



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES

***Finite Element Analysis of Internal Door Panel of a Car by
using Bamboo Fiber Reinforced Epoxy Composite***

**A Thesis Submitted to the Graduate School of Addis Ababa
University in Partial Fulfillment of the Requirements for the Degree
of Masters of Science**

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Mechanical Engineering (Mechanical Design)

By: Eniyew Eskezia Tiguh

Advisor: Daniel Tilahun (PhD)

Co-Advisor: Araya Abera (Candidate PhD)

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Addis Ababa University
Addis Ababa University Institute of technology
School of Mechanical and Industrial Engineering

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By: Eniyew Eskezia Tiguh

Approved by Board of Examiners

Getasew Ashagrie

Chairman of the School

Signature

Date

Daniel Tilahun (Dr.)

Advisor

Signature

Date

Araya Abera

Co-Advisor

Signature

Date

Mulugeta H/Mariam

Internal Examiner

Signature

Date

Behailu Mamo

External Examiner

Signature

Date

DECLARATION

Addis Ababa University

School of Graduate Studies

This is to certify that the thesis prepared by Eniyew Eskezia, entitled: Finite Element Analysis of Internal Door Panel of a Car by using Bamboo Fiber Reinforced Epoxy Composite, do here by declare this thesis is my original work and that it has not been submitted in full for a degree in any university/institution, which compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

Eniyew Eskezia Tiguh

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Advisor: _____ Signature _____ Date _____

Co-Advisor: _____ Signature _____ Date _____

Abstract

This thesis work presents the structural Finite Element Analysis of internal door panel of a vehicle by considering bamboo fiber reinforced epoxy composite materials.

The door panel of Toyota Corolla DX model vehicle was used to develop the geometric model of the internal door panel by CATIA V5 R20 modeling software. This 3D geometric model was imported to using ANSYS Workbench 15.0. The transient dynamic structural FEA was done after assigning displacement, load and boundary conditions. The applied load considered for this analysis is the self-inertial weight of the panel due to the acceleration field produced while the door is closing. The equivalent stress and the displacement are noted and investigated to compare with the literatures revised.

The result of this analysis shows that, the equivalent stress of bamboo fiber reinforced epoxy composite panel has the smaller value, as compared with the lignocellulosic composite and polypropylene one.

The displacements of bamboo fiber reinforced epoxy composite internal door panel obtained by FEA are smaller by 34% and 50% than that of the lignocellulosic composite materials and the polypropylene panel respectively. In addition, the mass of this newly modeled panel is reduced by 6% and 8% than that of the panels of the above mentioned materials respectively.

Based on these realities, it is recommended that bamboo fiber reinforced with epoxy composite materials are suitable for internal structural automotive panel applications.

Key words: Bamboo fiber, Epoxy, composite, door panel, structural analysis, displacement, vehicle

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Nomenclature

W_f	weight of Fiber
W_m	weight of Matrix
V_f	Volume of fibers
V_m	volume of matrix
W_C	weight of composite specimen
ρ_f	Density of Fiber
ρ_m	Density of Matrix
V_C	Volume of Composite material
V_F	Fibers Volume fraction
V_M	Matrix Volume fraction
W_M	Weight Fraction of Matrix
W_F	Weight Fraction of Fiber
σ	Stress
ε	Strain
A	Cross-sectional Area,
m	Mass of the panel
a	Acceleration
b	width of the panel
d	thickness of the panel
L	Length of the panel
F	Side impact force

List of Abbreviations

AJRSTEM: American International Journal of Research in Science, Technology, Engineering and Mathematics

ASTM: America Society for Testing and Material

BFREC: Bamboo Fiber Reinforced Epoxy Composite

FEM: Finite Element Method

FEA: Finite Element Analysis

IJERT: International Journal of Engineering Research & Technology

IJMET: International Journal of Mechanical Engineering and Technology

NFRC: Natural Fiber Reinforced Composites

NVH: Noise, Vibration and Harshness

RTM: Resin Transfer Molding

CHAPTER ONE

INTRODUCTION

It is a natural phenomenon that human beings keep on moving here and there to perform their day to day activities within a given time range. And vehicles are the dominant way of transportation system in many countries, including Ethiopia. Thus, researching on these area to design and provide a well improved, fast, economic and aesthetically attractive vehicles is a crucial idea for the development of these countries by providing fast, effective and sufficient way of transportation. To address this aim a wise material improvement and design excellency are a crucial mechanisms. Materials for automotive industries has been improved frequently starting from the very earlier one (wood) to the latest and most sophisticated modern materials.

