polymer composites. Recently, fiber reinforced polymer matrix composites have found applications in various areas such as automotive, marine, aerospace etc. due to their high specific stiffness and strength[6]. The fibers are the most important constituents of the FRCs. They occupy the largest volume fraction in the laminate. Thus, they bear a major portion of the load acting on the composite structure. Fiber reinforced classify in to two continuous or discontinuous (short) fibers if its composite properties like elastic modulus vary with fiber length but if not is called continuous.

The fibers in a fiber reinforced composite influence the following aspects [7].

- Density
- Tensile Strength and Modulus
- Compressive Strength and modulus
- Fatigue strength and Failure mechanisms
- Electrical and Thermal conductivities
- Cost of composite structure

Continuous fiber also classifies in to Natural fiber, Synthetic fiber and Hybrid fiber

Fort this thesis the natural fiber selected is bamboo fiber



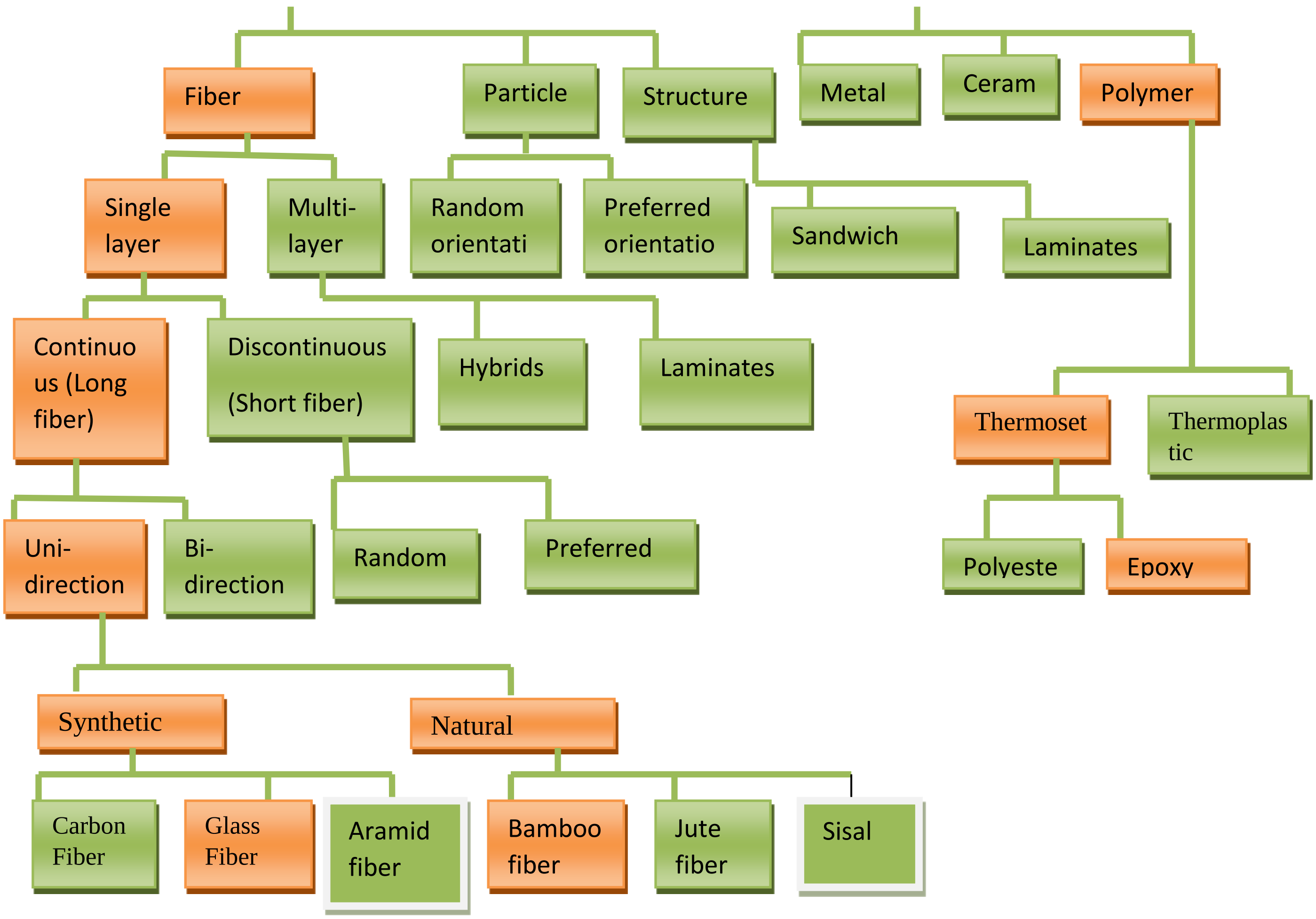


Figure 1-2 : Classification composite material

- **Bamboo fiber**

Bamboo is a fast-growing plant known for its strength and flexibility. It has been used as a natural composite material in various applications, including construction, furniture, flooring, and even bicycles. Bamboo fibers can be combined with resins or other binders to create composite materials with enhanced mechanical properties [8]. Bamboo has many benefits as a construction material. It is abundant in Africa just like its availability in Asia. It is a renewable and sustainable resource and its mechanical properties are similar to timber. There is a growing interest in the use of bamboo for development for construction globally because it is sustainable, affordable when it is commercialized and an alternative material for green building construction (De Flunder, 2009).

Figure 1-3 : a Bamboo plant b Bamboo fiber

Figure 1-4: Process of prepare bamboo glass

- **Glass fiber**

Glass fiber is a synthetic fiber with extremely strong, lightweight, and robust, making them advantageous over metals. Glass is a multipurpose composite material being used today. The glass fiber and surrounding matrix with their separate characteristic, while the combined generated product is superior in different applications[10] [11]. The glass fiber is the main constitutes that carry the load, while the enclosed matrix preserves the fiber in its selected orientation. Consequently, considerable efforts have been concentrated to find a new alternative for the performances of glass fibers and the achievement of the sustainable growth of crane materials.

Figure 1-5: Glass fiber

Epoxy resins

Epoxy resins are the most commonly used resins. They are low molecular weight organic liquids containing epoxide groups. Epoxide has three members in its ring, 1oxygen and 2 carbon atoms. The reactions of Epichlorohydrin with phenols or aromatic amines make most epoxies. Hardeners, plasticizers and fillers are also added to produce epoxies with a wide range of properties of viscosity, impact, degradation, etc. The main reasons for epoxy being the most used polymer matrix materials are:

- Good compatibility
- High strength
- Low viscosity and low flow rates, which allow good wetting of fibers and misalignment of fibers during processing

- Low shrink rates which reduce the tendency of gaining large shear stresses of the bond between epoxy and its reinforcement.
- Available in more than 20 grades to meet specific property and processing requirements.[12]

Hybrid composite material

Hybrid composites contain more than one type of fiber in a single matrix material. In principle, several different fiber types may be incorporated into a hybrid, but it is more likely that a combination of only two types of fibers would be most beneficial. Some of the specific advantages of hybrid composites over conventional composites include balanced strength and stiffness, balanced bending and membrane mechanical properties, balanced thermal distortion stability, reduced weight and/or cost, improved fatigue resistance, reduced notch sensitivity, improved fracture toughness and/or crack arresting properties, and improved impact resistance[9].

The mechanical performance of bamboo fiber reinforced polymer composites (BFRPs) for structural applications. Bamboo fibers are very promising reinforcements for polymer composites production due to their high aspect ratio, renewability, environmentally friendly, on-toxicity, cheap cost, non-abrasives, full biodegradability, and strong mechanical performances. Bamboo and glass fiber-reinforced composites have emerged as promising candidates for constructions applications due to their favorable properties, including high strength-to-weight ratio, corrosion resistance and potential for cost-effectiveness. Bamboo, a natural and renewable resource, offers excellent mechanical properties, while glass fibers provide additional reinforcement and structural integrity [13].

The main disadvantage of natural fiber composites is the poor resistance to moisture absorption. Hence, the use of natural fiber alone in polymer matrix is inadequate in satisfactorily tackling all needs of fiber-reinforced composites. Due to this, a natural fiber can be combined with a synthetic fiber with the same matrix material so as to take the best advantage of the properties of both natural and synthetic fibers [14].

1.4. Multi-Criteria Decision-Making Techniques

Multi-criteria Decision-making techniques (MCDMT) used t evaute identify the best option from all possible alternatives. In recent years several MCDM techniques and approach have been suggested in order to choose the optimal option. A technique for order preference by similarity to ideal solution (TOPSIS) is a valuable procedure for ranking and selection of number of externally determined substitute through distance measures. The idea for choosing the alternative based on the shortest distance from positive ideal solution and the furthers distance from the negative ideal solution on other side [4].

1.5. Problem Statement:

Construction industry is one of the most polluting prone industries of the world because the production of one tons of cement emits more than one tons of CO_2 in the atmosphere in the atmosphere. In addition, forest resources have been exploited and economic hardwood species are greatly disappearing which makes it a great concern to the scientist, technologist and users on the danger deforestation will pose on ecosystem. The supply of quality timber from the natural forest to wood-based industries is no more available in the quantities that can sustain the usual large diameter class logs required by these industries. Sustainable and affordable housing has been one of the social challenges faced by for decades and her construction industry.

Traditional partition wall materials like concrete, brick, gypsum board and plywood have been commonly used in construction for their structural and aesthetic benefits. However, these materials often come with significant drawbacks, such as high weight, susceptibility to water absorption and a substantial environmental impact due to their production processes. Concrete and brick are heavy and energy-intensive to produce, heavy leading to higher transportation and labor costs during installation. The added weight also increases the load on building structure requiring additional support and potentially raising construction cost.While plywood and gypsum board can be vulnerable to moisture and degrade over time requiring frequent maintenance and replacement.

This study aims exploration of alternative composite materials, such as bamboo/glass fiber reinforced epoxy composites, as a potential solution for problem. By importance in terms of weight reduction, water resistance, and sustainability, this research seeks to provide compelling reasons for the construction industry to transition towards composites, improving building performance while reducing environmental footprints. In order to solve such problems utilizes multi-criteria decision-making (MCDM) techniques to identify the optimal design configuration of partition wall panel, optimize using MATLAB and validity checked by ABAQUS software.

Figure 1-6: wall panel failure

1.6. Objective

1.6.1. General objective

The primary objective of this research is to design and optimize a bamboo/glass fiber hybrid reinforced epoxy composite for sustainable wall panel.

1.6.2. Specific objectives:

- ✓ To investigate the mechanical and physical properties of bamboo/glass fiber reinforced epoxy composite through hybridization and chemical treatment of bamboo fiber.
- ✓ To select the best laminate stacking sequence using TOPSIS.
- ✓ To design and optimize existing wall panel by bamboo/glass fiber hybrid reinforced epoxy composite
- ✓ Validate the optimization of the composite material using FEA (ABAQUS).

1.7. Scope of the study

The scope of this study is characterizing, investigating, and designing a wall panel member material from bamboo/glass fiber hybrid reinforced polymer composite based on the collected related data, and analysis investigated. This research attains the chemical treatment of the bamboo fiber and sample fabrication of natural and synthetic hybrid composites, characterizing the mechanical properties testing based on the ASTM standards, selecting the best stacking sequence laminate based on TOPSIS method, designing and optimizing the bamboo/glass hybrid composite of the loading body plate member using Genetic Algorithm and validate the optimized hybrid composite using ABAQUS.

1.8. Significance of the project

The significance of this research is to development of a composite material for wall panel that potential to provide a sustainable, cost-effective, and high-performance material. In this research aiming to weight reduction, water absorption minimization, and sustainability alternative to traditional building materials like concrete, helping to reduce labor costs, material waste, and environmental impact. By strategically optimizing fiber orientation the composite achieves high strength-to-weight ratio, reducing structural load while maintaining durability. The incorporation of bamboo fibers enhances sustainability and cost-effectiveness, while glass fibers improve mechanical properties and water resistance. This balance minimizes weight and water absorption, extending the panel's lifespan and making it suitable for humid environments. Such optimized composites contribute to eco-friendly construction, offering a viable alternative to conventional materials with enhanced performance and sustainability.

1.9. Justification of study

The construction industry is exploring alternatives material for wall panel due to the limitations of existing choices. This study explores the use of composite material made of bamboo, glass and epoxy as a potential solution. Bamboo is a rapidly renewable material that grows faster than traditional timber, making it an environmentally friendly option. Combining bamboo with glass fibers and epoxy resin reduces the overall carbon footprint compared to conventional construction materials. Furthermore, bamboo composites offer high strength-to-weight ratios while being biodegradable, reducing their long-term environmental impact. Glass fibers enhance the tensile strength and rigidity of the composite, ensuring that the final material can withstand the mechanical stresses associated with partition wall applications [15]. Epoxy resin provides enhanced moisture resistance, crucial for the durability of building materials, especially in humid environments[16] [17] [15] [18].

Optimized the composite material can potentially lower production costs compared to materials like steel and concrete, which are costly and energy-intensive to produce. The composite material is lightweight, which makes it easier to handle and install. Lighter partition walls also reduce the load on the overall building structure, leading to potential cost savings in terms of foundation and structural support. The optimization process will allow for tailoring the composite's mechanical properties to meet specific partition wall requirements, such as strength, flexibility, and durability [19] [20] [21]. The study will seek the ideal balance between bamboo fibers, glass fibers, and epoxy resin content, ensuring the composite achieves the desired tensile, compressive, flexural strength and reducing water absorption is essential to prevent the bamboo from degrading over time, improving the long-term durability of the composite [17] [18].The study of bamboo and glass fiber epoxy composites for partition wall panels represents an innovative approach to sustainable building materials. By combining renewable bamboo fibers with reinforcing glass fibers and durable epoxy resin, this composite material can offer a high-performance alternative to traditional partition wall materials. Through careful optimization of the material properties, the study aims to create a cost-effective, environmentally friendly, and functional product for modern construction needs.

CHAPTER TWO

2. Literature reviews

Literature review of such work needs to be done in order to understand the background information available, the work already done and also to show the relevance of the current research such as data collection and identification of the research gap. This chapter presents a general idea of the factors which affect the mechanical properties of hybrid fiber reinforced polymer composites. The related information corresponding to this study has illustrated below.

2.1. Natural and synthetic fiber reinforced

Adekomaya and K. Adama et al., 2018 [7] The application of natural fibers in reinforcement of composite have been reported in many past works with improvement and shortcomings depending on the application of the resulting composites. Environmental concerns and sustainability of convectional materials are stimulating research into natural fibers. Natural fibers have been a popular reinforcement in furniture, polymer matrix, and construction industries. Natural fiber is majorly sourced from plant-based derivatives and they are lignocellulose in nature with components usually of cellulose, hemicelluloses, lignin, pectin and waxy substances [7].

Many investigations have been conducted on elements of bamboo fiber morphology and size, bamboo fiber surface, and interfacial reactions of reinforcements and matrices, with plastic resin, types, and composite molding methods [10] [11].

The natural fiber-reinforced polymer (NFRP) composite derived from renewable resources, has been receiving attention to be used in several applications. These materials are now finding extensive uses in various fields from household articles to automobiles. Natural fibers like bamboo, sisal, banana, jute, oil palm and kenaf require little energy to produce and easily available in relatively lower cost. They also have better renewability and because possess high calorific values, they can be incinerated at the end of their lifetime for energy recovery[22]. Besides low cost and biodegradability, other advantages of natural fibers over synthetic fibers are good thermal insulation properties, light weight, high specific strength and low density [23].

Yang et al., 2020 [24] have reported the use of bamboo fibers as reinforcements in petroleum-based polymer matrices for the synthesis of bamboo composites. These composites can be used for structural applications. Natural fibers exhibit many advantageous properties as reinforcement for composites. Due to the scarcity and extreme use of fossil fuels and associated environmental problems, low-density, low-cost, short-growth-cycle, biodegradable natural plant fibers have been employed to replace synthetic fibers as fiber reinforcements for fabricating fiber-reinforced polymer composites (FRPs), thus reducing energy consumption and environmental pollution caused by FRP production Flax fibers, jute fibers, coir fibers, bamboo fibers, etc.

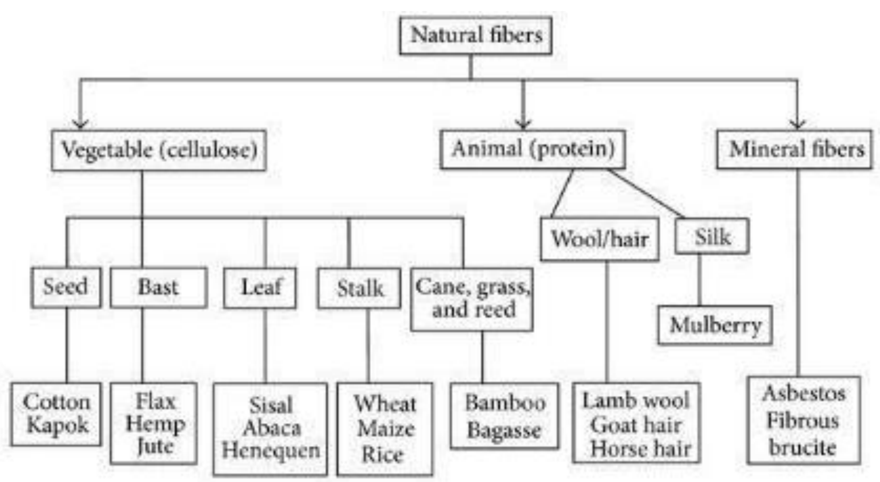


Figure 2-1: Classification of natural fiber

Synthetic fibers have been used in research and commercial purposes. High-performance synthetic composites are used to reduce weight in automotive, aerospace, construction and other transport applications. Thus, savings in running costs are ensured, and more significantly, carbon emission is reduced, helping to increase resource efficiency and drive our shift to low carbon vehicles [25].

2.2. Hybrid Laminated Composite

Laminates are sheet structures which are made by stacking layer by layers (plies or lamina) in a specified sequence. Hybrid laminate composite is made of two or more fibers lamina. The layers are often in the form of prepreg (fibers pre-impregnated with partly cured resin) which are consolidated in an autoclave. A laminate may have more than 2 layers & the fiber orientation changes from layer to layer in a regular manner through the thickness of the laminate. Again, this laminate can be in the form of hybrid composite which is a combination of both fiber and particulate reinforced in a common matrix to get the combined advantages of both the fiber and the particulate with better property. The hybrid effect was investigated by Hayashi & defined as the apparent failure strain enhancement of the low elongation fiber (carbon) in a carbon/glass hybrid composite [9] [26]

Sanjay et al., 2015 [27] studied the hybridization of glass fibers with natural fibers for the application in the aerospace and naval industry. They have stated that their design allowed for the cost reduction of 20% and weight saving of 23% compared to the commercial present at a time. And the lamina prepared with natural fiber mat showed lower mechanical properties compared to the lamina with glass mat. The mechanical properties such as tensile strength, flexural strength and impact strength of composites greatly influenced by fiber length.

2.3. Fabrication process for polymer composite

For development of new product, fabrication process is extremely important factor. Fabrication polymer in composite material the biggest challenge is to maintain the less cost and high production rate process in composite material [28].The composite will be fabricated by varying the ratio of bamboo fibers to glass fibers and adjusting the resin content. A series of composite panels will be manufactured, with the optimization of curing processes such as temperature and time being controlled to achieve consistency and improve the final product’s strength. Composite laminates have gained significant attention in various industries, including aerospace, automotive, marine, and construction, due to their superior strength-to-weight ratio, corrosion resistance, and design flexibility. The fabrication of composite laminates is a crucial step that influences their mechanical properties and performance. Among the most commonly used manufacturing techniques are Hand Lay-Up, Spray Lay-Up, and Resin Transfer Molding (RTM) [28][29][30].

2.3.1. Hand lay up or wet fabrication

The Hand Lay-Up process is one of the oldest and simplest methods for fabricating composite laminates. It involves manually placing reinforcement fibers, such as glass, carbon, or aramid, onto a mold and impregnating them with resin using rollers or brushes. The fibers are placed into the mold for a first time. Fibers can wove, or bonded. The resins are impregnated and rollers, brushes or other impregnators are used to impregnate the resins. Under normal atmospheric conditions, the laminates made up by this process are then cured. The process is low costing and used at room temperature and method is very simple. In this process any mixture of matrix and fibers can be used. Basically, in this process higher fiber content and longer fibers are used while comparing with another process. This is hand worked process so more care must be taken. In this technique less viscous resin are preferred to work easily. The quality of the product dependents on the worker, so highly skilled worker is required. Homogeneous resin distribution is unable in the fiber lead to voids. This procedure is appropriate to produce the wind-turbine blades, boats, etc. [31][32].