The basic aim of developing a new materials for automotive application is to enhance vehicle efficiency and fuel economy by reducing the dead weight of the vehicle. Moreover their aesthetical appearance should be upgraded by researching materials for this application too. A number of researches have been demonstrated that composite materials are lightweight, fatigue resistant and easily molded to any shape, in other words, a seemingly attractive alternative to metallic materials. If the benefits of composite materials in terms of light weighting, durability, good aesthetical value, high specific energy absorption ability and ease of forming are to be exploited more widely by the automotive industry, then there is a need to identify the critical technical barriers that must be overcome.[1, 9]

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile designers and manufacturers in the present scenario. Weight reduction can be achieved primarily by the research of better material, design optimization and better manufacturing processes, [10]. Due to rise in demand of lightweight and more efficient vehicles and better mechanical performance of materials in automotive applications, different material combinations such as composites, plastic and light weight metals are implemented on different structural parts of vehicles. Applications of composite materials in automotive industries already include some structural parts, such as dashboard, roof, floor, front & back bumper, passenger safety cell, and door panels [10, 15].

The internal door panel of an automobile is typically made up of a variety of materials. Unlike the materials used on the exterior side of the vehicle door, the material on the interior side

serves a greater purpose other than just aesthetic appeal. The internal door panel of an automobile contributes to the overall functionality and ergonomics of the ride, such as: armrests, various switches, lights, electronic systems like the window controls and locking mechanism; etc.[3,7]

Composite materials made of natural fibers and polymer matrix provides synergistic properties, improving their strength and durability. These materials are suitable for achieving automotive interior components, where in addition to their low weight have also high rigidity and good thermal and sound insulation. The most important internal vehicle elements include car internal door panels. [2]

1.1. Background

Now a days, substitution of conventional materials such as; steel, aluminum and other alloy materials by composite materials has grown significantly in aeronautic, automotive, naval, and civil construction sectors. This is due to their amazing properties, i.e. Composite materials have of high modulus to weight ratio and strength to weight ratio, excellent fatigue properties, and non-corroding behaviors. These advantages encourage the extensive application of composite materials in different areas including automotive industries, [15].

Traditionally, the materials used in the construction of vehicle bodies are mainly various grades of steel and aluminum. Moreover, plastics and some synthetic materials mostly dominate the vehicle interior parts. The manufacturers meet the requirements of a particular crashworthiness standard and fuel efficiency by making the approximate design change in their vehicle structure and by introducing necessary structural components that satisfy the overall design objectives. [4]

With the composite materials the designer can vary structural parameters, such as geometry and at the same time vary the material properties by changing the fiber orientation, fiber content. These properties of the composite materials create the positive environment in automobile industries, since they provide required strength for less weight when compared to steel and aluminum. [9, 10]

Composite Materials

The interest of a material with light weight and high performance is increasing in a dramatic way time to time. The improvement of the performance for a material is limited when there is only one composition. Therefore, there have to be a new material with high performance which constitutes two or more conventional materials.

Composite materials are engineering materials (engineered materials) in which two or more distinct materials are combined together but remain uniquely identifiable in the mixture, having strong fibers surrounded by a weaker matrix material to obtain better properties different from those of the individual components. The Reinforcing fibers provide the physical and mechanical properties; specifically to improve the physical and mechanical properties of the matrix and thus add strength and stiffness for the composite whereas the matrix serves to hold, protect and distribute the fibers, and also to transmit and distribute the load to the fibers. A collaboration between these two basic materials produce material properties that are not provided for each material element of origins. [11, 12, 13].