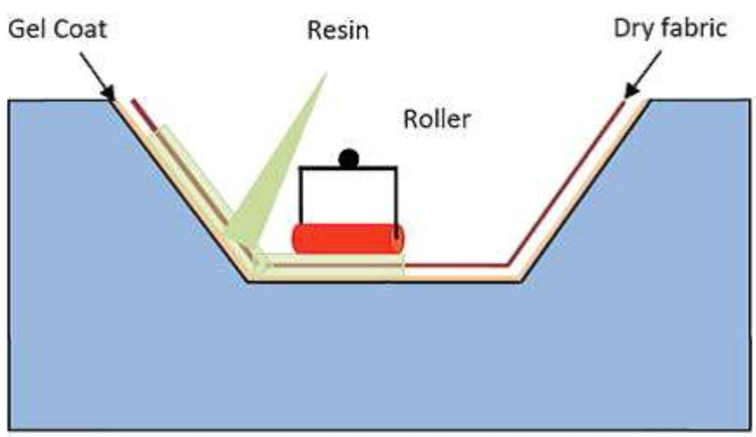


Figure 2-2: Hand lay-up or wet fabrication

2.3.2. Spray Lay-Up

Fiber is cut with hand and filled with weapon and resin spray is applied to the mold. Under normal atmospheric conditions, the products are held to heal. Polyester resins which are glass roved are suitable for this process. This method of manufacturing is not suitable for higher structural parts. Controlling of the fiber volume fraction and thickness is also difficult. Quality of a product is depending on worker skills. In this technique styrene emission takes place due to open nature. It Provides good surface finish only one side. Spray layup fabrication is not suitable for high dimensional accuracy parts. Low viscosity resin is preferred same as hand layup. Light stacked basic boards, e.g., baths, shower trays, few little dinghies and truck fairings [33]

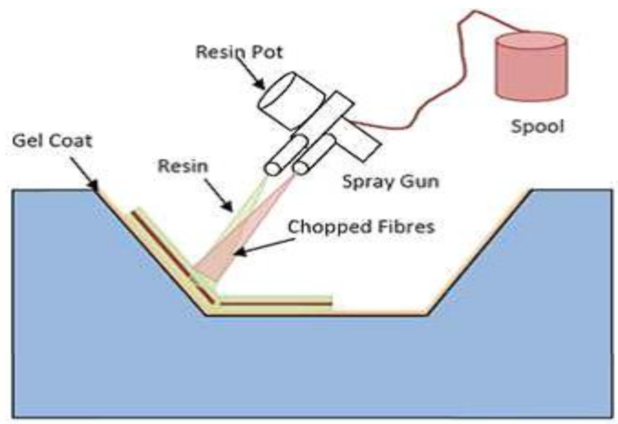


Figure 2-3: spray layup fabrication

2.3.3. Resin Transfer Molding - RTM

These are pre-squeezed up to formation of shape and hold with each other with the help of binder. A second coordinating mold instrument is after clinched on a first one. At that point pressurized resin is infused inside a cavity. This technique is called as Vacuum Assisted Resin Transfer Molding / Resin Injection (VARTM/VARI). The laminate is after restored. Both infusion and fixing can occur either at elevated or ambient temperature. This method is cost efficient process and best for complex shapes. But this technique tooling is very expensive and limited to smaller components. This technique is used for manufacturing tube shaped components as casing of motor, covers for engine, etc.[34] [35].

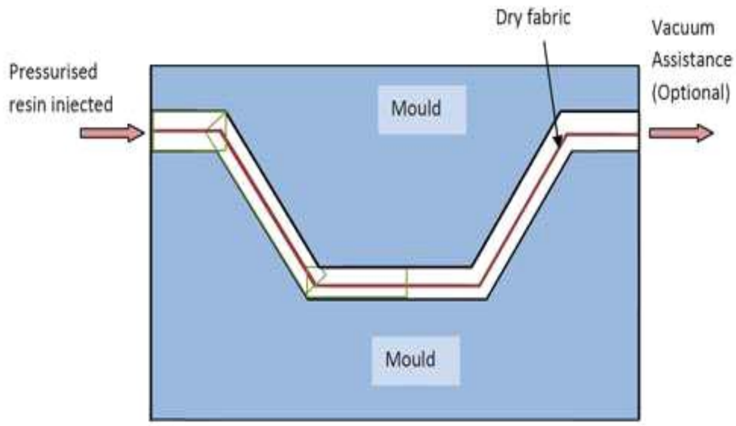


Figure 2-4: Resin Transfer molding

2.4. Chemical treatment of bamboo fiber

Due to the excellent mechanical properties of bamboo fibers, which reported to be comparable to glass fibers, they have been extensively used to reinforce polymer to produce natural fiber-based composites. However, incompatibility of bamboo fibers with some polymeric matrices is a major drawback for fully utilized these biomaterials. The fiber surface treatments are applied before composite processing to enhance the adhesion between hydrophobic polymers and hydrophilic bamboo fibers. Moisture resistance as well as mechanical properties is improved by chemical and physical modification methods. Treatment method has altered the hydrophilic nature of bamboo fibers which subsequently led in improving the adhesion between the fibers and the polymer matrices. The compatibility of bamboo fibers in polymer-based composited can be enhanced by applying appropriate treatment, various applications of bamboo fibers as reinforcement in polymeric materials have proven encouraging [5] [36].

The composites of polymer and bamboo fiber are, in facts, having the differences and incompatible each other's in terms of their polarity structures, the using fiber treatment agents (such as Sodium Hydroxide - NaOH or polypropylene with maleic anhydride –PPMA) will help to reduce interfacial tensions and improve the adhesion between the matrix and fiber. By using fiber treatment are expected will cause the material having an appropriate behavior of the many applications based on mechanical forces required for different application related in which the mechanical behavior of samples need to be known through the tensile tests, bending, impact and fatigue.

2.5. Physical and mechanical analysis of laminated composite material

In this study, the effects of different manufacturing methods on the physical and mechanical properties of carbon/epoxy composite laminates were investigated. The hand lay-up, compression molding, and vacuum bagging methods with two different vacuum characteristics were selected as the applied methods [37].

Van Rijswijk et al. [38] that composites are now as a part of everyday life and have entered nearly all major industrial sectors, including aerospace, ground transport, packaging, sports industry and civil engineering.by using the composite materials that are rapidly increased both in terms of the research and applications, the advantage over other conventional materials related to specific properties investigated such as on tensile, impact and flexural strengths, stiffness and fatigue characteristics, which enable structural design to be more versatile. Here, their features are also distinguished from synthetic fibers in relation to the low cost of acquisition, the light weight, low abrasiveness, and the great strength-to-weight ratio and increased the rate of biodegradability of the material viewing on the lucrative prospect of composite.

Machado et al., 2024 [39]Studied the micromechanics approach and propose that the volumetric percentages of constituent materials for the desired lamina stiffness and strength. Micromechanics determine the modulus of elasticity, volumetric percentages of the fiber and matrix; however, it's not responsible for defects which arise in fibers, matrix or laminate due to their manufacturing. The orientations of the lamina depend on the type of material properties and finite element is used to analyze the effect at the microscopic level along the mechanical properties within the composite. Micromechanical aspects of polymer matrix laminated composites, discussing how micro scale properties influence macro scale mechanical behavior. The paper emphasizes the importance of understanding fiber-matrix interactions to predict and enhance composite performance.

Porras and maranon,2012 [23]Studied the effects of concentration of fibers, fiber ratio and the modification of fiber surface in sisal/oil palm hybrid fiber reinforced rubber composites. Increasing the concentration of fibers resulted in reduction of tensile strength and tear strength. At the same time, an increase in modulus of the composites was also seen. The vulcanization parameters, process ability characteristics, and stress–strain properties of these composites were analyzed. The rubber/fiber interface was improved by the addition of a resorcinol-hex methylene tetra mine bonding system. It was revealed from the fiber breakage analysis that the extent of breaking was low. It was also found that the mechanical properties of the composites in the longitudinal direction of the fibers were superior to that in the transverse direction.

2.6. Review on the fiber orientation and stacking sequence of composition

Nagamadhu et al., 2018 [40] this study investigates the effect of wood veneer stacking sequence on mechanical properties of need wood polymer composite (WPC) experimentally. Wood laminated samples were fabricated by conventional hand layup technique in a mold and cured under pressure at room temperature and then post cured at elevated temperature. Initially the tensile, flexural, and impact test were conducted to understand the effect of weight fraction of fiber on mechanical properties. The mechanical properties have increased with the weight fraction of fiber. Moreover, the stacking sequence of name wood plays an important role. As it has a significant impact on the mechanical properties. The results indicated that 0Â°/0Â° WPC shows highest mechanical properties as compared to other sequences (90Â°/90Â°, 0Â°/90Â°, 45Â°/90Â°, 45Â°/45Â°). The Fourier Transform Infrared Spectroscopy (FTIR) Analysis were carried out to identify chemical compounds both in raw need wood and name wood epoxy composite. The microstructure raw need wood and the interfacial bonding characteristics of need wood composite investigated using Scanning electron microscopy images.

Sathish et al., 2017 [41] This paper deals with the fabrication and investigation of mechanical and thermal properties of banana-kenaf glass fiber reinforced epoxy composite which is relatively a newer hybrid composite. In this study, the composite is fabricated by a hand layup process with different fiber orientations and also with different volume fractions. The composites are prepared with five different proportions of banana-kenaf fibers. Various mechanical and thermal tests are conducted and the result shows that the hybrid composite in which fibers are arranged at 45^0 inclinations has better properties than the others. Also, failure morphology analysis is done using a Scanning Electron Microscope (SEM) through which the internal structures of the tested specimen are analyzed.

Mili et al. [42]This research examines how different stacking sequences affect the mechanical performance of hybrid fiber-reinforced epoxy-polyester composites. The study highlights the significance of stacking sequence in determining tensile strength and failure mechanisms. The main aim of this present investigation is to evaluate mechanical properties of different hybrid laminates prepared with different combinations of fiber and resin. The impregnation of laminates is done by epoxy and polyester resin as matrix material. Various structures under tensile strength were considered with different combinations glass, carbon fibers reinforced epoxy-polyester resin laminates. The current research work reveals the effect of stacking sequence on the mechanical behavior of symmetric laminated composites.

2.7. Multi-criteria decision-making techniques for select composite

Shih and olson,2022 [43]The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method, which was originally developed. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS).

Pavlc and Novoselac,2013 [44]In a general sense, it is the aspiration of human being to make "calculated" decision in a position of multiple selections. In scientific terms, it is the intention to develop analytical and numerical methods that take into account multiple alternatives with multiple criteria.

2.8. Composite materials for construction applications

Pastuszak and Muc,2013[45] The paper presents the general review of application of composite materials including the distinction of their specific features. The increasing role of composite materials in contemporary engineering and construction. It highlights their advantages, such as high strength-to-weight ratio, corrosion resistance, and design flexibility, which make them superior to traditional materials like metals and concrete. The use of composite is extended in applications such as, building development, long span roof construction, bridges component and water storage tanks etc. Jute and Sisal are being used for Ceiling & wall panels

Youngquist 1994 [46]reviewed the use of non-wood plant fibers for building materials and panels. More recently, Kozlowski et al. have reported that composite boards made from fibers and shives of non-wood lignocellulose sources such as hemp, flax and kenaf are competitive with traditional wood-based materials. Although in some cases the properties of the products were competitive with traditional wood-based composites, further studies to improve the performance and investigate the durability and weather ability of these materials is clearly needed. Their uses include doors, door and window frames (fenestration products), floor, ceiling or wall boards, and even furniture. In addition to being lighter than many conventional materials, bio composites have also been shown to have excellent insulation properties due to the cellular structure of the fibers or fillers.

2.9. Effect of weight minimize on wall panel application

Nurjannah et al.,2022 [47].Wall panels are commonly used for partitioning spaces in buildings. The mass of wall panels must be reduced to minimize earthquake risk and enhance structural resistance to lighter dead loads. This study used wall panel models that consisted of lightweight foamed concrete materials containing expanded polystyrene. The wall panels used in this study also had a variety of dimensions and reinforcements. The effect of openings on wall panel model performance was also investigated. The materials used for wall panels are made up of non-structural concrete that meet the strength of light mass requirements. One of the materials most appropriate to meet these requirements is foamed concrete. The mass of foamed concrete allows for the reduction of structural dimensions which results in buildings that are lighter than conventional ones, thus reducing the risk of damage under severe earthquake conditions, especially in high rise buildings. The mass of foamed concrete ranges from 1200 to 1800 kg/m3 and is included in the category of lightweight concrete.

El Gamal and Al Saadi,2022 [48]This research study aims at developing and investigating the mechanical and thermal properties of lightweight sandwich wall panels with good thermal insulation properties to reduce electric power for cooling of buildings. Within this study, several thermal insulation sandwich wall panels with two outer lightweight concrete layers and inner expanded polystyrene layer were developed and tested. The results showed that the panels with polystyrene beads were stronger, lighter, and had better thermal properties. Using the developed panels will help to reduce the self-weigh of buildings resulting in smaller structural elements. In addition, the excellent thermal properties of the developed panels are expected to reduce power consumption and develop more sustainable buildings [49].

2.10. Effect of moisture resistance on building

Trechsel and Vlgener, 2009 [50]The majority of building performance problems are caused by water leakage through the building envelope and condensation of moisture in exterior wall and roof assemblies. Identifying the sources of water leakage is a critical first step to developing a regimen of effective building repairs. It discussed various techniques and methods for measuring moisture content and for moisture-related tests in buildings and for building components, products, and materials. It is the intent of this chapter to provide guidance on how and when to apply the testing and measurement methods to identify causes and mechanisms of moisture problems and to determine the most effective remedial actions.

Almeida et al., 2008 [51]The use of polymer matrix composite materials at offshore facilities has many advantages, such as weight savings. However, the properties of these composites can be affected when exposed to their service environment, in particular due to water absorption. In this context, fiberglass pipes used for the transport of the so-called service waters must maintain their integrity for long periods of time, without losing their mechanical performance, although directly exposed to water. In this work the water absorption behavior of fiberglass pipes was measured and the effects of the absorbed water on the mechanical performance of the pipes were accessed. The results show that water absorption caused plasticization of the resin, reducing the stiffness of the pipes. However, the tensile strength, and the associated pressure class of the pipes, was not affected. The results show that failure of these pipes after being exposed to water is more probable by mechanical constraints due to large dimensional changes caused by water plasticization and swelling than by the loss of mechanical strength.

2.11. Review on design analysis of wall panel

Rafiq et al.,2003 [52]This paper introduces a new concept of a stiffness/strength corrector to model the variation in masonry properties in laterally loaded masonry panels. Research by the authors has established that the variation in masonry properties is closely related to structural characteristics such as boundary conditions rather than material constituents. The paper proposes rules which relate the stiffness/strength corrector values from a known experimental panel to a panel for which only geometric form and boundary conditions are known. An investigation is presented into the validity of using these correctors for improving the finite element analysis results of the panel.

The research presented in this paper has identified two factors which have a major influence on the behavior of the panel. They are: (1) the boundary restraints along the edges of the panel, and (2) the variation in masonry properties at various locations (zones) within the panel. The research has properly modeled the variation in masonry properties and has proposed suitable methodologies for establishing zone similarities in panels which are mainly influenced by panel boundaries. The proposed concept of a stiffness/strength corrector reflects the structural characteristics of variation in masonry properties and boundary conditions both qualitatively and quantitatively. The corrector synthesizes the combined effect of the variation in the masonry properties and boundary conditions on the behavior of masonry panels [52].

The first study investigates the suitability of the model to predict the in-plane behavior of a brickwork masonry wall panel subjected to combined shear and axial pre-compression. The developed numerical model compared against experimental test results obtained by testing two masonry wall panels (ZW1 and ZW2) made of concrete blocks and bonded together with mortar. The walls had dimensions equal to 3,600 mm × 2,000 mm × 150 mm (width × height × thickness) and were constructed by 10 rows of stretcher bonded concrete blocks. The dimensions of the blocks were 300 mm × 200 mm × 150 mm. Two partition walls were also attached at the ends of each of the main wall. The partition walls had dimensions equal to 150 mm × 2,000 mm × 600 mm (width × height × thickness). Also, two concrete beams were positioned at the base and at the upper end of the wall to ensure an optimal transfer of the loading in the upper part and a fixed condition at the base. The three dimensional geometric model representing the masonry wall panels tested in the laboratory developed. To allow for the 10 mm thick mortar joints in the real wall panels, each masonry unit was based on the nominal brick size used in the laboratory built panels increased by 5 mm. Vertical pre-compression equal to 419 kN and 833 kN applied on the walls ZW1 and ZW2 respectively. An external horizontal load was also applied incrementally to the upper beam until the panel could no longer carry the applied load. The constitutive law to be used for representing the material behavior will affect the simulation results. In this paper, a new type of panel manufacturing has been presented and optimized. The results show optimal results from 30 to 70 % of moisture content. The effect of the amount of adhesive is not significant in the studied parameter.

Lowak and polcyn [53]This paper presents the experimental and analytical results for blast loaded pre stressed concrete wall panels. Full scale, 16-ft simple-span, pre-stressed concrete wall panels were tested with blast loads generated from a shock tube. The panels tested included 6-inch thick solid pre stressed concrete panels, and pre stressed concrete sandwich panels with 3-inch thick Wythe’s separated with 2 inches of rigid insulation. Panels were tested in both a non-load-bearing and load-bearing configuration. Load-bearing panels had a static concentric axial load applied throughout the dynamic shock tube tests. The axial load magnitude was 10 percent of the gross static axial capacity of each wall member using the nominal concrete compression strength. All panels had simple bearing connections without in-plane restraint. Panels were tested multiple times to define support rotations at which different levels of damage occurred.

J. Bartlett [54] Non-load bearing wall systems are required to meet multiple Performance Requirements, but primarily they are a structure. A failure to holistically meet the Structural Provisions results in reduced performance for fire resistance, acoustic and other defects. These performance losses are compounded under earthquake excitation with increased actions upon boundary elements and premature or intensified damage states. Additional complexity is encountered through wall interactions with fire doors service penetrations, passive fire treatments, ceilings, and other elements. For this paper, non-load bearing walls are non-structural elements and should not be part of the seismic force-resisting system (of the structure). The Australian Building Codes Board (ABCB) 'Construction Dictionary' references AS1530.4 for a definition: Non-loadbearing Walls (NLB): 'a wall not designed to be subjected to an external load, other than its self-weight'. Interestingly, AS1530.4 defines a Load-bearing Wall 'a wall designed to support an externally applied vertical load or a load transferred from other components', which is essentially what occurs with all of the external elements listed above.

Pitroda et al., 2016 [55] The main objective of this study is to develop the integrated framework that can be useful in analyzing factors affecting the non-load bearing wall construction. Non-load bearing walls are important part of any structure. Construction of this type of wall depends on self-weight, structural design, easiness in transportation and construction. Main characteristics of non-load bearing wall are depending on types of materials and its specification so, study or analysis of different materials which are suitable for the constructions of non-load bearing wall are necessary. The study of the most significant key indicators like strength, cost, weight, flexibility, availability, sound proofing, life span, thermal conductivity etc. of non-load bearing wall. This analytic study aimed to investigate the adequacy and advantages of non-load bearing wall based on different materials like Concrete Hollow Blocks containing Recycled Window Glass, Polymer Precast Panel, Fly Ash Brick, Autoclaved Aerated Concrete (AAC)Block, Acotec Panel, Traditional Stone, Paper Fiber Reinforced Foam Concrete (PFRFC) Material, Clay Bricks, Glass Fiber Reinforced Gypsum (GFRG) Panel.

2.12. Evolution material for wall panel

Habib et al 2015 Autoclaved Aerated Concrete (Aac) Block found that in this research, generation method of hydrogen gas was used for the aeration process. In this gasification method, a finely powdered aluminum powder was added to the slurry of Ordinary Portland cement with different percentages such as 0.05%, 0.1%, 0.15%, 0.2%, and 0.25%. To determine the effect of aluminum powder on the final product properties, some test has been conducted such as density, water absorption and compressive strength test. However, it was observed that the concrete having 0.15% aluminum powder contributes in the strength gaining process of aerated concrete [56].

Abbas et al.,2017][57] Clay Brick found that the clay burnt bricks manufactured with fly ash and rice husk ash had similar appearance when compared to the conventional clay bricks. The clay bricks having fly ash as an admixture showed the best performance, having a compressive strength of about 23% greater than that of conventional bricks. The percentage of water absorption for these bricks was found to be more than that of conventional bricks but still within the prescribed maximum limit as per Indian Standards. (Maximum allowable water absorption as per Indian Standards is 20%) Hence fly ash can be used as an admixture with clay bricks.
[58]fly ash is waste generated from combustion of coal in power generation plants. Due to its pozzolanic properties, utilized in construction industry. In this paper Fal-G brick production process, uses of rap-trap bond in Fal-G brick masonry prism test study and economy have been described. The observations, limitation and suggestions in various areas have been described.

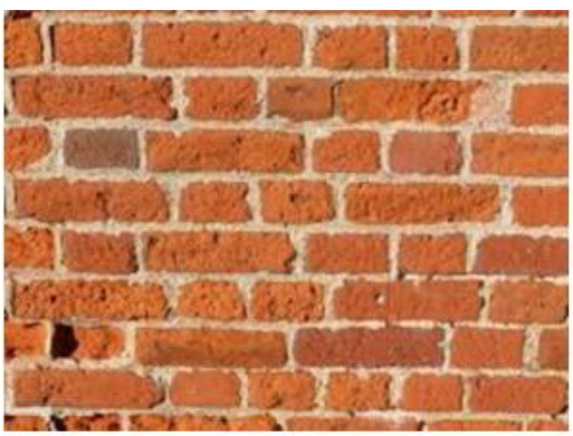


Figure 2-5: Clay brick wall

Mistry et al., 2011[58] Fly Ash Brick Wall fast growing today's world development of new building materials and Processing & utilization of industrial waste is being given the top priority in the program of building research at a very high rate. In the present study, the effects of fly ash on the properties of bricks are studied and the behavior of fly ash bricks is compared with conventional burnt clay bricks. The various properties of fly ash bricks with different materials were tested. The properties studied water absorption, hardness, efflorescence, soundness, shape and size, crushing strength and basic compressive strength of the prism using different mortar mixes normally 1: 3, 1: 4 and 1: 5 cement-sand mortars. In general bricks are made by top fertile agricultural soil but by using fly ash, 28 percent of top fertile agricultural soil is saved. Use of fly ash in brick making also is beneficial in diverse ways. As compared to conventional clay bricks fly ash bricks are stronger, more durable and yet more economical. Also, the process of fly ash brick manufacturing results in lesser pollution. Being less permeable as compared to clay bricks dampness related issues are far lesser in case of fly ash bricks than their clayey counterparts.

Kumar et al (2014) found that Structure of the bricks was found to be compact, homogeneous and free from any defects like holes, lumps etc. as compared to normal bricks. The average absorbed moisture content of clay bricks and fly ash bricks are found to be 11.93% and 9.77% respectively. Thus there is net 18.10% decrease in moisture absorbed for fly ash bricks as a part to clay bricks.

Mistry et al (2011) found that as compare to conventional brick masonry prism compressive strength it is between 13.75 kg/cm2 to 121.80 kg/cm2at 28 days strength. While FaL-G brick prism strength is 88.83kg/cm2 for cement mortar (1:6) and 85.05 kg/cm2 for fly ash mortar (1:6) just in 14 days. It can be increased up to 135 kg/cm2 to 145 kg/cm2at 28 days. According to case study the fly ash bricks with conventional masonry work have 28% saving in cost with common red brick and conventional masonry work. The masonry work with new technology Rattrap bond in fly ash bricks have 33% saving in cost as compared to common bricks.

Figure 2-6: Fly ash brick wall

Manjummekudili et al., 2015 [59] Glass Fiber Reinforced Gypsum (GFRG) Panel is a huge growing requirement of building materials in India due to the existing housing shortage. To meet this challenge, India requires innovative, energy efficient building materials for strong and durable housing in fast track method of construction at affordable cost. Rapid wall is an alternative building material to replace bricks or concrete blocks. This study deals with the physical properties of GFRG Panel and finding out the suitable filler materials to strengthen it. Various experiments were conducted on the physical characteristics of GFRG panels. From the results obtained, variations in the compressive strength with different filler materials were noted. This paper concludes with selection of the filler materials to improve the strength of GFRG panels in a cost effective way. Besides this, certain methods to overcome its drawbacks are also discussed. GFRG Panels are light weight building material which can be used as walls and roof slab. Gypsum, which is bi-product of fertilizer industry, can be effectively used in the production of panel. Compressive strength of GFRG Panel was obtained as 1.25 N/mm2. Water absorption value is obtained as 1.225% [60].

Shukla et al.,2016 [60]This review paper summarizes and reviews developments in the field of building systems using glass fiber reinforced gypsum panels. GFRG panels, manufactured in standardized parts or sections ready for rapid assembling and erection as buildings, are ready-made gypsum panels with hollow cavities. This Rapid wall is utilized in residential as well as commercial constructed dwellings. GFRG walls are used both architecturally and structurally as walls and slabs, with no columns and beams needed. It has now found large utilization, even without use of sophisticated codes of structural design, to a great extent because of their environmentally friendly behavior. GFRG panels are a composite material consisting of calcined gypsum plaster and glass fiber (a slender filament). When the hollow cavities of GFRG panels are filled with reinforced self-compacting concrete, the bond between the concrete and the GFRG panels yields another composite. As a result, the structural performance of Rapid wall and the related building systems are more sophisticated than that of other conventional building systems.

Figure 2-7: Glass Fiber Reinforced Gypsum (GFRG) Panel

Material	Weight	Water absorption (%)	Reference
Concrete	2200-2400kg/m3	3-10	Properties of Concrete," by A. M. Neville [61]
brick	1800-2200kg/m3	10-20	"Brickwork," by R. Hearn[62]
plywood	1600-1800kg/m3	8-12	"Properties of Wood-Based Materials" [63]
gypsum	7-10kg/m2	5-10	"The Drywall Handbook," by Robert W. Harris [64]

2.13. Optimization algorithm

Elkabany et al., 2020 [65]The idea of a genetic algorithm was thought to have been conceived by John Holland at the University of Michigan in the 1970s. Holland was interested in applying the laws of natural selection towards the development of artificial systems rather than systems that are based on some reasoning process. These artificial systems could be constructed using computer software and applied to various disciplines which emphasize design, optimization and machine learning. The use of algorithms enables the creation of a wide range of solutions characterized by speed and effortlessly, in addition to allowing the development of different design methods. The improvement aimed to maximize hardness to obtain the lowest material density and thus the lowest cost while preserving the shape and preventing deformation. The optimization of the structural wall provides mechanical properties as designed with the parameter where a structure weighs 18.36% less than similar cases before optimization, Where in the first case, the rate decreased from 62 ton to 53.514 ton by 13.7 percent, In the second case, the rate decreased by 29 percent from 63,525 ton to 45.10 ton and In the third case, it decreased by 12.4 percent from 28.56 ton to 25.01 ton. The use of algorithm programs to improve materials has a Clear on the relationship between form and functionality. As for the improvement of conventional reinforced concrete, it resulted in lower density, hardness and better surface quality than white concrete, followed by fiberglass-reinforced concrete. Conventional reinforced concrete can be used to build lightweight structures after improvement which is more structurally functioning.

Almeida et al., 2008 [66] A technique for the design optimization of composite laminated structures is presented in this work. The optimization process is performed using a genetic algorithm (GA), associated with the finite element method (FEM) for the structural analysis. The GA is adapted with special operators and variables codification for the specific case of composite laminated structures optimization. Some numerical examples are presented to show the flexibility of this tool to solve different kinds of problems. Two cases of multi objective optimization of plates under transverse or in-plane load are studied. In these examples the minimization of two objectives, such as weight and deflection or weight and cost, are simultaneously performed and an optimal set is obtained by shifting the optimization emphasis using a weighting factor. The stiffness maximization of a composite shell under pressure load is presented in the last example, where the geometrically nonlinear behavior of the structure is considered. Some aspects of the optimization performance, such as the apparent reliability and the computational cost, are investigated in each application.

2.14. Gaps in Existing Research

Identify areas where current research is lacking, particularly in optimization techniques or specific applications of bamboo/glass fiber composites. From the above research and literature reviewed, much research has been done on different types of hybridizing natural fiber with synthetic fiber for fabricating the polymer composite. Highlight the need for further studies to validate mechanical properties and environmental benefits. These literature review articles provide a solid foundation for understanding the current state of research on natural fiber-reinforced polymer composites, fiber hybridization, varied fiber orientations of materials have not been sufficiently investigated in many previous works. This lack of exploration in composite materials presents a gap in the research, particularly in terms of optimizing performance for construction applications. Additionally, previous research on wall panel has primarily focused on traditional materials like clay brick, fly ash brick, plywood, gypsum which, while widely used, present challenges such as high environmental impact, moisture absorption, increasing costs. This research gap highlights the need to explore the potential of these eco-friendly composites as a viable alternative to traditional sheathing materials.

CHAPTER THREE

3. Methodology

3.1. General procedure

The generally procedure for this research design optimization of bamboo/glass fiber epoxy composite for a sustainable wall panel application involves defining the problem, designing experiments, analyzing data, developing objective functions, selecting an optimization algorithm, optimizing the solution, validating the results, and implementing the optimized solution in the design and manufacturing of the wall panel. This process aims to maximize the strength to weight ratio and improve moisture resistance of the composite while considering factors such as cost, environmental impact, and manufacturing process limitations. The validation of the analysis will check by Tsai-Wu Failure Theory, and validated using ABAQUS software.

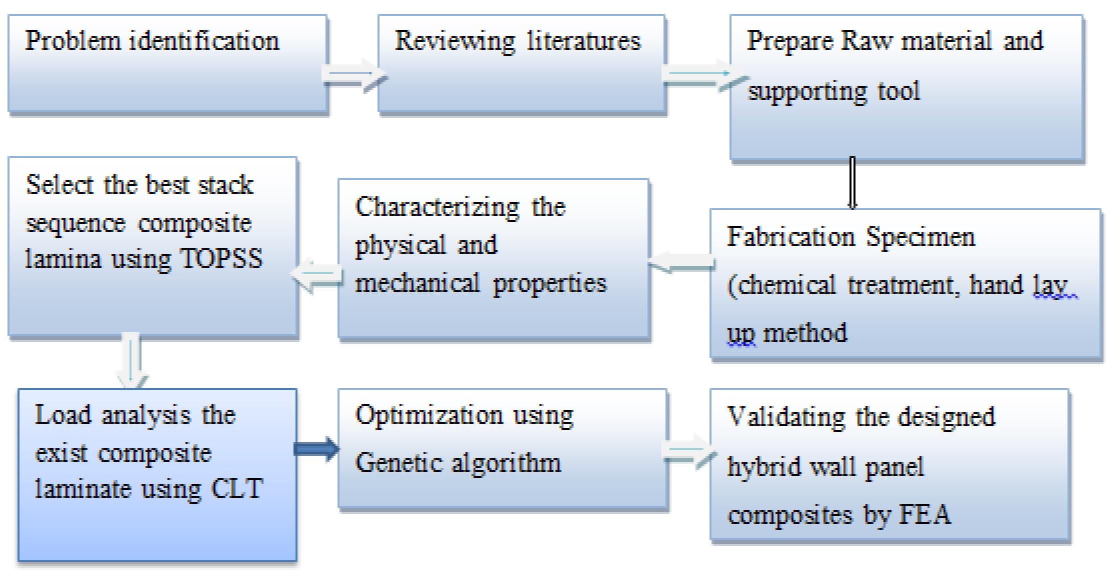


Figure 3-1: methodology step

3.2. Materials

3.2.1. Raw material

Material selection is one of the important tasks that should be done carefully. In this studies bamboo fiber, glass fiber and epoxy matrix are used for the preparation of composite specimen. The bamboo and glass fiber are durable and light weight material used as reinforcement and serves to strengthen the composites laminate. Sodium hydroxide used as a chemical treatment agent to improve the mechanical properties of the fiber. Epoxy is used as a matrix in composite material and binding the composite laminate enhance high strength and resistance to water absorption.

3.2.1.1. Bamboo fiber

Bamboo is a fast-growing plant known for its strength and flexibility. Bamboo fiber is low cost, low density, high specific strength and modulus, easy availability. Bamboo fibers can be combined with resins or other binders to create composite materials with enhanced mechanical properties [8], [12], [13]. It is purchased from Adane furniture in Mekelle, Tigray.

3.2.1.2. Glass fiber

Unidirectional E- type glass fiber relatively having high strength, low density, low cost, available, Resistant to heat & Good chemical resistant. Glass fiber is a synthetic fiber with extremely strong, lightweight, and robust, making them advantageous over metals. The glass fiber is the main constitutes that carry the load, while the enclosed matrix preserves the fiber in its selected orientation [14], [27], [31].

Figure 3-2: Glass fiber

3.2.1.3. Epoxy resins

Epoxy resins are the most commonly used resins. They are low molecular weight organic liquids containing epoxide groups. Epoxy resins are thermoset materials used as a matrix in composite material for their excellent adhesion and to enhance high strength and resistance to water absorption. Hardener refers to a substance or component that is added to a material or mixture to promote or accelerate the curing or hardening process. Both epoxy and hardener are purchased from the companies that [16].

Figure 3-3: Epoxy and hardener

3.2.1.4. Sodium hydroxide

Sodium hydroxide (NaOH) is used as a chemical treatment agent to improve the mechanical properties of the fiber. It is found from Chemical stores.

Figure 3-4: Sodium hydroxide

3.2.2. Tools, machines and other necessary

The main tools which used for the project to fabricate the laminated composite material are electronic balance, Roller, cutter, wood plate, ruler, press load, cups, stirrer, a caliper, scissor and disc cutter, supporting table, brush and molding carpet and testing machine were used.

Figure 3-5: Different tools

3.3. Methodology

To characterize the mechanical properties of the specimen, by preparing different arrangements of bamboo and glass fibers to designed and fabricated according to ASTM standards. They are many techniques of processing polymer matrix and natural fiber composite. Hand layup techniques is one of the simplest and continent methods for processing of composite materials applied to the laminate preparation. The fiber volume fraction and matrix volume fraction of the hybrid composite were determined. The laminated hybrid composite structure's ply thickness and stacking order were designed before the fabrication of the composite laminate. The hand layup method was used to fabricate the composite materials for this experiment.

3.3.1. Preparation of the materials

1. **Bamboo Fiber**: - The bamboo fiber is manually extracted from the bamboo tree available in most furniture in Mekelle, Tigray. Most inner parts and outer thin layer of exoderm of

the highland bamboo have been removed; the remaining parts have cleaved in longitudinal direction to thin strips using band saw. Then these strips are bundled and kept in water for five days in order to soften them. After removing, they are beaten gently at slow constant impact load using rubber hammer in order to loosen and separate the fiber. The resulting fiber bundle is combed using wire comb. Next these fibers were soaked in 5% NaOH solution for 48 hours at 60 ºC in the in oven dry to remove excess fats from individual fiber. Finally, the fibers washed many times in distilled water, and dried under the sun for a week.

2. **Glass Fiber**: - the glass fiber was bought from the roto production Fiber with a cost of 565birr/kg.

3. **Epoxy Resin and its Hardener**: - The epoxy was bought from production super fiber horizontal water tanker(roto) in Mekelle by 600bir/liter cost with its proper ratio of hardener

3.3.4. Sample Preparation Using Hand Layup Method

It is a rectangular shaped frame made up of either wood used for preparation of specimen. Its approximate Size is 300x300 xtmm. The main tools which used for the project to fabricate the laminated composite material are electronic balance, Roller, cutter, wood plate, ruler, press load, cups, stirrer, a caliper, scissor and disc cutter, supporting table, brush and molding carpet and testing machine were used.

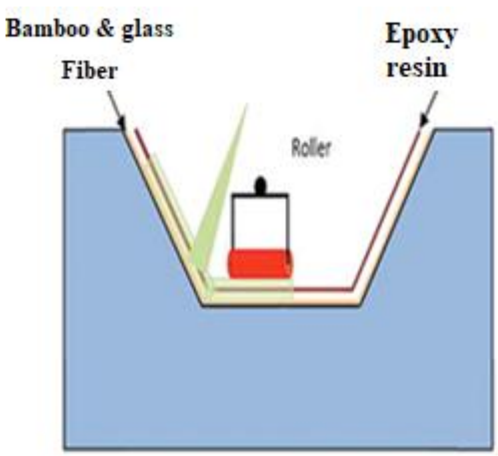


Figure 3-6: Hand lay-up method

3.3.5. Chemical treatment of bamboo fiber

The bamboo fiber was treated with an alkaline solution of sodium hydroxide (NaOH), a treatment to clean the surface of the fiber and improve the bonding property with epoxy. The NaOH solution was formed from the water with NaOH pellets 5% by weight. The bamboo fiber was immersed in the solution for 48 hr. The treated fiber was washed with running water to wash off any NaOH and dried at room temperature for up to 48 hrs. The alkaline treatment and stacking sequences of the fibers relative to one another have a significant effect on the strength of fiber-reinforced composites [5], [19], [36].

3.3.6. Determination of the percentage composition of fiber to matrix ratio

Fabrication of composite materials determination of constituent percentages such as fiber to matrix fraction present is important for;

- ✓ To prepare and estimate the size of the composite laminate
- ✓ To bring good laminate mechanical property by varying these values.
- ✓ To keep composite constituents from wastage So,

The fabrication of bamboo/E-glass fiber hybrid reinforced epoxy composite was designed with the stacking sequences B-G-B, G-B-G, G-G-B and B-B-B in the form of unidirectional fiber mat containing alkaline-treated bamboo fiber lamina. Before reinforcement bamboo fiber was treated with NaOH to enhance its properties. For each stacking sequence, the composites were reinforced with a bamboo/glass fiber [0, 0] orientation. The fiber and matrix volume fraction of the hybrid composite were calculated by the rule of mixture using the measured mass of the fibers and matrix on an electronic balance device.

Therefore, to go through the rule-of-mixtures here are the steps to be followed

Step-1: Weight & Weight Fraction of Fiber to Matrix

Depending on the pressing load available on the laboratory it is possible to estimate the amount of fiber to resin in percent. The composite sample is assumed to contain 3 hybrid plies either Bamboo fiber or Glass Fiber mat.

- ✓ First prepare fiber mates of Bamboo & Glass to produce sample. Approximated Area of Single ply is 300X300mm^2 & measured the weight using electronic balance.

- ✓ Then produce the composite laminate sample by adding the resin plies and finally press using pressing load of 20 Kg to stick the plies together.
- ✓ Finally, estimate the Fiber-to-Matrix weight ratio.

Weight fraction of fiber and matrix

$$Wc = Wff + Wfm \quad \text{3-1}$$

Where; Wc is total weight of composite,

Wff is weight of fiber &

Wfm is weight of matrix.

Again, to calculate weight fraction of fiber Wff & weight fraction of matrix Wfm

$$Wff + Wfm = 1 \quad \text{3-2}$$

Where, mb- mass of bamboo, mg- mass of glass, me- mass of epoxy, weight fraction, mc- mass of composite, wfb-bamboo weight fraction, wfg-glass weight fraction, wfe-epoxy weight fraction

Step-2: Volume & Volume fraction of Fiber and matrix (V_{Fiber}, V_{Matrix})

Even though determination of volume and Volume fraction of fiber and matrix is not such quite simple like weight ratio it can be calculated using the following formula.

$$Vc = Vf + Vm = \frac{Wf}{\rho f} + \frac{Wm}{\rho m} \quad \text{3-3}$$

$$Vff = \frac{Wf * \rho m}{(Wf * \rho m + Wm * \rho f)} \quad \text{3-4}$$

$$Vfm = \frac{Wf * \rho f}{(Wf * \rho m + Wm * \rho f)} \quad \text{3-5}$$

The total composite volume fraction (V_{cf}) must be unique i.e., $V_{cf} = V_{ff} + V_{mf} = 1$

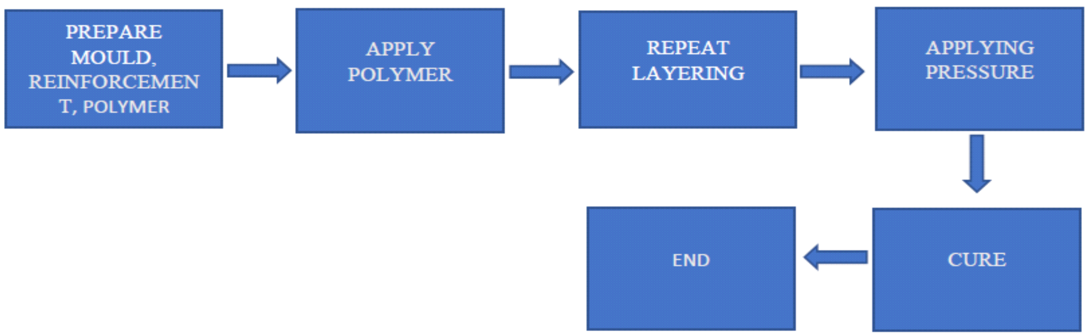
Step 3 Density of composite material

The theoretical density of composite can easily be obtained using the following equations.

$$\rho c = \frac{Wc}{Vc} = \frac{Wf + Wm}{Vc} \quad \text{3-6}$$

3.3.7. Sample fabrication procedures

In this study, the sample fabrication process was started by extract bamboo fiber then cutting the glass fibers, chemical treated bamboo fiber to a size of 300 mm x 300 mm per the size of the mold, Then the mixture (for every l kg of epoxy resin 20 ml of MEKP M50 was added) was gently stirred for about two minutes before being applied to the composite fiber in the mold,



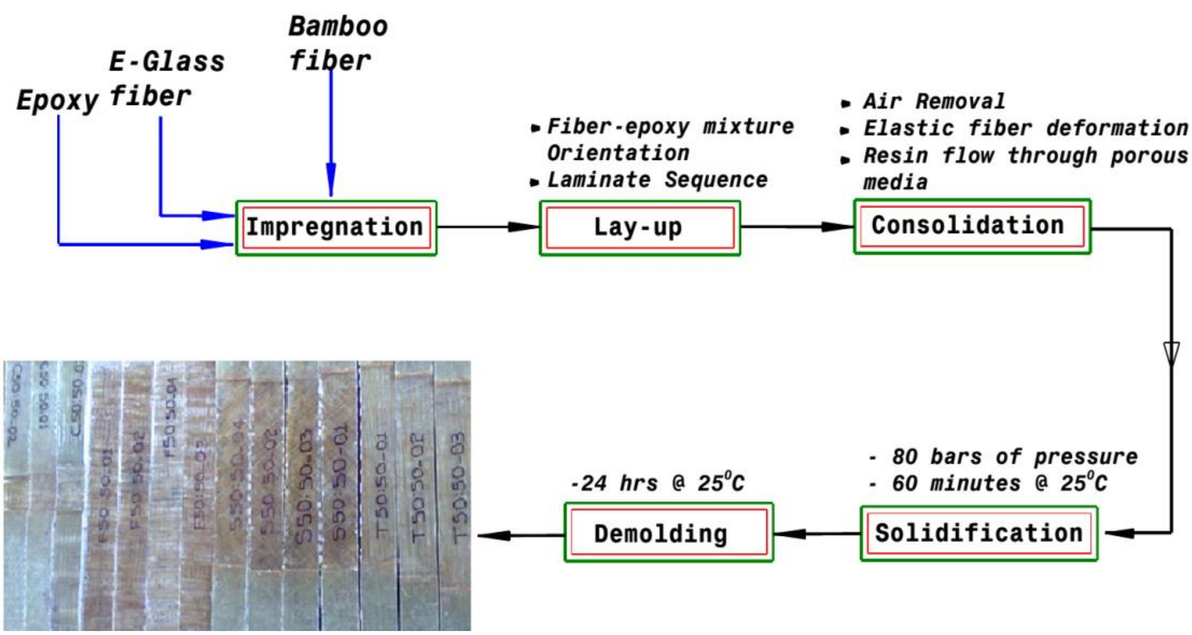
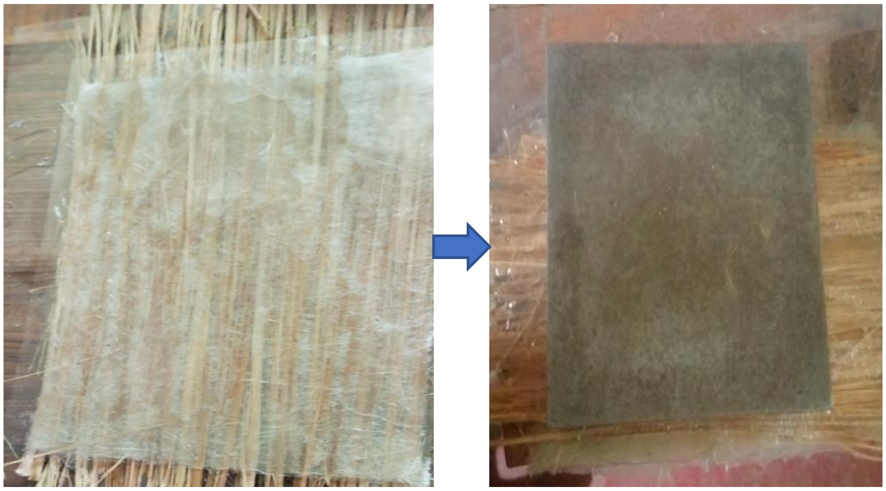


Figure 3-7: Flowchart of fabrication process of laminated composite

- The Cutting the bamboo & Glass fiber to a size of 300 mm x 300 mm then a unidirectional bamboo fiber is prepared and sew in to bamboo mat and mold is prepared from wood.