Overall, the properties of the composite material are determined by the properties of the fiber, the properties of the resin, the ratio of fiber to resin in the composite (Fiber Volume Fraction) and the geometry and orientation of the fibers in the composite

Classification of composite materials

Different criterias are taken in to account to classify Composite materials. The fiber arrangements and the types of matrix materials used in a composite can be considered.

I. Fiber arrangement

The fiber arrangement and its orientation with in the composite is varying from one composite material to the other during manufacturing process. This variation helps the manufacturer to get a material with different properties. On the bases of fiber orientation and arrangement, composite materials can be classified as follows.

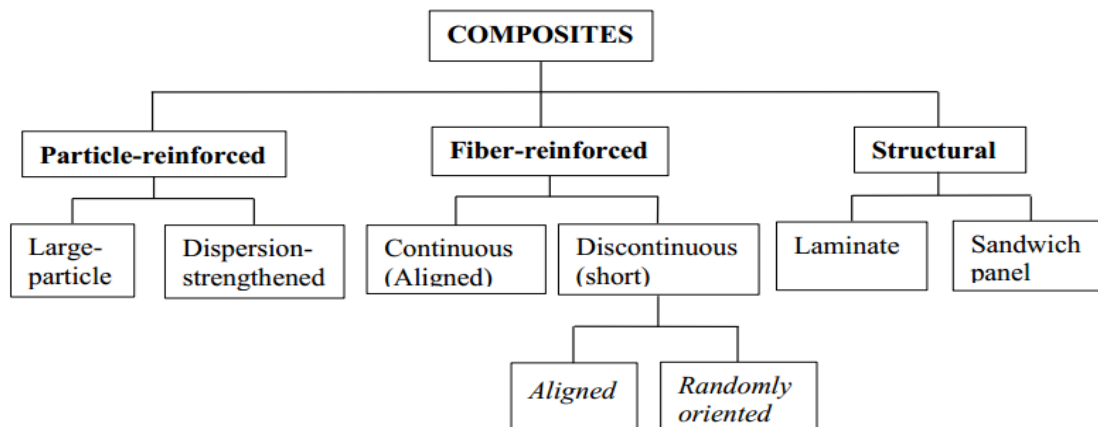


Fig. 1.1. Composite materials classification based on fiber orientation [13]

A. Particle-reinforced composite

The role of reinforcement in composite materials is primarily to add mechanical properties to the material such as strength and stiffness. Thus, particles are used to increase the modulus of the matrix, to decrease the permeability of the matrix, or to decrease the ductility of the matrix.

Particle reinforced composites support higher tensile, compressive and shear stresses

Particles used for reinforcing include: ceramics and glasses, metal particles, and amorphous materials. [13]