- For the mixed stacking sequence the mixture of epoxy resin add to the bamboo and glass ply. The resin is uniformly spread with the help of roller and the samples are prepared based on different compositions.

- The prepared laminate is covered with a plastic sheet the top and bottom of the mold plate to get good surface finish; release agent is applied to the mold surface for easy removal, about 200KN load is applied and stayed for at least 24 hours to cure at room temperature.



- Final results of sample is takeout from the mold

- Each fabricated sample were cut into the required size as per ASTM standards for each testing by using disc cutter

3.4. Experimentation to determine physical and mechanical property of the composite

For all fabricated laminate samples, test is conducted and based on the test results the output of the product is validated and optimized using finite element Analysis ABAQUS. Tensile strength, compressive strength, flexural strength and impact strength are tested.

Testing equipment's is;

- ✓ universal tensile testing equipment (for tensile & compressive strength, flexural strength),
- ✓ Chirpy impact testing machine (for impact strength)

3.4.1. Tensile testing

Tensile testing in composite according to ASTM D3039-76 is used to measure the longitudinal force required to break a polymer composite specimen and the extent to which the specimen stretches or elongates to that breaking point using Universal Testing Machine. For tensile strength testing, a specimen of the manufactured composite material was cut into 250 $mm x$ 25 $mm x$ t. The samples are tested using universal tensile testing machine [67].

Figure 3-8: Tensile test

3.4.2. Compression Testing

Compressive properties were determined by static compression test by ASTM D3410[68]. A compression test was performed on a designed specimen with nominal geometrical dimensions of 100mm x 20mm x t, in which the maximum compressive strength and compression modules of the hybrid composite specimen were recorded during the compression.

Figure 3-9: compression test

3.4.3. Flexural Test

According to ASTM D7264 [69] flexural test of composite measures the force required to bend using a bar of rectangular cross section supported on a beam. For this test 3-point loading was applied. The samples are tested using universal tensile testing machine, As a result, the nominal specimen's geometrical dimensions were 150mm x 13mm x t mm. The specimen was placed horizontally on two supports in the flexural testing machine and the load was then slowly increased to the center of the specimen with a speed of 5mm/min. the data was recorded on the computer and bending strength was estimated from the data using the bending strength equation.

$$\sigma = \frac{3PL}{2bt^2} \quad \text{(3-7)}$$

Where:
σ = flexural stress, MPa,
P = applied force, N,
L = support span, mm,
b = width of sample, mm, and
t = thickness, mm.

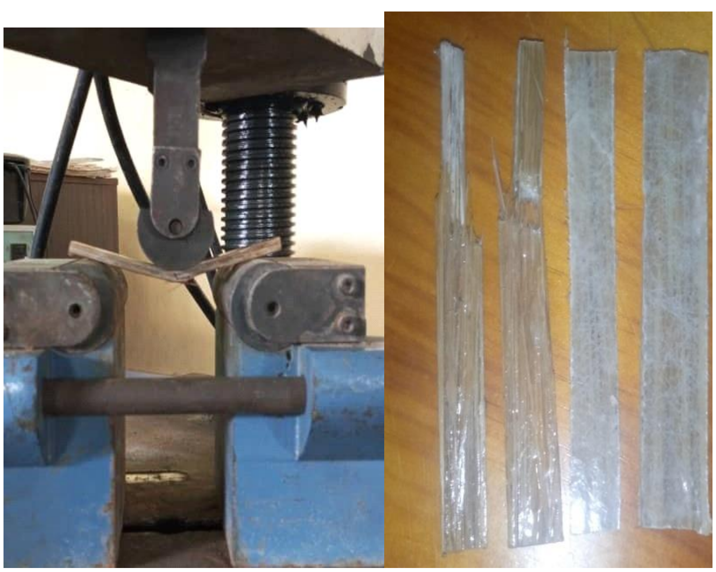


Figure 3-10: Flexural test

3.4.4. Impact Test

According to ISO 179–1 (2010),[70] is impact resistance of material which measures the amount of force needed to break a specimen under a high-speed load introduced through a swinging pendulum. The Charpy impact test was carried out for the sample's specimens with dimensions of 80mm x10mm x t. Test Procedure After fixing of specimen pendulum is released and allowed to strike until failure occurs. The machine pendulum energy engaged for the testing was 2 Joule with a speed of 2 m/s & having 25-kg weight mounted in material testing laboratory in our campus. Finally, the Impact energy measured in joule was recorded from the apparatus.

Figure 3-11 impact test

3.4.5. Water Absorption Test

According to ASTM D 570 [71] the specimens are prepared with 60mm x 60mm x t and soaked in water for a week, the surface water was wiped off using dry cloth and the wet weight measured each day using electronic balance to see the amount of water absorbed until it reaches its highest limit. The percentage water absorption was calculated using the following formula given below:

$$\mathbf{W}\ (\%) = \frac{W_t - W_d}{W_d} \times \mathbf{100} \quad \text{…………………………………………… 3-8}$$

Where; W_d and W_t denote the dry weight and weight after time t of composite respectively [71]

3.4.6. Density of the Hybrid Composite

Density of composite laminate sample can be determined experimentally using Archimedes method with distilled water. Dimension of the sample is 60 x 60 mm x t. The apparatus used to determine the density of laminated composite are: The actual density (ρa) (experimental density) of the composite was determined by the formula below.

ρa (g/cm3) = m/V…………………………………………… . 3-9

Where; m= mass

V=Volume

ρa= experimental density

Density of composite is determined by the fraction of mass to volume of composite based on the ASTM D1895 standard [72].

Also, the theoretical density of the composite is determined by the equation of the Rule of Mixture; Properties of fibers and matrix from table below.

ρtheoretical= 1/ [(Wf/ ρf) + (Wm/ ρm) ………………………………………………… 3.12

Where: Wf is fiber weight fraction,

Wm is matrix weight fraction,

ρf is fiber density, and

ρm is matrix density.

Table 3-1: properties of raw materials

	Density(g/cm3)	Young's modulus(Gpa)	Poisson's ratio	Shear modulus (GPa)	Reference
Bamboo	1.3	22.27	0.3	0.8	[5], [6], [7]
Glass	2.55	75	0.27	27.5	[20 21 24]
Epoxy	1.3	4.5	0.35	2	[15],[16],[17]

3.5. Application of TOPSIS method

This method is to construct the ideal solutions and minus idea solutions to the problems of multiple attributes and uses the two benchmarks of being close to the ideal solutions and being far away from the minus ideal solutions as the criteria of evaluating the feasible projects. "Ideal solution" and "minus ideal solution" are the two basic concepts of TOPSIS method.

TOPSIS method is aggression that compares set of alternatives by identify weight on it criterion normalizing of score and then use of normalizing distance between each alternative and ideal alternative.

TOPSIS method considers three types of attributes or criteria.

- ✓ Qualitative benefit attributes/criteria
- ✓ Quantitative benefit attributes.
- ✓ Cost attributes or criteria.

APPLICATION OF TOPISIS

- ✓ Supply chain management and logistics
- ✓ Design engineering and manufacturing system
- ✓ Business and marketing management
- ✓ Energy management
- ✓ Chemical engineering
- ✓ Water resources management

TOPISIS METHODOLOGY

- ✓ Define criteria and alternatives
- ✓ Formulate decision matrix
- ✓ Normalize matrix
- ✓ Weight normalizes matrix
- ✓ Finding positive and negative ideal solutions
- ✓ Closeness coefficient
- ✓ Ranking alternatives

Definition of criteria and alternatives

The Tensile, compression, Flexural, Impact strength and Density are positive criterion whereas the water absorption and cost is a negative criterion.

Step 1: Calculate the normalized decision matrix. For simplify, a vector normalization method is introduced who's normalized value Nij calculated as:

$$\boldsymbol{N_{ij}} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad \boldsymbol{i = 1, 2, 3 \ldots . n \; and \; j = 1, 2, 3 \ldots . m} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3\text{-}10$$

Step 2: Calculate the weighted normalized decision matrix.

$$\boldsymbol{V_{ij} = W_j * N_{ij} \quad i = 1, 2, \ldots n \; and \; j = 1, 2, \ldots . m} \ldots\ldots 3\text{-}11$$

Where is the relative weight of the jth criterion/attribute?

Step 3: Determine the positive ideal and negative ideal value solution as below:

Maximum value for the positive attributes and minimum value for the negative attributes

$\boldsymbol{V^+ = V_j max}$ In case of a benefit criterion.......... 3-12

$V^+ = V_j \min$ In case of a negative criterion

Minimum value for the positive attributes and maximum value for the negative attributes

$\boldsymbol{V^- = V_j \min}$ In case of a negative criterion 3-13

$V^- = V_j max$ In case of a benefit criterion

Step 4: Calculate the separation measures, using the m-dimensional Euclidean distance. The separation of each alternative from the ideal solution and the negative ideal solution are given below, respectively:

$$\boldsymbol{S^+ = \sqrt{\sum_{j=1}^{m} (V_{ij} - V_j \, max)^2} \quad i = 1, 2 \ldots n} \ldots\ldots 3\text{-}14$$

$$\boldsymbol{S^- = \sqrt{\sum_{j=1}^{m} (V_{ij} - V_j \, min)^2} \quad i = 1, 2 \ldots n} \ldots\ldots 3\text{-}15$$

Step 5: Calculate the relative closeness of each alternative to the ideal solution. Select the alternative which is closest to ideal solution and farthest from negative ideal solution. The relative closeness of the alternative A with respect to is defined as follows:

$$P=\frac{S^-}{S^-+S^+}$$

Step 6: Rank preference order. Choose an alternative with maximum P* or rank alternatives according to Pin * descending order

3.6. Design Analysis of partition Wall Panels

Designing a wall panel involves both functional and aesthetic considerations. Wall panels can serve to improve elevate the visual appeal of a space. Load analysis for wall panels is essential to ensure the structural integrity and safety of the wall system. Wall panels, especially those used in construction design, must support both dead loads (the weight of the wall and any materials attached to it) and live loads (temporary loads, such as people, furniture). The analysis should be done to evaluate whether the wall panels will perform safely under these loads. The limiting deflection is normally taken as 1/240th of the Allowable wall. For non-load bearing partition wall panel live load refers temporary movable load that might be applied, such as people leanings against the wall or item like furniture placed against it in a typical office or residential building. Live load is typical around 0.5KN/m2 for interior wall [73],[74],[75], [76], [77].

Assumption

- ✓ Wind and seismic load are negligible
- ✓ Simply supported at both ends (pinned) and the load is uniformly distributed load (UDL)
- ✓ The plate material is linear elastic and follows Hooke's law
- ✓ The plate material is homogeneous and isotropic. Its elastic deformation is characterized by Young's modulus E and Poisson's ratio ν.
- ✓ The thickness of the plate is small compared to its lateral dimensions.
- ✓ The deflection of the plate is small compared to the plate thickness.
- ✓ Loads are applied in a direction perpendicular to the center plane of the plate

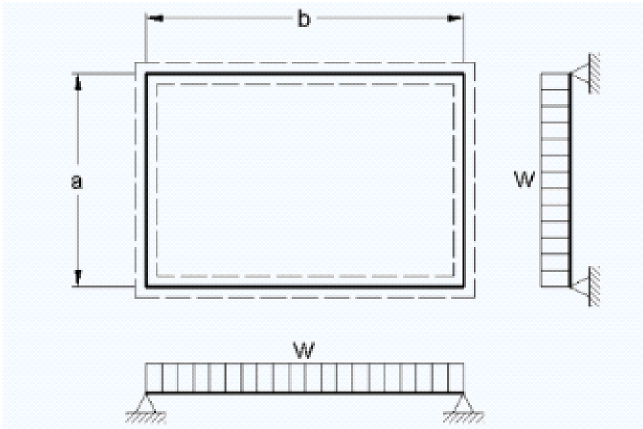


Figure 3-12: A FBD of a rectangular thin plate simple support in all edges and load distribution [77]

Given data	Value
Design load	M*g
Live load	0.5KN/m2
Impact load	0.5-1.5KN/m2
Height	1.83-7.32m
Length	1.2-366m
β	0.1017
β1	0.0464
γ	0.465
γ1	0.370
m	$\rho * v$
ρ	1.369g/cm3

Figure 3-13: Standard dimensions and load partition wall panel according it ASCE 7-98 [76] [77].

$$Total\ design\ load\ = DD\ +\ LL\ + Fi \quad \text{3-16}$$

$$\mathrm{DD} = \ m * g \quad \text{3-17}$$

$$\mathbf{m} = \boldsymbol{\rho} * \boldsymbol{V} \quad \text{3-18}$$

Take from the standard load and dimensions of partition wall panel

Live load = 0.5KN/m2

Impact load = 0.5KN/m2

Normal forces per unit length of sections of a plate perpendicular to x and y direction, Nx and Ny respectively[77].

$$\mathbf{Nx} = \boldsymbol{\gamma w l} \quad \text{3-19}$$

$$\boldsymbol{Ny} = \boldsymbol{\gamma 1 w l} \quad \text{3-20}$$

For simple support the bending moment per unit length of sections of a plate perpendicular to the x and y axes, Mx and My respectively

$$\mathbf{Mx} = \boldsymbol{\beta}\mathbf{wl^2} \quad \text{3-21}$$

$$\mathbf{My} = \boldsymbol{\beta}\mathbf{1wl^2} \quad \text{3-22}$$

3.7. Design composite laminate wall panel

A laminate is an organized stack of unidirectional composite plies (unidirectional meaning the plies have a single fiber direction rather than a weave pattern). The stack is defined by the fiber directions of each ply [78]. The analytical design of a composite plate developed for wall panel applications is presented in this research. Laminate composite of unidirectional ply orientation of bamboo, and glass fiber reinforced epoxy is prepared up to three layers. The optimal stacking sequence is selected using TOPSIS. The laminate is designed symmetrically, ensuring equal dimensions (length, width and ply thickness) above and below the mid-plane, all with aligned fiber orientation.

3.7.1. Classical lamination theory (CLT)

The classical lamination theory (CLT) is utilized to determine the stresses and strains at any position of laminates subjected to force and/or moment resultants. Classical Lamination Theory (CLT) is the method which depends upon the material properties and sequence of stacking of the layers to calculate the stress and strain distribution in the laminate [78],[79], [80].

Assumptions used in classical lamination theory are

- ✓ The bond between fibers and matrix is perfect.
- ✓ The elastic moduli, diameters, and space between fibers are uniform.
- ✓ The fibers are continuous and parallel.
- ✓ The fiber and matrix follow Hooke's law (linearly elastic).
- ✓ The fibers possess uniform strength.
- ✓ Each layer of the laminate is orthotropic.
- ✓ State of stress is plane stress. That is, $\sigma 3 = \tau 13 = \tau 23 = 0$
- ✓ No slip or void occurs between the lamina interfaces. This means the boding is infinitesimally small, has non shear deformation (no lamina slip) and the bonds are as strong as it need to be to prevent shear.

3.7.2. Stress-Strain Relationship for Orthotropic Lamina

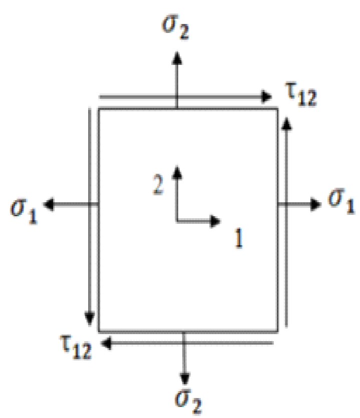
For a thin layer of composite lamina, it is assumed that the lamina is under plane stress conditions in the direction of lamina thickness. The stress-strain relationship in principal material generalized by Hooke's law for orthotropic material is given by

$\{\sigma\}= [Qij]\ \{\varepsilon\}$.. 3-23

Where; the stress-strain relationship can be expressed in the matrix as follow

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{12} \\ \tau_{13} \\ \tau_{23} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 & 0 & 0 & 0 \\ Q_{12} & Q_{22} & 0 & 0 & 0 & 0 \\ 0 & 0 & Q_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & Q_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & Q_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{12} \\ \gamma_{13} \\ \gamma_{23} \end{Bmatrix}$$ 3-24

From the lamination theory, stiffness matrices were usually obtained about the mid plane of a laminate. For a symmetric laminate that is subjected only to forces, it will have zero mid plane curvatures, and if it is subjected only to moments, it will have zero mid plane strains. The structural response of laminate is represented by the strain and curvatures about its mid plane. The global stress (angle ply stress) of the laminate is calculated from the strain and curvatures of its mid-plane.



The stiffness matrix describes the elastic behavior of the ply in plane loading

$$\boldsymbol{Q}_{ij} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix}$$ ………………………………………………………………. 3-25

$Q11 = \frac{E1}{1-\upsilon12\upsilon21}$……………………………………………………. 3-26

$Q12 = \frac{v12E2}{1-\upsilon12\upsilon21}$……………………………………………………. 3-27

$Q22 = \frac{E2}{1-\upsilon12\upsilon21}$……………………………………………………. 3-28

Q66 =G12………………………………………………………………. 3-29

Where; E1 - Longitudinal Young's modulus

E2 - Transverse Young's modulus

v12- Major Poisson"s ratio

G12 - In-plane shear modulus

Calculate the transformed reduced stiffness matrix $\underline{Q}\ \underline{ij}$ for each ply based on the reduced stiffness matrix and fiber angle.

Where

$$\overline{Q_{11}} = Q_{11}\cos(\theta)^4 + 2(Q_{12} + 2Q_{66})\cos(\theta)^2 \cdot \sin(\theta)^2 + Q_{22}\sin(\theta)^4$$
$$\overline{Q_{12}} = \overline{Q_{21}} = Q_{12}(\cos(\theta)^4 + \sin(\theta)^4) + (Q_{11} + Q_{22} - 4Q_{66})\cos(\theta)^2\sin(\theta)^2$$
$$\overline{Q_{16}} = \overline{Q_{61}} = (Q_{11} - Q_{12} - 2Q_{66})\cos(\theta)^3\sin(\theta) - (Q_{22} - Q_{12} - 2Q_{66})\cos(\theta)\sin(\theta)^3$$
$$\overline{Q_{22}} = Q_{11}\sin(\theta)^4 + 2(Q_{12} + 2Q_{66})\cos(\theta)^2\sin(\theta)^2 + Q_{22}\cos(\theta)^4$$
$$\overline{Q_{26}} = \overline{Q_{62}} = (Q_{11} - Q_{12} - 2Q_{66})\cos(\theta)\sin(\theta)^3 - (Q_{22} - Q_{12} - 2Q_{66})\cos(\theta)^3\sin(\theta)$$
$$\overline{Q_{66}} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66})\cos(\theta)^2\sin(\theta)^2 + Q_{66}(\cos(\theta)^4 + \sin(\theta)^4)$$

$$\overline{\boldsymbol{Q}_{ij}} = \begin{matrix} \overline{Q_{11}} & \overline{Q_{12}} & \overline{Q_{16}} \\ \overline{Q_{12}} & \overline{Q_{22}} & \overline{Q_{26}} \\ \overline{Q_{16}} & \overline{Q_{26}} & \overline{Q_{66}} \end{matrix}$$

……………………………… 3-30

3.7.3. Force and Moment Resultants Related to Mid-plane Strains and Curvatures:

The mid-plane strains and plate curvatures are the unknowns for finding the lamina strains and stresses. The stresses in each lamina can be combined through the laminate thickness to give resultant forces and moments. The forces and moments applied to a laminate will be known, so the mid-plane strains and plate curvatures can be found. This relationship between the applied loads and the mid-plane strains and curvatures is developed. The mid-plane strains and mid surface curvatures can be found using the ABD matrix which is a 6x6 matrix that serves as a connection between the applied loads and the associated strains in the laminate. It essentially defines the elastic properties of the entire laminate. [A], [B], [D] are called extensional, coupling, and bending stiffness matrices respectively, their formulas are

Calculate the Aij, Bij, Dij matrices using the following equations where z represents the vertical position in the ply from the mid plane measured in meters

$$\boldsymbol{A}_{ij} = \sum_{k=1}^{n} \{Q_{ij}\}_n (z_k - z_{k-1})$$
$$\boldsymbol{B}_{ij} = \frac{1}{2}\sum_{k=1}^{n} \{Q_{ij}\}_n (z_k^2 - z_{k-1}^2)$$
$$\boldsymbol{D}_{ij} = \frac{1}{3}\sum_{k=1}^{n} \{Q_{ij}\}_n (z_k^3 - z_{k-1}^3)$$

…………………………………………………………… 3-31

Calculate mid plane strains and curvatures induced in the laminate. These represent the deflections of the laminate.

$$\begin{bmatrix} N \\ M \end{bmatrix} = \begin{bmatrix} [A] & [B] \\ [B] & [D] \end{bmatrix} \begin{bmatrix} \varepsilon^0 \\ k \end{bmatrix}$$

$$\begin{bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_x \\ M_{xy} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{12} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \\ k_x \\ k_x \\ k_{xy} \end{bmatrix}$$

…………………………………………… 3-32

For each ply

a. Calculate ply strains in the x-y coordinate system

$$\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} \varepsilon_{x0} \\ \varepsilon_{y0} \\ \gamma_{xy0} \end{bmatrix} + Z \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix}$$

……………………………………………… 3-33

b. Calculate ply stresses in the x-y coordinate system

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} = \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix}$$

……………………………… 3-34

The global and local coordinate systems are related to each other by the angle at which the lamina is placed (θ). Using a transformation matrix, it is possible to convert the global stress in a laminate into the local of a lamina.

$$[\mathrm{T}] = \begin{bmatrix} \mathrm{m}^2 & \mathrm{n}^2 & 2\mathrm{mn} \\ \mathrm{n}^2 & \mathrm{m}^2 & -2\mathrm{mn} \\ -\mathrm{mn} & \mathrm{mn} & \mathrm{m} - \mathrm{n}^2 \end{bmatrix}$$

…………………… 3-35

Where; m cos θ sin θ

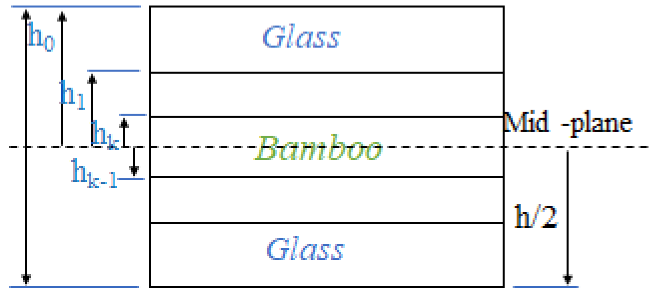


Figure 3-14: coordinate locations of the three-ply laminate

The laminate extensional stiffness matrix can be calculated by using the stiffness matrixes and the position and thickness of the lamina. [A], [B], and [D] matrix is given by;

$[A] = \frac{1}{3}\sum_{K=1}^{3}[\mathbf{Qij}]\,\mathbf{K}\,(h\mathbf{K} \;- h\mathbf{K}-\mathbf{1})$ 3-36

$[B] = \frac{1}{2}\sum_{K=1}^{3}[\mathbf{Qij}]\,\mathbf{K}\,(h^2\mathbf{K} \;- h^2\mathbf{K}-\mathbf{1})$ 3-37

$[D] = \frac{1}{3}\sum_{K=1}^{3}[\mathbf{Qij}]\,\mathbf{K}\,(h^3\mathbf{K} \;- h^3\mathbf{K}-\mathbf{1})$ 3-38

[A]= [A]top+ [A]middle+ [A]bottom 3-39

[D]= [D]top+ [D]middle+ [D]bottom 3-40

Using this mathematical relationship, structure weight and geometry dimensions of the composite formwork sheathing will be optimized by Genetic Algorithm software in MATLAB.

3.7.4. Failure Analysis of Laminate

Classical Lamination Theory (CLT) is the method which depends upon the material properties and sequence of stacking of the layers to calculate the stress and strain distribution in the laminate. The traditional definition of failure does not fit here. In case of composites or particularly FRPs, failure does not mean sudden failure or no failure, but it denotes when the first failure is observed in the laminate and on which ply [81]. Material failures occur when component is subjected to higher stresses & strain values beyond, they can handle. It includes fracture, buckling, and matrix cracking. So, a laminate will fail under increasing mechanical and thermal loads until all the plies fail. Laminate failure is not catastrophic. If one ply fails the other ply in the laminate is still capable of taking more loads until all the plies fail. Tsai-Hill and Tsai-Wu are some interactive failure criteria which can approximate first ply, and consequent ply failure. In case of cyclic loadings which in maximum applications, load causes first ply failure [82].

Tsai-Wu result is more accurate and agrees with the experimental values, because it does distinguish between the tensile and compressive strengths and shows as if it exists failure surface in the stress space. Again, the Tsai–Wu failure criterion used to predict the first-ply failure load. For orthotropic lamina in a general state of plane stress for Tsai-Wu failure theory is given by

$$F1\sigma1 + F2\sigma2 + F11\sigma1\,2 + F12\sigma1\sigma2\,2 + F22\sigma2\,2 + F66 < 1 \quad \text{3-41}$$

Where F1 = $\frac{1}{Xt} - \frac{1}{Xc}$ & F2 = $\frac{1}{Yt} - \frac{1}{YC}$ are coefficient for longitudinal strength F11 = $\frac{1}{XtXc}$ & F22 = $\frac{1}{YcYt}$ are coefficient for transversal strength, F66 = $\frac{1}{\tau 2}$ coefficient for shear & F12 is determined experimentally. But if no experimental value, Tsai-Wu recommends using: F12 = $-1/2\sqrt{F11F22}$

Where

Xt = longitudinal tensile stress

Xc = longitudinal compression stress

Yt = transverse tensile stress

Yc = transverse compression stress

τ = shear stress in shear

$$SR = \frac{\textbf{Ultmat strength}}{\textbf{allowable strength}} > \mathbf{1} \quad \text{3-42}$$

If SR>1 then the lamina is safe and the applied stress can be increased by a factor of SR.

If the SR < 1the lamina is unsafe and the applied stress needs to be reduced by a factor of SR.

3.8. Optimization of composite wall panel

Composite laminate design and optimization requires discrete programming in order to find the correct number of plies with thicknesses, orientation angles, and material types which are usually restricted to a discrete set of values. Genetic algorithms are one of the few optimization tools available that are well suited to such discrete problem-solving environments. The goal would be to minimize the mass and optimize the thickness while ensuring the laminate's performance [20], [20], [21].

A genetic algorithm (GA) is a method for solving unconstrained and constrained optimization problems based on a process of natural selection that mimics biological evolution. This algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm randomly selects individuals from the current population and uses them as parents to produce the offspring of the next generation. After several successive generations, the population "evolves" toward an optimal solution [65], [66], [83].

Design optimization aims to determine the optimal shape of a structure by maximizing or minimizing a given criterion, such as stiffness or weight, subject to stress or displacement constraints. Minimize weight, cost, and material waste.

3.8.1. Objective of Optimization

Mathematical equation that represents that specific goal i want to achieve by adjusting designs parameters; it defines what needs to be maximized or minimize to find the best designs solution with a set of constraints essentially acting as the metric used to evaluate different design options and guide the optimization process toward the desired outcome.

Objective function for design partition wall panels from bamboo and glass fiber epoxy composites is to optimize the design parameters to reduce weight to strength ratio. The objective function for optimizing a partition wall panel, the primary goal is to **minimize the weight** of the panel while ensuring it meets all performance. Therefore, the objective function is;

To minimize f(y), which is the weight of the composite plate also can be calculated as;

$$f(x)=\sum_{i=1}^{n} \rho i A i\ ti \quad \text{.......................................} \quad 3\text{-}43$$

Where; x is design variable,

ρ-Material densities.

tg- thickness of glass,

tb- bamboo thickness

3.8.2. Design Parameters

Design parameters are measurable attributes that can be adjusted or controlled to achieve desired outcomes in a design. They serve as the foundation for defining how a product will behave under various conditions. It includes length, width, and load, modulus of elasticity (E), density and maximum allowable stress.

3.8.3. Design Variables:

Design Variables are system parameters that can vary to optimize system performance which change to get the best of several possible design configurations. In this study, the design variable is the thickness of each ply and lamina angle orientation.

3.8.4. Constraints:

Constraints are a lower limit or an upper limit on any response that is dependent on the design variable. In this study constrain used on the analysis of determining optimized partition wall pane was the Tsai-Wu failure theory equation, based on the total which is dependent of material properties of the laminate composite. Failure occurs when the stress condition is critical. Therefore, a lamina is considered to be failed if equation (3-50) is not satisfied.

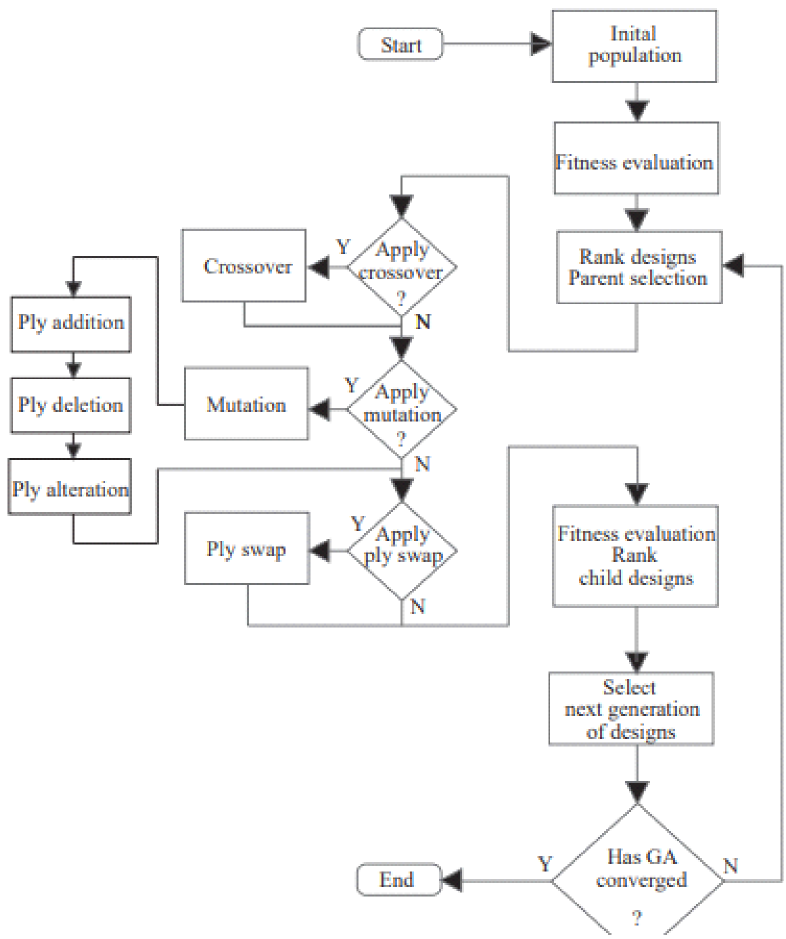


Figure 3-15: procedures for Size Optimization using GA

3.9. FEA for Validation OF the Result

Validation of the result is done using ABAQUS software. In order to confirm the result, the optimized wall panel was analyzed by using ABAQUS for validation purpose. It ensures that the optimized outcomes produced by the genetic algorithm are reliable and consistent with real world behavior modeled in ABAQUS.

3.9.1. Define Geometry and Material Properties (model)

Model the partition wall panel (dimensions: thickness, length, width). Assign the material properties for each component (Density, Elastic properties, and Strength properties): Figure 3-13 illustrates the structural model of the bamboo, glass fiber and epoxy laminate, along with the stacking sequence of the ply laminate. Based on the results from the genetic algorithm it is designed to the optimized dimension and optimized ply orientation which is (90°, 0°, and 90°).

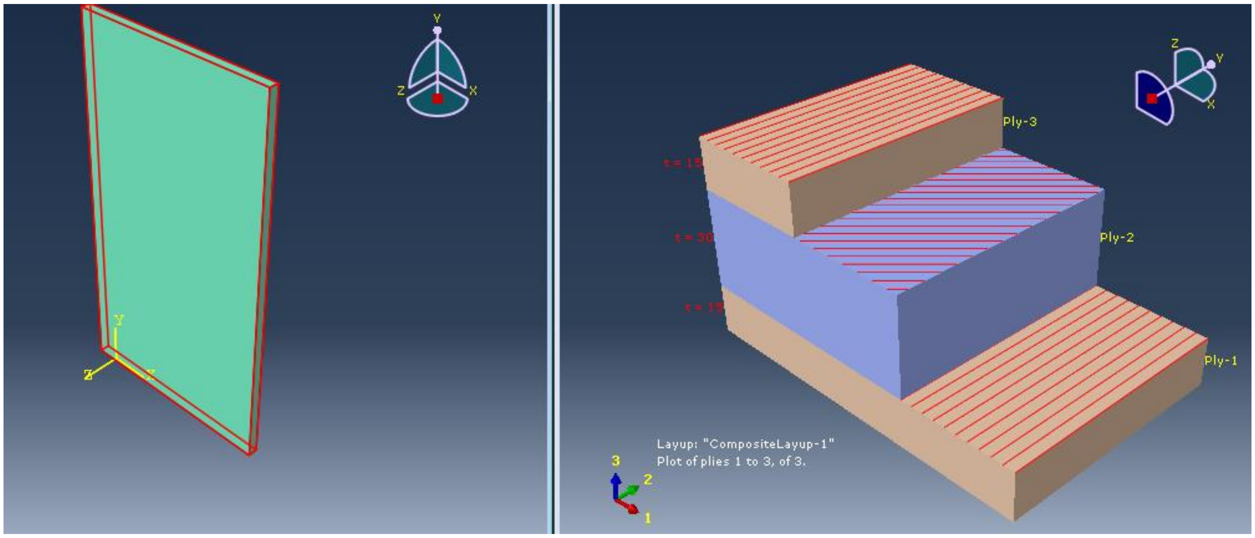


Figure 3-16: Optimized 3D model and ply stacking sequence wall panel

3.9.2. Mesh the Model

Meshing refers to the process of dividing a geometric model which is the wall panel made of composite into smaller, discrete elements that can be analyzed. This division is crucial because it allows the ABAQUS software to approximate the behavior of the entire structure by solving equations for each individual element. It was meshed by S4R of 0.05 mesh size as shown in figure below.

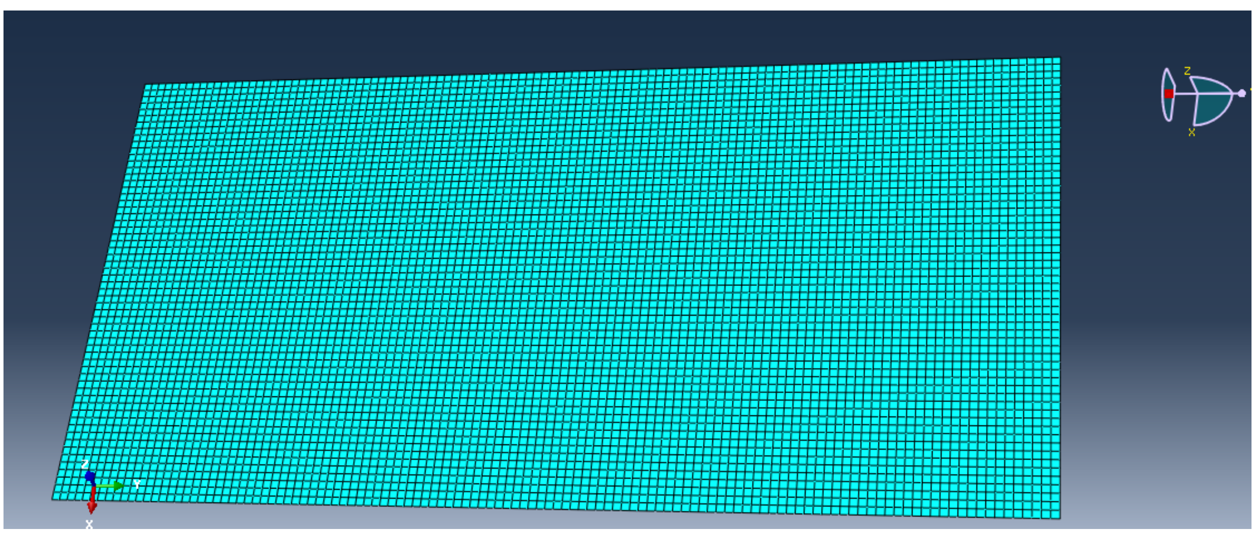
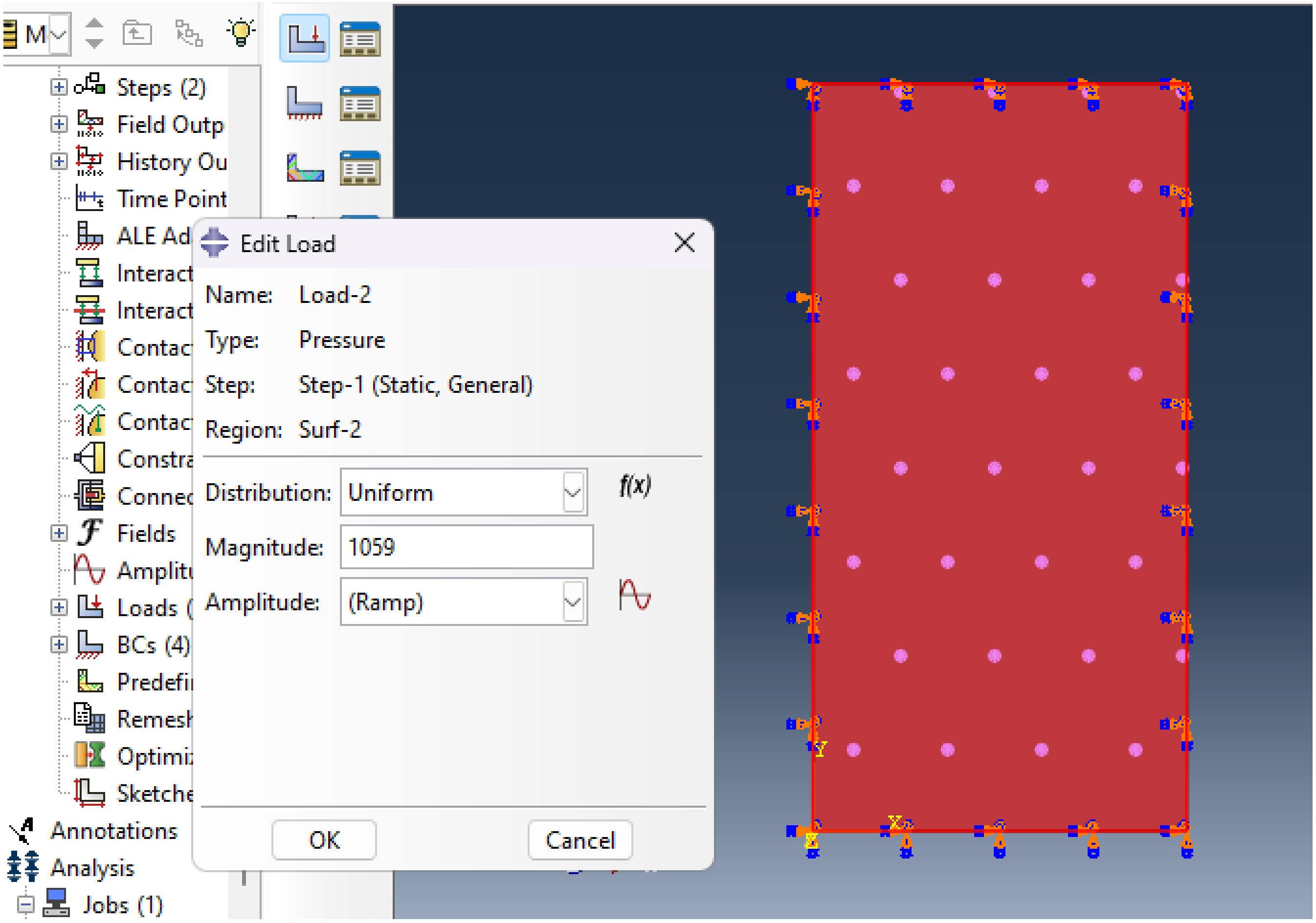


Figure 3-17: Meshing of the 3D mode



3.9.3. Defining the Boundary Conditions and Applied Load

The applied load and the constraints are defined as in figure below. Simple support wall panel supports a distributed load of 1059N/m2 and it is defined as simple support in all edges.

Figure 3-18: Load defining

CHAPTER FUOR

4. Result and discussion

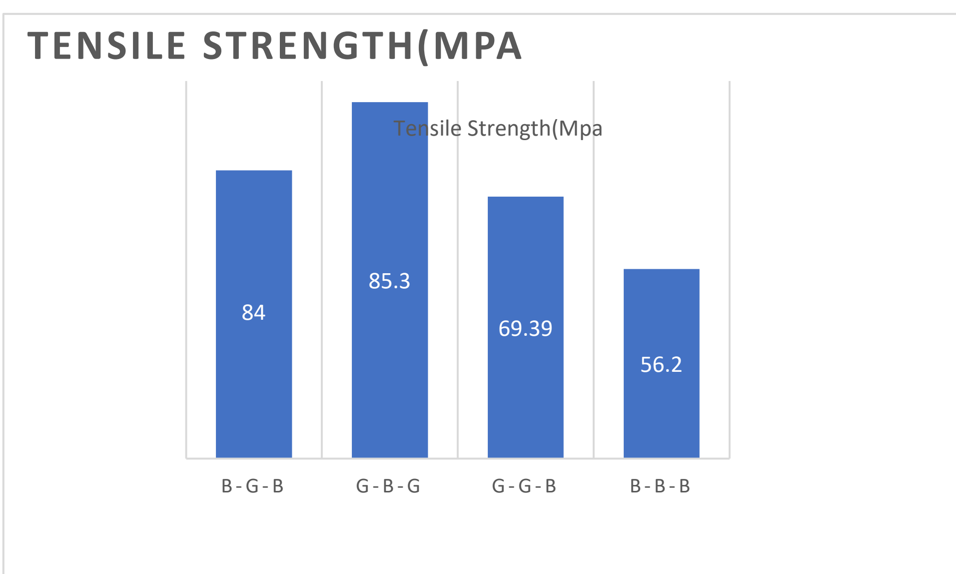
This chapter includes the results obtained from the different sample tests conducted in the experiment with the same composite composition 40% to 60% weight fraction of fiber to matrix ratio and selection of the best laminate using TOPSIS multi criteria decision making method, the analysis of the laminated wall panel using the classical laminate theory analysis of the an optimization to minimize the weight of the partition wall pane using genetic algorithm by MATLAB software, the optimized result validated using ABAQUS software, Hence, the results were presented and discussed as follows.

4.1. EXPERIMENTAL RESULT OF LAMINATED COMPOSITE

4.1.1. Tense strength

The values for tensile strength for different combination of developed composites are given in figure below. The maximum value of tensile strength is 85.3 MPa for Epoxy 60% + E glass fiber 35% + bamboo fiber 5% combination after reaching this value further apply of bamboo fiber decrease the tensile strength. The minimum value obtained is 56.2MPa for Epoxy 60%+E glass fiber 0% and bamboo 40% composition. Incorporation of bamboo fiber with glass fiber in matrix shows improved results than the usage of bamboo fiber alone as reinforcement.

Figure 4-1 : Tensile strength results



4.1.2. Flexural strength test

The values of flexural strength of the developed composites shown in figure below and the maximum value of flexural strength is 497 MPa for the Epoxy 60% + E glass fiber 15% + bamboo fiber 25% hybrid composite and the minimum value of the flexural strength is 299 MPa for the bamboo/ epoxy composite. It is observed that the value of flexural strength increases with decrease in weight percentage of bamboo fiber and increases with increase in weight percentage of glass fiber. After that increase in weight percentage of bamboo fiber decreases the power. This may happen because of the improper impregnation of bamboo fiber into the matrix which leads the deboning of threads.