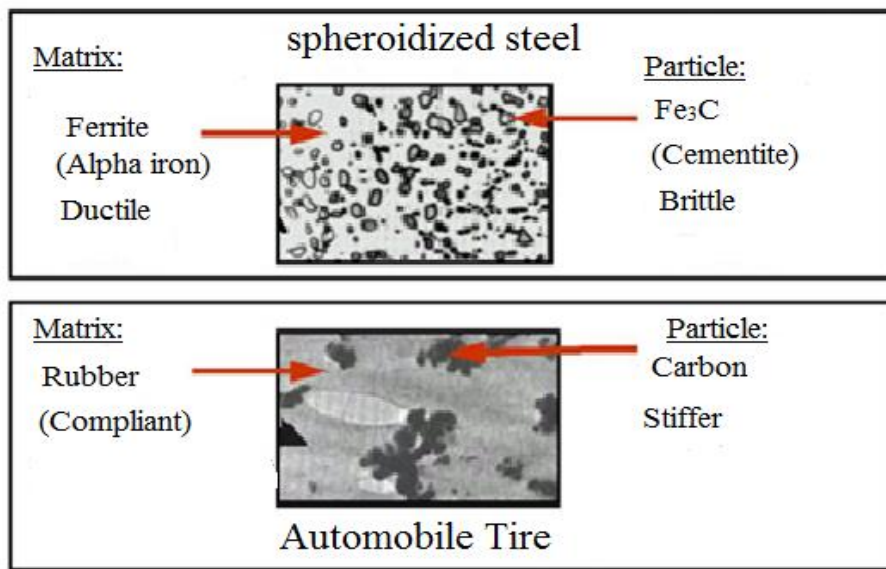


Fig. 1.2. Particle reinforced composite [13]

B. Fiber-reinforced composites

Fiber reinforced composites provide improved strength, fatigue resistance and strength to weight ratio over the constituent materials. Reinforcing fibers are responsible to increase the modulus of the matrix material in the composite. The strong covalent bonds along the fiber's length gives them a very high modulus in this direction because to break or extend the fiber the bonds must also be broken or moved. [12, 13]

The arrangement or orientation of the fibers relative to one another, the fiber concentration, and the distribution all have a significant influence on the strength and other properties of fiber-reinforced composites. [13]

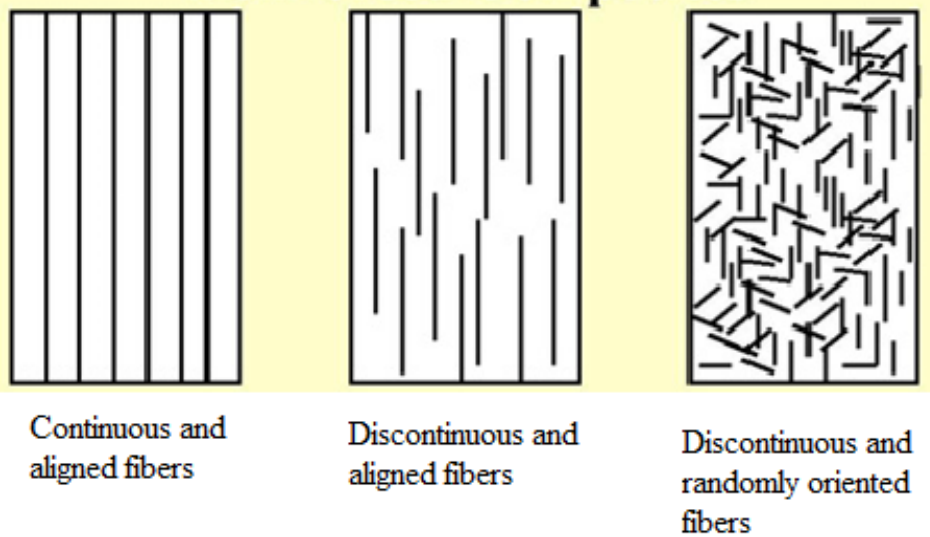


Fig. 1.3. Fiber reinforced composites [13]

C. Structural composites

Composite Laminate

Laminates are sheet constructions which are made by stacking layers (also called plies or lamina) in a specified sequence. The layers are often in the form of „prepreg“ (fibers preimpregnated with partly cured resin) which are consolidated in an autoclave. A laminate may have more than 4 layers and the fiber orientation changes from layer to layer in a regular manner through the thickness of the laminate. The figure shown below describes how the laminate is formed from the ply or lamina [12, 15].