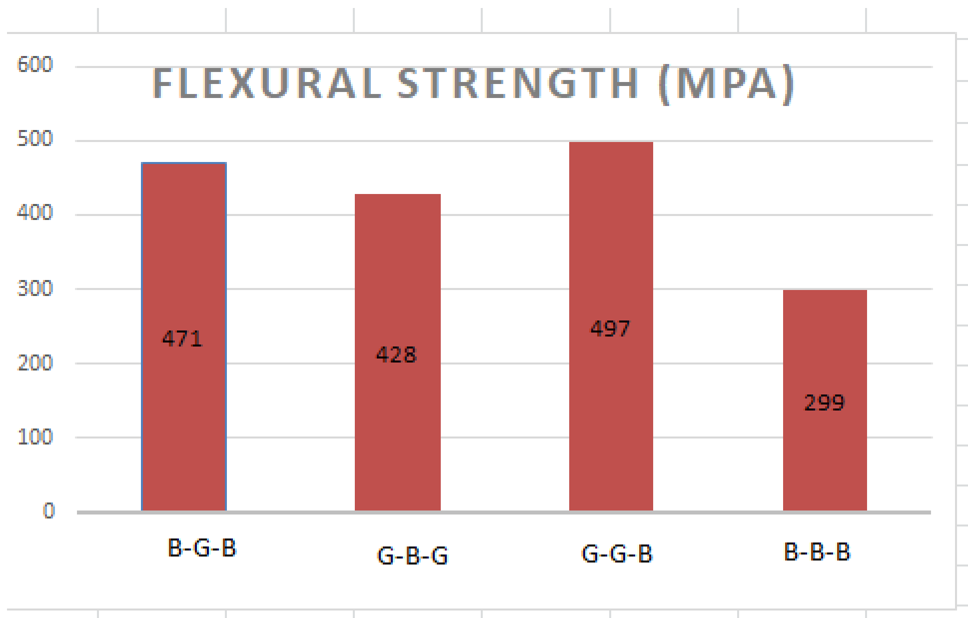


Figure 4-2: Flexural strength results

4.1.3. Compressive strength

The values for Compressive strength for different combination of developed composites are given in figure below. The maximum value of Compressive strength is 17.3 MPa for Epoxy 60% + E glass fiber 10% + bamboo fiber 30%. The minimum value obtained is 13.7 MPa for Epoxy 60%+E glass fiber 0% and bamboo 40% composition.

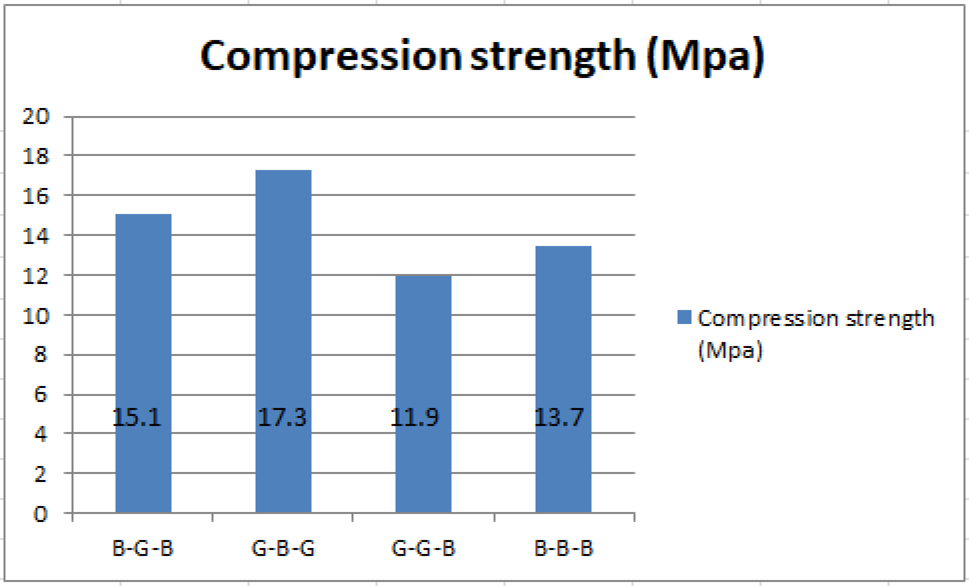


Figure 4-3: compression strength results

4.1.4. Impact strength

Figure below shows the impact resistance of the tested composites. The maximum impact force value for the Epoxy 60 % + E glass fiber 10 % + bamboo fiber 30 % composite sample is 81.7 Mpa and the minimum value for the Epoxy 60 % + Bamboo fiber 40 % composite sample is 25.5 Mpa. By the integration of bamboo fibers with glass fibers improves the impact strength of glass / epoxy composite. Further increasing the weight percentage of a bamboo fibers results in decreased impact strength of bamboo / glass / epoxy hybrid composite as shown in Figure. this may be due to the increasing weight percentage of bamboo fibers in glass/epoxy composite may involve improper wetting of bamboo fibers with epoxy matrix which weakens the interface and hence reduction in impact strength of hybrid composite.

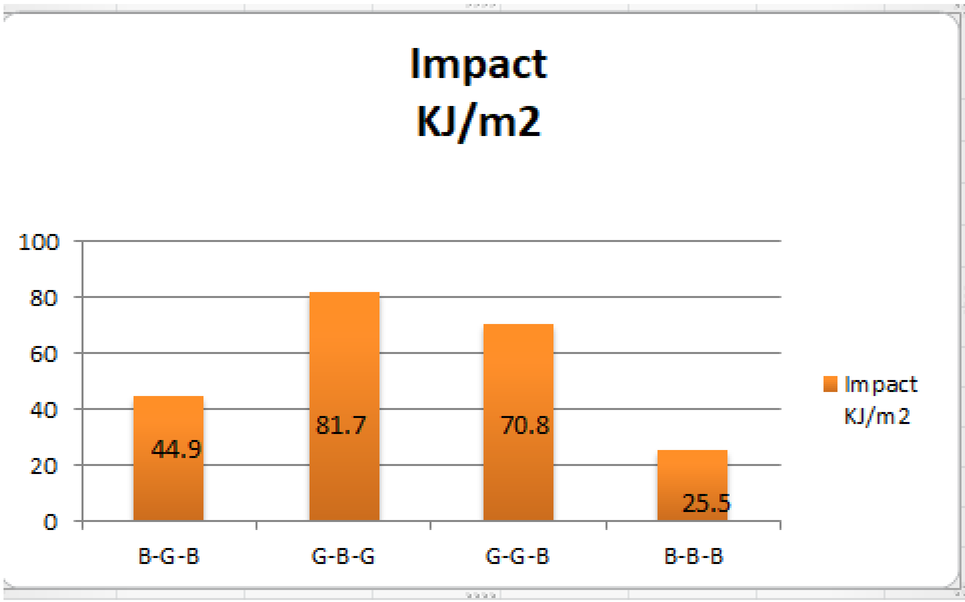


Figure 4-4: Result of impact strength

4.1.5. Water absorption

In the case of water absorption, it can be observed that an increase in bamboo fiber in the matrix increases the rate of water absorption. The minimum value of water absorption is 2.98 % (G-B-G) for bamboo/glass/epoxy composite and the maximum value of water absorption is 3.89 % (B-B-B) for bamboo/epoxy composite.

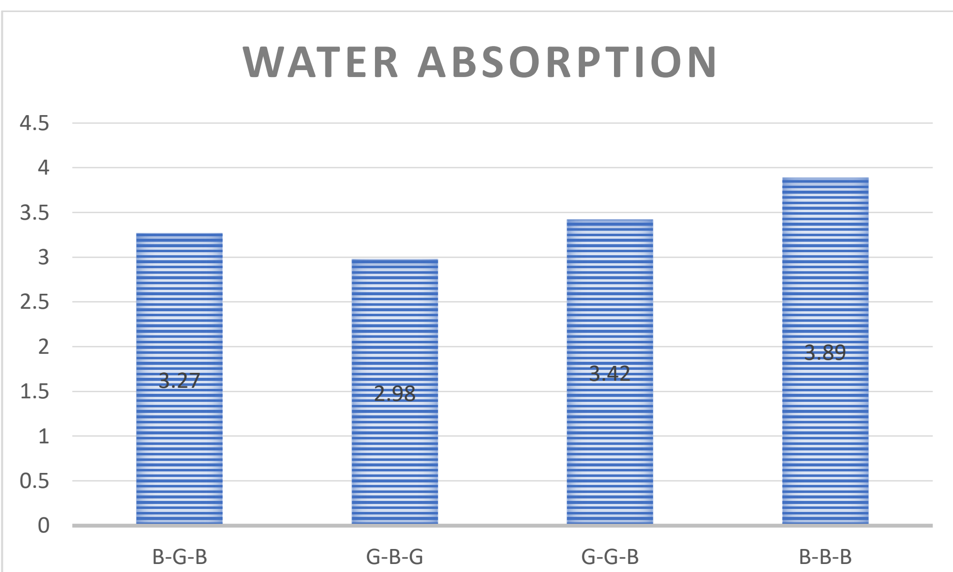


Figure 4-5: Water absorption

4.1.6. Density result

Based on the procedures expressed in chapter three, the density of each laminate is determined. The actual and theoretical densities of composite laminate results are summarized in Appendix A. The theoretical densities of the composite are higher than the actual due to voids and the porosity effect is neglected.

4.2. Analysis TOPSIS analysis method

The application of the TOPSIS method to evaluate the mechanical and physical properties of fabricated laminate composite samples, based on the criteria of tensile strength, compressive strength, flexural strength, impact strength, water absorption, density, and cost, G-B-G effectively balances mechanical property with economic feasibility, the overall results of each step of TOPSIS method are shown in the appendix C

4.3. Result of shear force and bending moment analysis of partition wall pane

The design loads and standard parameters are discussed in chapter 2 & 3. Design loads

Table 4-1: Given parameters for normal force and bending moment analysis [77]

Given data	Value
Design load	59KN/m2
Height	2.4m
Length	1.2m
β	0.1017
β1	0.0464
γ	0.465
γ1	0.370
m	25kg
ρ	1.369g/cm3

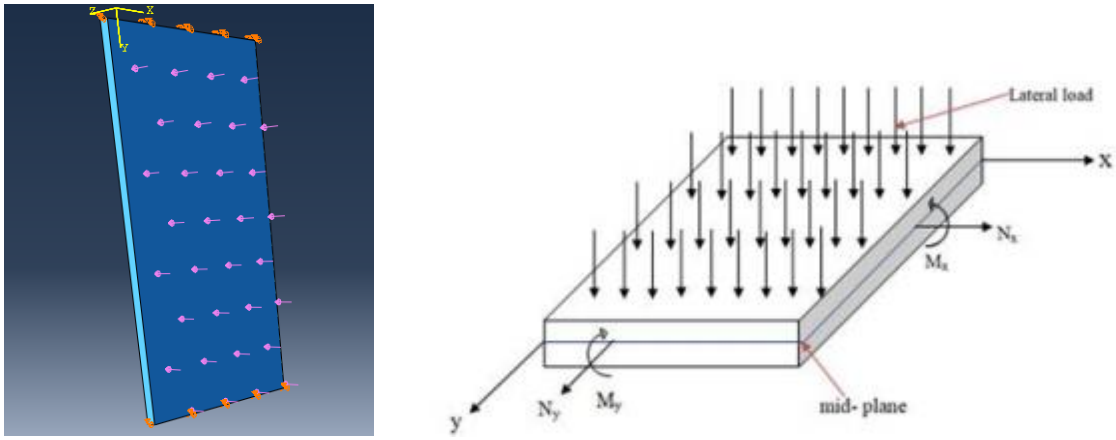


Figure 4-6: In-plane normal forces and bending moments

$$Total\ design\ load\ = DD\ +\ LL\ + Fi$$

m = $\rho * V,$ Where V=l*h*t, ρ =1.369

m = 25Kg

DD = m *g= 25 *9.81=232N

= 59N/m2,

Take from the standard load and dimensions of partition wall panel

Live load = 0.5KN/m2

Impact load = 0.5KN/m2

$$Total\ design\ load\ = DD\ +\ LL\ + Fi$$

DD=q =0.059KN/m2 +0.5KN/m2+0.5KN/m2= 1.059KN/m2

Normal forces per unit length of sections of a plate perpendicular to x and y direction, Nx and Ny respectively.

Nx = γwl = 0.465 * 1.059KN/m2* 1.2m=590N/m

$Ny = \gamma 1wl$ = 0.370 * 1.059KN/m2*1.2m=470N/m

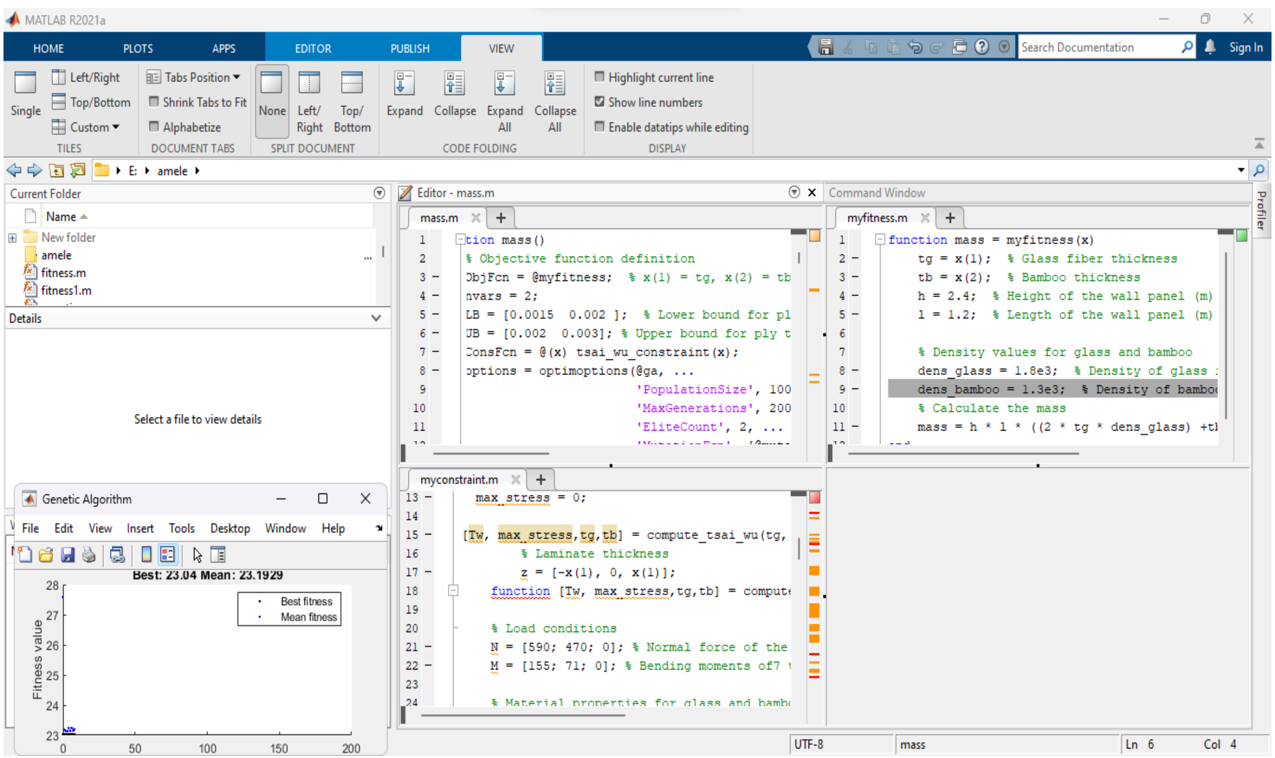
For simple support the bending moment per unit length of sections of a plate perpendicular to the x and y axes, Mx and My respectively

$Mx = \beta wl^2 = 0.1017 * 1.059 KN/m2 * 1.2^2 m = 155 Nm/m$

$My = \beta 1 wl^2 = 0.0464 * 1.059 KN/m2 * 1.2^2 m = 71 Nm/m$

4.4. Optimized Result of the designs

To obtain the optimized laminated wall panel, the thickness of the laminate was first solved using MATLAB software. This was done using the results of the classic laminate theory, which was used in the structural design of the composite. The weight of the wall panel was minimized based on the thickness of the structure obtained in the design by taking into account the properties of the laminated hybrid composite based on the MATLAB. The density of fibers



obtained from the experiment was used to determine the mass, and finally, the equation can generalize the minimized mass of the laminate composite wall panel. The minimized mass $f(x)$ of the laminate composite wall panel can be generalized by the (3.52) and the constraints (3.50).

Using the MATLA program in APPENDIX E the angle orientation is optimized from different orientations. When the laminate is arranged to $(90^0, 0^0, 90^0)$ angle orientation, it gives the following bending stiffness matrix and mid plane curvatures in the function of thickness t.

The optimized angle orientation of the laminate from the Genetic algorithm method is $(90^0, 0^0, 90^0)$. This gives the optimized thickness that minimizes the weight of the composite plate. The obtained total thickness 0.005m then the weight is 23.04kg and the maximum stress obtained is 4.466Mpa

Common materials of wall panel; weight of the **plywood** is 28kg, weight of the **gypsum board** (dry well) is 24kg, and **concrete panel** weighs 60kg, weight of **brick** 38kg. The composite wall panel made of bamboo /glass fiber epoxy reduced the plywood weight by 15%, **gypsum board by** 5.8% **and concrete panel** by 38.4% and **brick** by 36%.

Using literature review optimization, the water absorption of composite is 2.98% Common materials of wall panel; water absorption of the **plywood** is (8-12%) of the **gypsum board** (dry well) is (7-10%), and **concrete panel** (5-10%), **brick panel** is (10-20%). The composite wall panel made of bamboo /glass fiber epoxy, reduced the plywood water absorption **plywood** by (7.11%) of the **gypsum board** (dry well) is (9.11%), and **concrete panel** (2.11%), but **brick partition panel** is good water absorption reduce by (8%).

4.5. FEA Analysis Result

In order to confirm the results from Genetic algorithm method are validated using ABAQUS are discussed below.

4.5.1. Von Misses Stresses on each ply

The Von Misses stress provides a measure of equivalent stress that accounts for the combined effects of all the individual stress components

Glass fiber-reinforced epoxies ply (ply-1 and ply-3)

The glass fiber-reinforced epoxy plies show higher von Mises stress values compared to the bamboo epoxy fiber-reinforced ply.

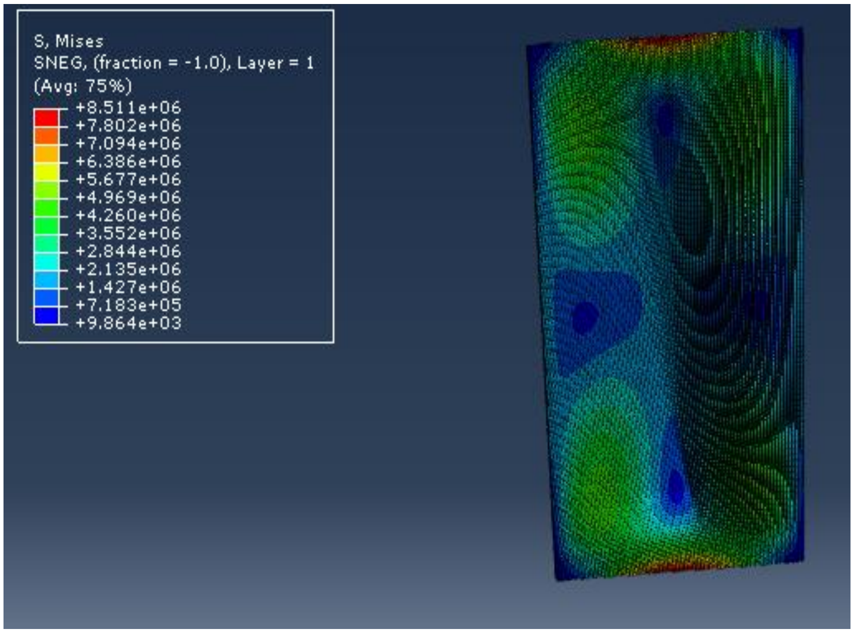


Figure 4-7: Ply-1 Von Mises Stress

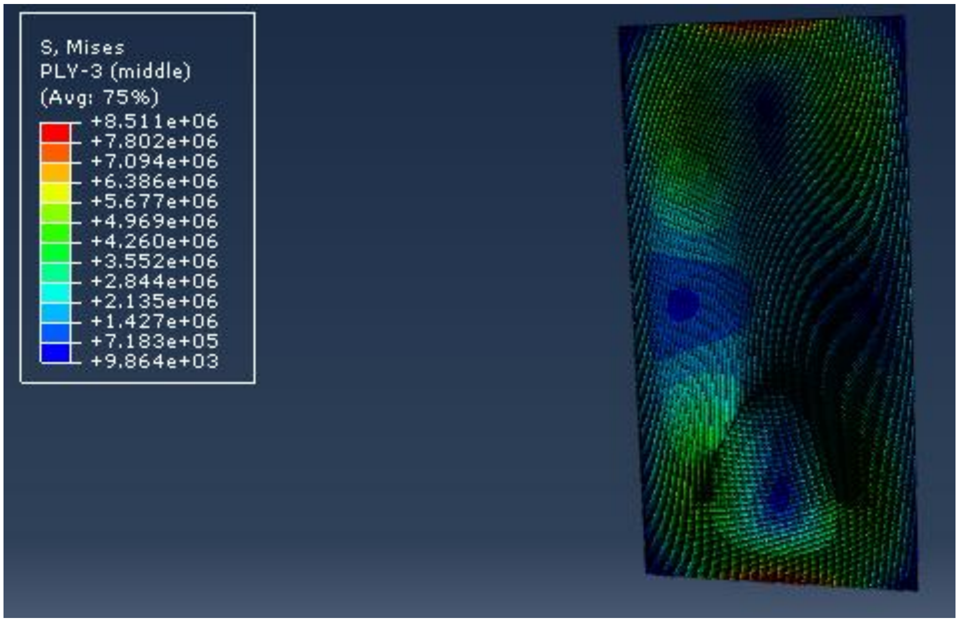
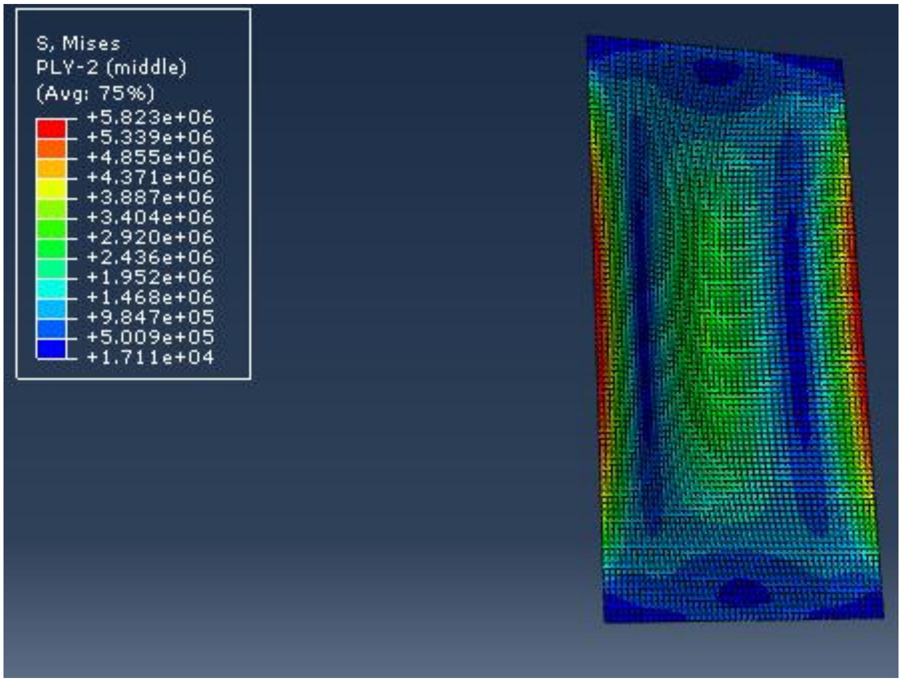


Figure 4-8: Ply-3 Von Mises Stress

Bamboo fiber-reinforced epoxies ply (ply-2)

The bamboo fiber-reinforced ply exhibited a lower Von Mises stress of 5.823Mpa as shown in Figure 4-9, which indicates less overall stress compared to the glass fiber-reinforced plies. This could be due to the lower stiffness and strength of bamboo fibers compared to glass fibers. The significant difference in Von Mises stress between the plies indicates a differential stress distribution, where the glass fiber-reinforced plies bear the majority of the load.