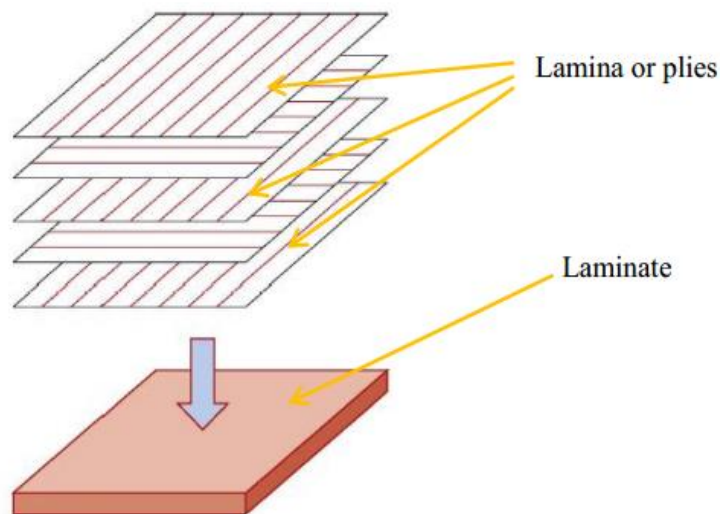


Fig. 1.4. composite laminate [15]

Sandwich panels

These composite polymer matrixes have low density, honeycomb core as a reinforced bonded with the face sheet matrix by adhesive layers. Sandwich panels have the benefits of light weight, large bending stiffness and energy absorption. [12, 13]

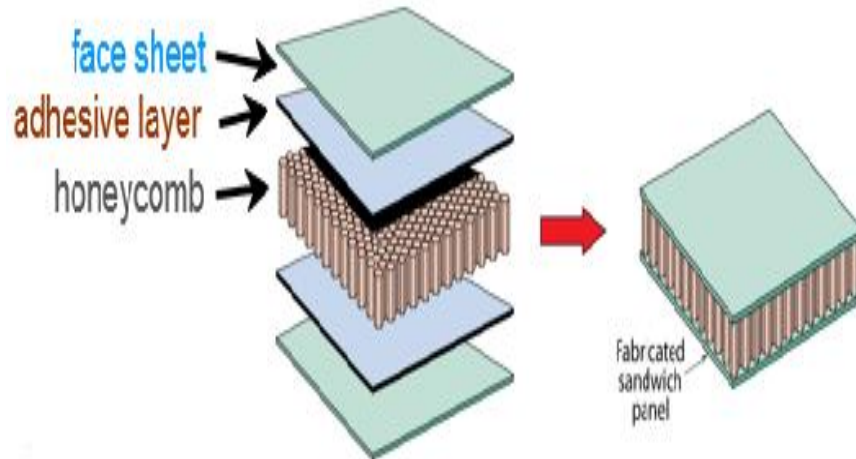


Fig. 1.5 composite sandwich panel

II. Matrix materials

Another way of classifying composite materials is focusing on the type of its matrix component of the composite. Based on this measurement, composite materials can be arranged as the following chart shown below.

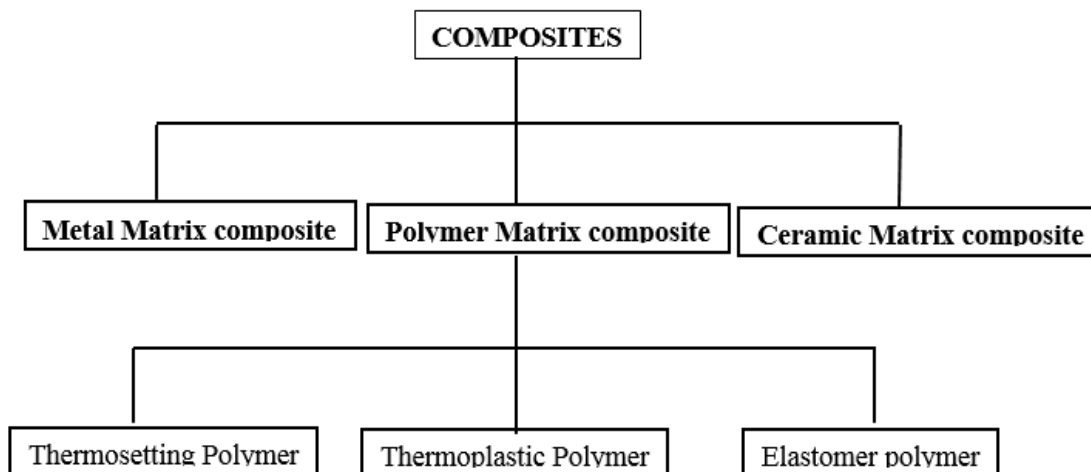


Fig. 1.6. composite materials classification based on matrix type [15, 20]

Here in this paper, we are interesting on the polymer matrix composite materials only. They are composed of long chain-like molecules consisting of many simple repeating units. The most commonly adopted polymer composites in more industries are thermosetting and thermoplastic polymer matrix composites. These fiber-reinforced polymer composites can be found in products that people interact with every day, including cars and sporting goods.