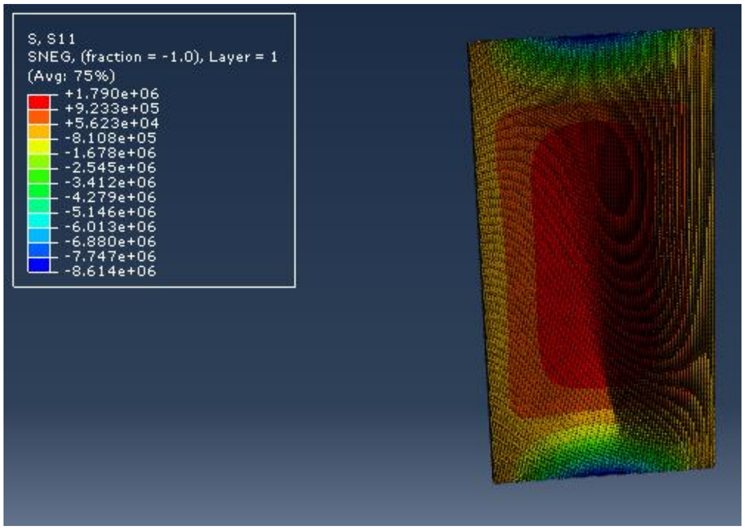


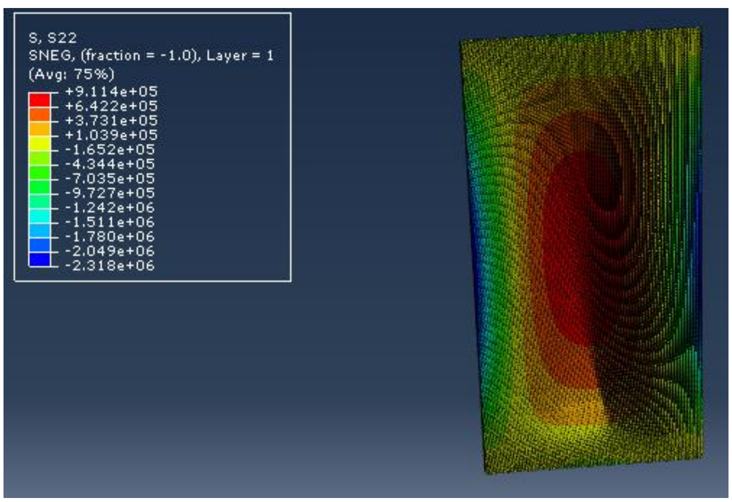
The maximum Von Mises stress is 8.511Mpa which is at the edges due to the boundary conditions and stress concentration effects. The maximum stress result from the MATLAB is 4.66Mpa. The difference of the stress results from the MATLAB analysis and FEM is 55%. Analysis indicates that MATLAB might not have captured all the complexities of the problem as effectively as ABAQUS. ABAQUS being a more advanced FEA tool, likely gives more accurate results, especially when dealing with real-world geometries and boundary conditions. The experimentally found hybrid composite's tensile and compression stresses are 85.3Mpa and 17.3Mpa respectively. Therefore, since the maximum stress of the structure is less than the ultimate strength, the composite wall panel remains within a safe operational range.

4.5.2. Plane stress components of optimized composite panel

These components represent normal and shear stress in different directions. Longitudinal stress (S11) is the normal stress in the direction aligned with the fiber direction, transverse direction stress (S22) is the normal stress in the direction perpendicular to the fiber direction, and in-plane shear stress (S12) is the shear stress in the plane parallel to the plane of the material. These are the components for orthotropic composite material under plane stress condition. And the results are obtained as in figure below.

Glass fiber-reinforced epoxies ply (ply-1)


S, S11
SNEG, (fraction = -1.0), Layer = 1
(Avg: 75%)
+1.790e+06
+9.233e+05
+5.623e+04
-8.108e+05
-1.678e+06
-2.545e+06
-3.412e+06
-4.279e+06
-5.146e+06
-6.013e+06
-6.880e+06
-7.747e+06
-8.614e+06


S, S22
SNEG, (fraction = -1.0), Layer = 1
(Avg: 75%)
+9.114e+05
+6.422e+05
+3.731e+05
+1.039e+05
-1.652e+05
-4.344e+05
-7.035e+05
-9.727e+05
-1.242e+06
-1.511e+06
-1.780e+06
-2.049e+06
-2.318e+06

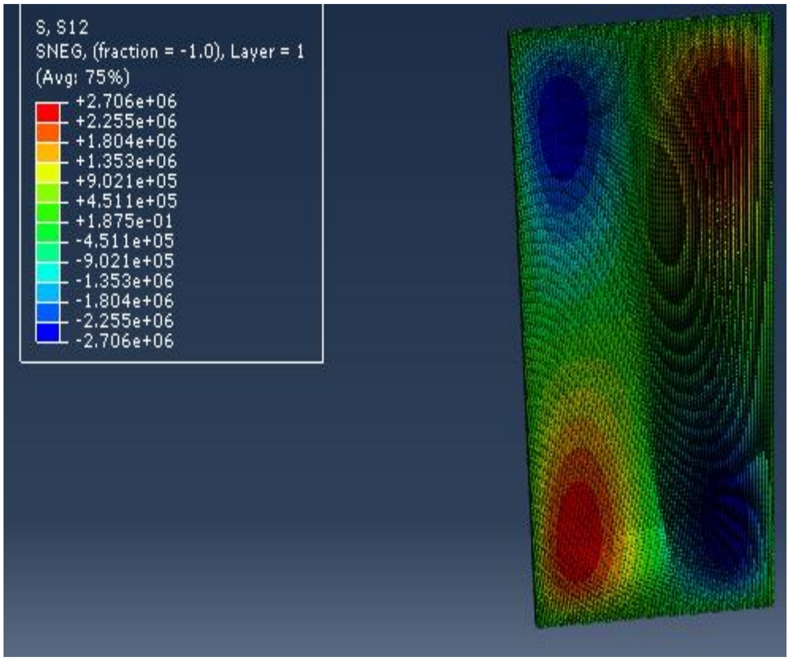
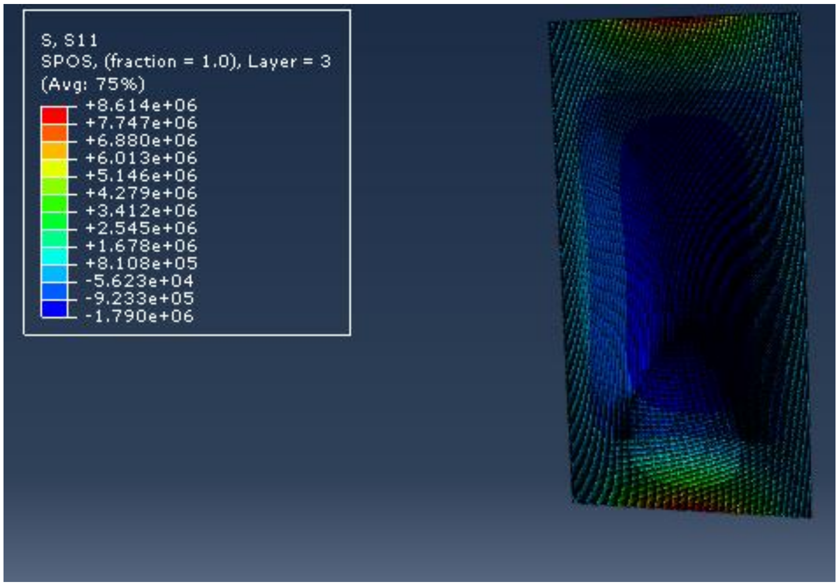
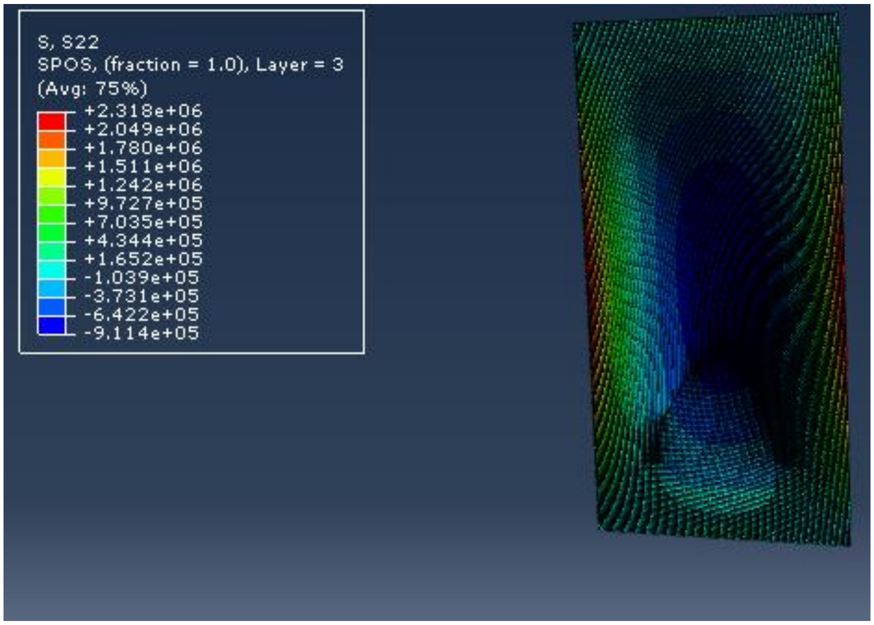


Figure 4-9: ply-1 stresses Longitudinal (S11), transverse (S22), and in-plane shear (S12)

Glass fiber-reinforced epoxies ply (ply3)





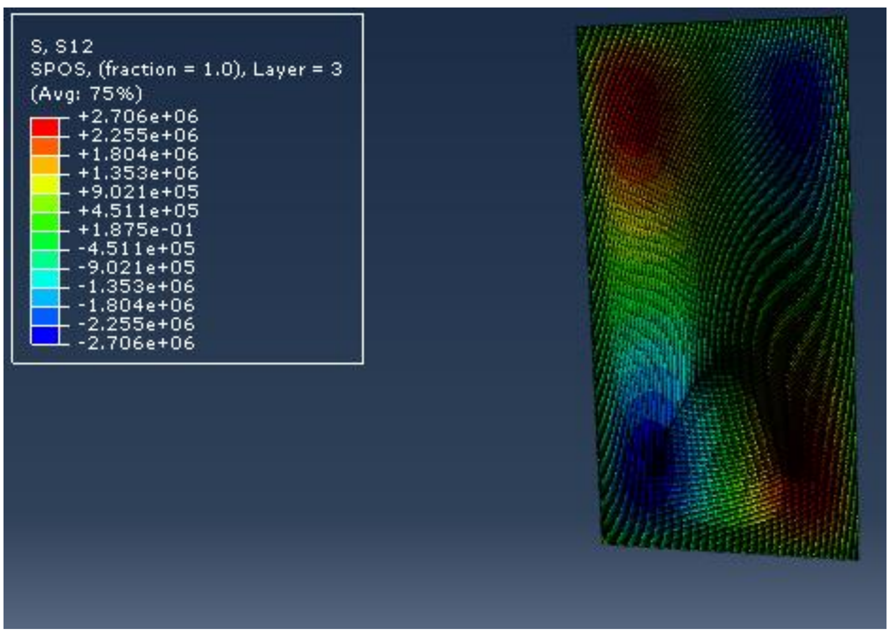
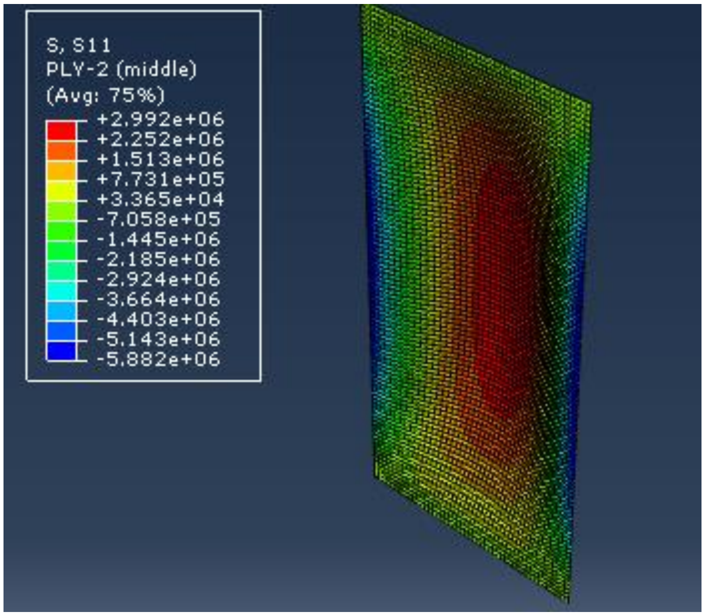
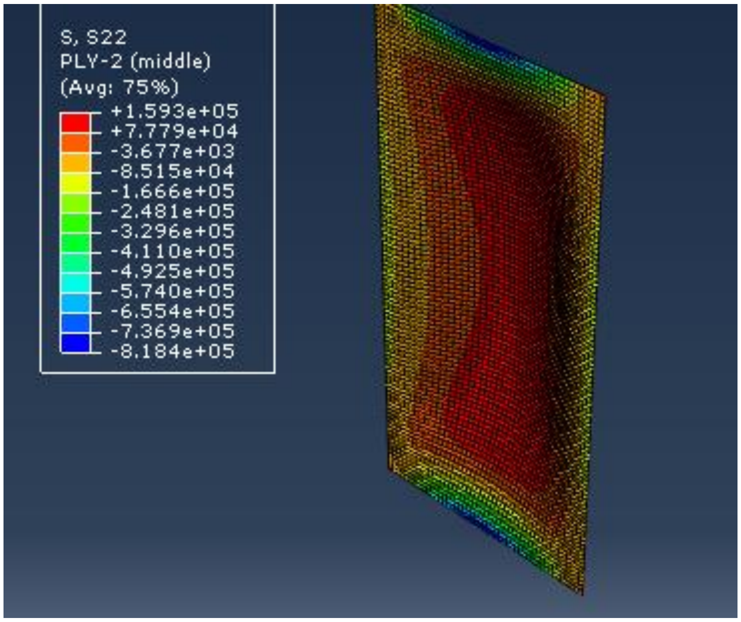


Figure 4-10: ply-3 stresses Longitudinal (S11), transverse (S22), and in-plane shear (S12)

The normal stress component in the fiber direction (S11) is higher in glass fiber-reinforced plies, with ply-3 showing a value of 8.614Mpa. It indicates the superior load-carrying capacity of glass fibers in the principal direction. The normal stress component in the fiber direction (S22) is higher in glass fiber-reinforced plies, with ply-3 showing a value of 2.314Mpa. Shear stresses (S12) in the glass fiber and bamboo fiber reinforced plies are the same value of 2.706Mpa. It indicates that these plies are effectively handling the in-plane shear forces. The experimentally determined results are 17Mpa longitudinal compression strength and 5.7Mpa transversal compression strength. This suggested even though the material is stressed at the edges, it is not being overstressed, meaning the composite wall panel can handle the applied load without risk of failure. Experimentally shear strength is 39Mpa. The FEA predicted much lower shear stress than the materials capacity. This demonstrates safe design.

Bamboo fiber-reinforced epoxies ply (ply-2)





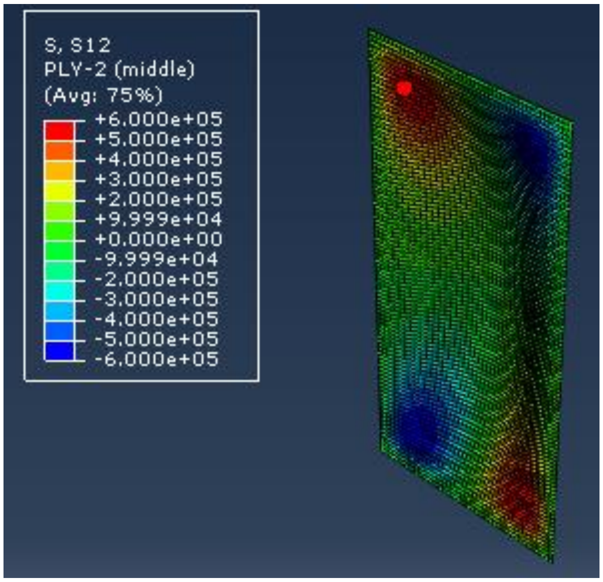


Figure 4-11: ply-2 stresses Longitudinal (S11), transverse (S22), and in-plane shear (S12)

The normal stress in the fiber direction (S11) for the bamboo ply is 2.99Mpa, which is lower than the glass fiber-reinforced plies but still indicates a reasonable load-bearing capacity. The transvers stress (S22) and shear stress (S12) of bamboo ply is also much smaller than glass epoxy lamina.

4.5.3. Deformation

The magnitude U represents the displacement from its original position. The resulting displacement magnitude is shown in Figure below.

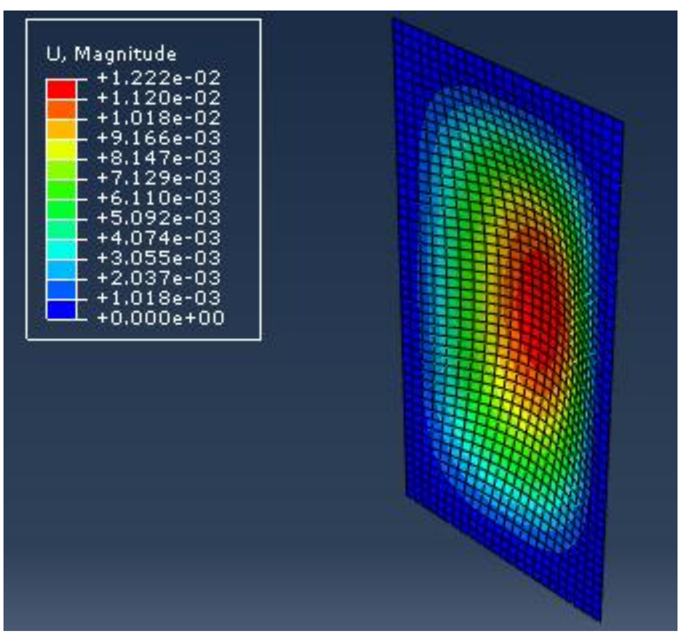


Figure 4-12: Deformation of the hybrid composite

U=12.2mm representing the maximum deformation of the composite laminate under the applied load. This indicates the small movement suggesting that the structure is under low levels of deformation or it is very hard.

CHAPTER FIVE

5. Conclusion and Recommendation

5.1. Conclusion

This research successfully developed and optimized bamboo/glass fiber reinforced epoxy composites for sustainable wall panel applications. The findings of this study highlight the feasibility of producing sustainable and cost-effective wall panels using hybrid bamboo /glass fiber composites, offering a promising alternative to conventional materials. Further research could explore the long-term durability and environmental impact of these composite wall panels.

- ✓ Alkali treatment of bamboo fibers decreases the moisture absorption and significantly improved due to enhanced interfacial bonding, increases the mechanical properties of the hybrid reinforced epoxy composites.
- ✓ The bamboo/E-glass hybrid reinforced epoxy composites were successfully manufactured using a hand lay-up technique.
- ✓ The TOPSIS method effectively identified (G-B-G) the optimal composite configuration based on multiple performance criteria.
- ✓ The optimized angle orientation of the laminate from the Genetic algorithm method is $(90^0, 0^0, 90^0)$. This gives the optimized thickness that minimizes the weight of the composite wall panel. The obtained total thickness 0.005m then the weight is 23.04kg reduced the plywood weight by 15%, gypsum board by 5.8% and concrete panel by 38.4% and brick by 36%.
- ✓ Using literature review optimization of the water absorption of composite is 2.98%, reduced the water absorption plywood by 7.11% of the gypsum board (dry well) is 9.11%, concrete panel 2.11% and brick water absorption reduce by 8%.
- ✓ In order to confirm the results from Genetic algorithm method are validated using FEA.
- ✓ The maximum stress obtained from Genetic algorithm is 4.466Mpa and the maximum Von Mises stress is 8.511Mpa. This is less than the ultimate strength, proving the composite wall panel is safe and shows the safety factor is 2.5 against failure.

- ✓ The maximum deformation of the composite laminate is 12.2mm under the applied load. This indicates the small movement suggesting that the structure is under low levels of deformation.
  - ❖ Finally, it can be concluded that bamboo/E-glass fiber reinforced epoxy composite meets most of the requirements like reduce weight to strength ratio, less moisture absorption, less deformation and environmental friendliness, so that it can replace conventional material of wall panel, the composite panels become an ideal choice for modern construction.

5.2. Recommendation

Based on the findings of this research, the following recommendations are made:

- ✓ Conduct long-term durability tests to assess the performance of the composite wall panels under various environmental conditions, including humidity, temperature fluctuations, and UV exposure.
- ✓ Perform a comprehensive life cycle assessment to evaluate the environmental impact of the bamboo/glass fiber composite wall panels, from material sourcing to end-of-life disposal.
- ✓ Investigate the fire resistance properties of the composite wall panels and explore potential fire-retardant treatments.
- ✓ Optimize the hand lay-up process or explore alternative manufacturing techniques (e.g., vacuum bagging, compression molding) to improve production efficiency and consistency.
- ✓ Implement the optimized composite wall panels in a prototype building or construction project to evaluate their performance in real-world conditions.
- ✓ Conduct a detailed cost analysis to compare the cost-effectiveness of the composite wall panels with traditional wall materials.

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APPENDIX-A

Table 0-1: properties of bamboo fibers

properties	Unit	Bamboo fiber
Density	$g/cm3$	1.3 – 1.5
Tensile strength	$kN/mm2$	610 – 780
Stiffness	kN/mm	15 – 35
Elongation at break	%	1.0 – 1.9
Max. elongation	mm	10 – 14
Tensile modulus	Gpa	12 – 60
Specific modulus	-	32
Young’s modulus	Gpa	15 – 30
Cellulose content	%	59 – 70
Hemicellulose content	%	15 – 20
Lignin content	%	11 – 15
Lumen size	mm	13
Fiber length	mm	120 – 900
Microfibrillar angle	Deg	8 – 9
Moisture absorption	%	•

Table 0-2: properties of Glass fibers

properties	Unit	Glass fiber
Density	$g/cm3$	2.5 – 2.7
Tensile strength	$kN/mm2$	3400
Stiffness	kN/mm	70 - 75
Elongation at break	%	3 -5

Max. elongation	mm	20 - 30
Tensile modulus	Gpa	68 - 75
Specific modulus	-	29
Young's modulus	Gpa	72

Table 0-3: Property of Thermoset polymer used in bamboo fiber composite fabricate

Property	Epoxy	Polyester
Density (Kg/cm3)	1.1-1.4	1.2-1.5
Tensile strength (Mpa)	35-100	30.9
Elongation (%)	1-6	2
Yang's modulus (Gpa)	3-6	3.1

- ***Weight & Weight Fraction (Ratio) of the hybrid composite material***

Table 0-4: Weight fraction

Laminate name	Weight(kg)				Weight fraction (%)		
	wb	wg	we	wc	Wfb	Wfg	Wfe
B-G-B	192	30	333	555	34.6	5.4	60
G-B-G	180	60	360	600	30	10	60
G-G-B	96	60	234	390	24.6	15.4	60
B-B-B	288	0	432	720	40	0	60

Where, wb- mass of bamboo, wg- mass of glass, we- mass of epoxy, weight fraction, wc- mass of composite, wfb-bamboo weight fraction, wfg-glass weight fraction, wfe-epoxy weight fraction

- ***Volume & Volume fraction of the hybrid composite material***

Table 0-5: Volume fraction (%)

Laminate name	Volume(cm3)				Volume fraction (%)		
	Vb	Vg	Ve	Vc	Vfb	Vfg	Vfe
B-G-B	147.69	11.54	237.86	397.09	37.19	2.91	59.9
G-B-G	138.46	23.08	276.9	438. 44	31.58	5.3	63.16

G-G-B	74.85	23.08	167.14	265.07	28.23	8.71	63.06
B-B-B	221.54	0	308.57	530.11	41.8	0	58.2

Where; Vb – volume of bamboo, Vg – volume of glass, Ve- volume of epoxy, vc - volume of composite, Vfb – bamboo volume fraction, vfg – glass volume fraction, vfe- epoxy weight fraction

- ***The experimental and theoretical densities of composite laminate and cost.***

Table 0-6: Density and cost of composite

Laminate name	Theoretical density (gm/cm3)	Actual Density (gm/cm3)	Cost (ETB)
B-G-B	1.398	0.933	288.15
G-B-G	1.369	0.838	223.5
G-G-B	1.471	0.838	223.5
B-B-B	1.358	0.778	352.8

Where; ρt- theoretical density, ρa- experimental density

APPENDIX-B

Test result mechanical and physical property

Composite type	Stacking sequences	Tensile Strength (Mpa)	Flexural Strength (Mpa)	Impact KJ/m2	Compression strength (Mpa)	Density(gm/cm3)	Water absorption (%)	Cost (ETB)
L01	B-G-B	84	471	44.9	15.1	1.398	3.27	288.15
L02	G-B-G	85.3	428	81.7	17.3	1.369	2.98	223.5
L03	G-G-B	69.36	497	70.8	11.9	1.471	3.42	245.5
L04	B-B-B	56.8	299	25.5	13.47	1.358	3.89	352.8

APPENDIX-C

TOPSS method analysis

Step 1: Calculate the normalized decision matrix

Formulate decision matrix

	Tensile strength	Compressive strength	Flexural strength	Impact strength	Water absorption	Cost	Density
B-G-B	84	15.1	471	44.9	3.27	288.15	1.398
G-B-G	85.3	17.3	428	81.7	2.98	223.5	1.369
G-G-B	69.36	23.8	497	70.8	3.42	245.5	1.471
B-B-B	56.8	14.9	299	25.5	3.89	352.8	1.358

Construct the normalized decision matrix

weight	0.1	0.15	0.2	0.15	0.2	0.1	0.1
B-G-B	0.561635623	0.416284517	0.546996	0.374768	0.48004322	0.511206	0.499395
G-B-G	0.570327603	0.476935241	0.497058	0.681928	0.43747058	0.396511	0.489036
G-G-B	0.463750557	0.656130563	0.577191	0.590949	0.50206355	0.435541	0.525472
B-B-B	0.379772659	0.410770814	0.347244	0.212842	0.57106059	0.625901	0.485106

Step 2: Calculate the weighted normalized decision matrix.

	Tensile strength	Compressive strength	Flexural strength	Impact strength	Water absorption	Cost	Density
B-G-B	0.056163562	0.062442677	0.082049	0.056215	0.09600864	0.076681	0.049939
G-B-G	0.05703276	0.071540286	0.074559	0.102289	0.08749412	0.059477	0.048904
G-G-B	0.046375056	0.098419584	0.086579	0.088642	0.10041271	0.065331	0.052547
B-B-B	0.037977266	0.061615622	0.052087	0.031926	0.11421212	0.093885	0.048511

Step 3: Determine the positive ideal and negative ideal value solution as below:

	Tensile strength	Compressive strength	Flexural strength	Impact strength	Water absorption	Cost	Density
V+	0.05703276	0.098419584	0.074559	0.102289	0.08749412	0.065331	0.048511
V-	0.037977266	0.071540286	0.052087	0.031926	0.11421212	0.093885	0.052547

Step 4: Calculate the separation measures, using the m-dimensional Euclidean distance. Distance to positive ideal and negative ideal

	Si+	Si-
B-G-B	0.060641345	0.050352663
G-B-G	0.027512297	0.087921207
G-G-B	0.025049732	0.078773081
B-B-B	0.093288681	0.010714153

Step 5: Calculate the relative closeness of each alternative to the ideal solution.

Step 6: Rank preference order

	Pi+	Rank
B-G-B	0.453652083	3
G-B-G	**0.761661081**	**1**
G-G-B	0.758726126	2
B-B-B	0.103017895	4

APPENDIX-D

Composite laminas property

Variables	E-glass epoxy lamina	Bamboo epoxy lamina
E1(Gpa)	6.81	9.96
E2(Gpa)	0.711	0.648
V12	0.235	0.317
V21	0.0244	0.0216
G12(Gpa)= G13	3.16	1.398
Q11 (Gpa)	6.81	9.96
Q12= Q21(Gpa)	0.235	0.317
Q22(Gpa)	0.711	0.648
Q66(Gpa)	3.16	1.398

The laminate extensional stiffness matrix is calculated by using the stiffness matrixes and thickness of the lamina using Equation

[A] = $\frac{1}{3}\ \sum_{K=1}^{3} [\bar{Q}ij]\ K\ (hK\ - hK - 1\ )$ = [50.61 1.12 0]

[1.12 4.101 0]

[0 0 13.674]Mpa m

[B] = $\frac{1}{2}\ \sum_{K=1}^{3} [\bar{Q}ij]\ K\ (h^2K\ - h^2K - 1\ )$ = 0

[D] = $\frac{1}{3}\ \sum_{K=1}^{3} [\bar{Q}ij]\ K\ (h^3K\ - h^3K - 1\ )$ = [130.4370 3.1121 0]

[3.1121 12.7308 0]

[0 0 52.9155] Gpamm3

Calculating mid-plane strains and

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x{}^0 \\ \varepsilon_y{}^0 \\ \gamma_{xy}{}^0 \end{Bmatrix}$$

εx^0 =0.2124mm/mm

εy^0= 1.9302mm/mm

γxy^0=0

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} K_x \\ K_y \\ K_{xy} \end{Bmatrix}$$

Kx =61.2254mm/mm

Ky =283.4628mm/mm

Kxy =0

Calculating global strains of the plies

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_x{}^0 \\ \varepsilon_y{}^0 \\ \gamma_{xy}{}^0 \end{Bmatrix} + Z \begin{Bmatrix} K_x \\ K_y \\ K_{xy} \end{Bmatrix} =$$

εx =1.4287 mm/mm

εy = 1.2563mm/mm

$$\gamma xy = 0$$

Calculating global stresses for each ply

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} = \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix}$$

Global stress E glass epoxy lamina

σx =1242.3N/mm2

σy= 131.2N/mm2

τxy =0

Global stress Bamboo epoxy lamina

σx = 1812.8N/mm2

σy = 129.1N/mm2

τxy =0

Local strain Eglass

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12}/2 \end{bmatrix} = \begin{bmatrix} C^2 & S^2 & 2SC \\ S^2 & C^2 & -2SC \\ -SC & SC & C^2 - S^2 \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy}/2 \end{bmatrix}$$

ε1 =1779

ε2 =1416

$\frac{\gamma 12}{2}$ =0

Local Stress for E-glass epoxy ply:

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} = [T] \begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix}$$

σ1=1242.3 N/mm2

σ2= 131.2 N/mm2

τ12=0

Local Strain for Bamboo epoxy ply:

ε1 =1779

ε2 =1416

$\frac{\gamma 12}{2}$ =0

Local Stress for Bamboo epoxy ply:

σ1= 1812.8

σ2= 129.1

τ12 = 0

	Bamboo epoxy lamina	Glass epoxy lamina
Xt	155.51	265.74
Xc	-146.2	-206.25
Yt	7.71	7.12
Yc	-5.75	-5.45
Sxy	39.97	39

APPENDIX-E

MATLAB PROGRAM

For different angle orientation of plies the following MATLAB program for objective function, constraint function and genetic algorithm is used. The angle orientation is differentiated by interchanging the value of theta in the constraint function. And the orientations used are [0^0 0^0 0^0], [45^0 45^0 45^0], [0^0 90^0 0^0],, [90^0 90^0 90^0], [0^0 45^0 0^0], [90^0 45^0 90^0], [90^0 0^0 90^0], [45^0 90^0 45^0],

```
function mass()
    % Objective function definition
    ObjFcn = @myfitness;  % x(1) = tg, x(2) = tb
    nvars = 2;
    LB = [0.0015  0.002 ];  % Lower bound for ply thickness
    UB = [0.002  0.003]; % Upper bound for ply thickness
    ConsFcn = @(x) tsai_wu_constraint(x);
    options = optimoptions(@ga, ...
                           'PopulationSize', 100, ...
                           'MaxGenerations', 200, ...
                           'EliteCount', 2, ...
                           'MutationFcn', {@mutationadaptfeasible}, ... %
Adaptive mutation
                           'CrossoverFraction', 0.8, ...
                           'FunctionTolerance', 1e-9, ...
                           'ConstraintTolerance', 1e-4, ...
                           'PlotFcn', @gaplotbestf);  % Plot the best fitness
value


    % Run the GA solver
    [tbest, mbest] = ga(ObjFcn, nvars, [], [], [], [], LB, UB, ConsFcn,
options);
```

```
    % Display results
    disp('Optimized Thicknesses (tg and tb):');
    disp(tbest);
    disp('Best Fitness Value (Mass):');
    disp(mbest);
end
% Subfunction: Objective (Fitness) Function
function mass = myfitness(x)
    tg = x(1);  % Glass fiber thickness
    tb = x(2);  % Bamboo thickness
    h = 2.4;  % Height of the wall panel (m)
    l = 1.2;  % Length of the wall panel (m)

    % Density values for glass and bamboo
    dens_glass = 1.8e3;  % Density of glass in kg/m^3
    dens_bamboo = 1.3e3;  % Density of bamboo in kg/m^3

    % Calculate the mass
    mass = h * l * ((2 * tg * dens_glass) +tb * dens_bamboo);  % kg
end

function [c,  ceq]=  tsai_wu_constraint(x)
% Ply orientations
     thicknesses = [x(1), x(2), x(1)];
    N_layers = length(thicknesses);
% Number of layers
N_layers = 3;
       tg = x(1);
       tb = x(2);
       x(3)=90;
       x(4)=0;
     theta = [x(3), x(4), x(3)];
     % Compute Tsai-Wu failure index (Tw)
  max_stress = 0;

[Tw, max_stress,tg,tb] = compute_tsai_wu(tg, tb, theta);
        % Laminate thickness
        z = [-x(1), 0, x(1)];
    function [Tw, max_stress,tg,tb] = compute_tsai_wu(tg, tb, theta)

    % Load conditions
    N = [590; 470; 0]; % Normal force of the wall panel
    M = [155; 71; 0]; % Bending moments of7 the wall panel

    % Material properties for glass and bamboo
    % E-glass epoxy
    E1_G = 6.81e9;  % Longitudinal modulus (Pa)
    E2_G = 0.711e9; % Transverse modulus (Pa)
    V12_G = 0.235;
    G12_G = 3.16e9;  % Shear modulus (Pa)
    Xt_G = 265.74e6; % Tensile strength (Pa)
    Xc_G = 206.25e6; % Compressive strength (Pa)
    Yc_G=5.575e6;
    Yt_G = 7.12e6;   % Transverse tensile strength (Pa)
    Sxy_G = 39e6;    % Shear strength (Pa)
```

```
    % Bamboo epoxy
    E1_B = 9.96e9;  % Longitudinal modulus (Pa)
    E2_B = 0.648e9; % Transverse modulus (Pa)
    V12_B = 0.317;
    G12_B = 1.398e9; % Shear modulus (Pa)
    Xt_B = 155.51e6; % Tensile strength (Pa)
    Xc_B = 146.2e6;  % Compressive strength (Pa)
    Yt_B = 7.71e6;   % Transverse tensile strength (Pa)
    Yc_B=5.575e6;
    Sxy_B = 39.97e6; % Shear strength (Pa)




    % Initialize bending and extension stiffness matrices
    D11 = 0;
    D12 = 0;
    D22 = 0;
    D66 = 0;
    A11 = 0;
    A12 = 0;
    A22 = 0;
    A66 = 0;

    % Reduced stiffness matrix constants for glass and bamboo
    V21_G = V12_G * E2_G / E1_G;
    Q11_G = E1_G / (1 - V12_G * V21_G);
    Q12_G = V12_G * E2_G / (1 - V12_G * V21_G);
    Q22_G = E2_G / (1 - V12_G * V21_G);
    Q66_G = G12_G;

    V21_B = V12_B * E2_B / E1_B;
    Q11_B = E1_B / (1 - V12_B * V21_B);
    Q12_B = V12_B * E2_B / (1 - V12_B * V21_B);
    Q22_B = E2_B / (1 - V12_B * V21_B);
    Q66_B = G12_B;

thicknesses = [x(1), 2*x(1), x(1)]; % Thickness of each layer (tg, tb, tg)

% Loop through the layers to calculate stiffness matrices
    z_current = -sum(thicknesses) / 2; % Start at the bottom of the laminate
    % Loop through the layers to calculate stiffness matrices
    for i = 1:N_layers
     t = thicknesses(i);
      z_bottom = z_current;
      z_top = z_bottom + t;
      z_current = z_top;

       deg = theta(i) * pi / 180; % Convert angle to radians

        m = cos(deg);
        n = sin(deg);

        % Select the material (glass or bamboo) for the ply
        if mod(i, 2) == 1
```

```
            % Glass ply
            Q11 = Q11_G;
            Q12 = Q12_G;
            Q22 = Q22_G;
            Q66 = Q66_G;
        else
            % Bamboo ply
            Q11 = Q11_B;
            Q12 = Q12_B;
            Q22 = Q22_B;
            Q66 = Q66_B;
        end

        % Transformed stiffness matrix
        Qbar11 = Q11 * m^4 + 2 * (Q12 + 2 * Q66) * m^2 * n^2 + Q22 * n^4;
        Qbar12 = (Q11 + Q22 - 4 * Q66) * m^2 * n^2 + Q12 * (m^4 + n^4);
        Qbar22 = Q11 * n^4 + 2 * (Q12 + 2 * Q66) * m^2 * n^2 + Q22 * m^4;
        Qbar66 = (Q11 + Q22 - 2 * Q12) * m^2 * n^2 + Q66 * (m^2 - n^2)^2;

       Qbar=[Qbar11 Qbar12 0; Qbar12 Qbar22 0; 0 0 Qbar66];
        % Layer thickness

        % Bending stiffness matrix contribution
        D11 = D11 + Qbar11 * (z_top^3 - z_bottom^3) / 3;
        D12 = D12 + Qbar12 * (z_top^3 - z_bottom^3) / 3;
        D22 = D22 + Qbar22 * (z_top^3 - z_bottom^3) / 3;
        D66 = D66 + Qbar66 * (z_top^3 - z_bottom^3) / 3;

        % Extension stiffness matrix contribution
        A11 = A11 + Qbar11 * (z_top - z_bottom);
        A12 = A12 + Qbar12 * (z_top - z_bottom);
        A22 = A22 + Qbar22 * (z_top - z_bottom);
        A66 = A66 + Qbar66 * (z_top - z_bottom);
    end

    % Extension stiffness matrix
    A = [A11 A12 0; A12 A22 0; 0 0 A66];
    D = [D11 D12 0; D12 D22 0; 0 0 D66];
    % Calculate strains and curvatures
    e0 = A \ N; % Strain due to applied normal force
    K = D \ M; % Curvature due to applied bending moments

  % Initialize maximum stress
    max_stress = 0;

zvalues = [(2 * x(1)+x(2)) / 2, x(2)/2];  % z for upper and lower surfaces of
the ply
for j = 1:length(zvalues)
        z = zvalues(j);
        epsilonk = z * K;
        epsilone = e0+epsilonk;
        global_stress = Qbar * epsilone;

      max_stress = max(global_stress);
```

```
% Stress transformation matrix
T_sg = [m^2, n^2, 2*n*m;
       n^2, m^2, -2*n*m;
       -n*m, n*m, m^2 - n^2];
T_sb = [m^2, n^2, 2*n*m;
       n^2, m^2, -2*n*m;
       -n*m, n*m, m^2 - n^2];
% Transform global stresses to local stresses
local_stressg = T_sg * global_stress; % global_stress is [sigma_x; sigma_y;
tau_xy]
local_stressb = T_sb * global_stress; % global_stress is [sigma_x; sigma_y;
tau_xy]
% local stress of glass fiber
sigma_1g = local_stressg(1); % Local stress in fiber direction
sigma_2g = local_stressg(2); % Local stress in transverse direction
tau_12g = local_stressg(3);  % Shear stress in the ply plane
% local stress of bamboo fiber
sigma_1b = local_stressb(1); % Local stress in fiber direction
sigma_2b = local_stressb(2); % Local stress in transverse direction
tau_12b = local_stressb(3);  % Shear stress in the ply plane
    % Tsai-Wu failure criterion (simplified version)
    F1g = 1 / Xt_G + 1 / Xc_G;
    F2g = 1 / Yt_G + 1 / Xc_G;
    F11g=(-1/(Xt_G*Xc_G));
    F12g = -0.5 * sqrt((1 / Xt_G + 1 / Xc_G) * (1 / Yt_G + 1 / Xc_G));
    F22g = 1 / (Yt_G * Yc_G);
    F66g = 1 / Sxy_G^2;
     F1b = 1 / Xt_B + 1 / Xc_B;
    F2b = 1 / Yt_B + 1 / Xc_B;
    F11b=(-1/(Xt_B*Xc_B));
    F12b = 0.5 * sqrt((1 / Xt_B + 1 / Xc_B) * (1 / Yt_B + 1 / Xc_B));
    F22b = 1 / (Yt_B * Yc_B);
    F66b = 1 / Sxy_B^2;
Twg  = F1g * sigma_1g + F2g * sigma_2g + F11g * sigma_1g^2 + F22g *
sigma_2g^2 + 2 * F12g * sigma_1g * sigma_2g + F66g * tau_12g^2;
Twb  = F1b * sigma_1b + F2b * sigma_2b + F11b * sigma_1b^2 + F22b *
sigma_2b^2 + 2 * F12b * sigma_1b * sigma_2b + F66b * tau_12b^2;

 Tw=2*Twg+Twb;
end

% Display the maximum stress value
    max_stress = max(global_stress);  % Maximum stress
    disp('Maximum Stress Value:');
    disp(max_stress);
    disp('Optimized Thicknesses:');
    end
    % Nonlinear constraints
    t = 2 * x(1)+x(2); % Total thickness
    c = ( Tw - 1);% Tsai-Wu criterion

    ceq = []; % No equality constraints
end
```