Thermoset polymers are polymers that are cured into a solid form and cannot be returned to their original uncured form. Composites made with thermoset matrices are strong and have very good fatigue strength. They are extremely brittle and have low impact-toughness making. They are commonly used for high-heat applications because the thermoset matrix doesn't melt like thermoplastics. Thermoset composites are generally cheaper and easier to produce because the liquid resin is very easy to work with. Thermoset composites are difficult to recycle because the thermoset cannot be remolded or reshaped; only the reinforcing fiber used can be reclaimed. [16]

Thermoplastic polymers are polymers that can be molded, melted, and remolded without altering its physical properties. Thermoplastic matrix composites are tougher and less brittle than thermosets, with very good impact resistance and damage tolerance.

Thermoplastic composites are less dense than thermosets making them a viable alternative for weight critical applications. The thermoplastic composites manufacturing process is more energy intensive due to the high temperatures and pressures needed to melt the plastic and impregnate fibers with the matrix. The energy required makes thermoplastic composites more costly than thermosets. These two similar materials have such different properties that both will continue to be used in different applications for very different reasons and the products of the future will likely be a combination of both [16].

1.2. Motivation

The demand of transportation system is increasing in a dramatic manner in our country, Ethiopia. To meet these needs the automotive industries in Ethiopia import the spare parts from abroad. But if these spare parts can be replaced by lightweight, unexpensive and locally available materials, we can improve the vehicle performance and simultaneously save foreign currency for imported one. Thus, bamboo which is the abundant resource in Ethiopia can be the suitable material for the internal body parts of an automotive.

Among the internal body parts, the internal door panel consists the largest shares of an automobile. So applying the bamboo fiber composite for this parts will have a significant improvement of the automotive efficiency and fuel economy by reducing its dead weight.

Therefore, the motivation of this research is to propose the application of bamboo fiber reinforced composite for the internal door panel of an automotive.

1.3. Problem statement

Now a days, the automotive industry in Ethiopia is emerging and incorporates assembling of different types of automobile cars. The parts to be assembled are not manufactured here in Ethiopia, rather imported from other car manufacturing industry outside the country. Even some of the fiber composite body parts which are manufactured here in Ethiopia aren't well investigated. Rather the manufacturers take the manufacturing process and give to automotive company without essential analysis to determine the overall performance of the material during different loading conditions. [15]

Several researchers studied the mechanical properties of bamboo fiber composites and reported that these materials have comparable mechanical properties with currently used automotive materials, such as glass fiber composites and conventional plastics. [21-27].

These researches were done on the enhancement of automotive parts in experimental or analytical ways. The experimental method has time consuming and expensive procedures. The analytical (software) analysis were done by considering some materials such as, steel, aluminium, glass fiber composite materials, etc.[2, 9]

Even though different researchers proposed that bamboo fiber composites have a very good and comparable properties, they are rarely applied for automotive structures, especially internal door panels. [27]

For these reasons, the structural FEM modeling and analysis of internal door panel using bamboo fiber reinforced epoxy composite has been perceived as an excellent enhancement to simplify the analysis of internal door panel of an automobile. Therefore, this research is proposed to fill these gaps.

1.4. Objective

a. General Objective:

The general objective of the proposed research is:

- To do the Finite Element Analysis for internal door panel of a vehicle by considering bamboo fiber reinforced epoxy composite material.

b. Specific objective:

The specific objectives are:

- To develop a suitable model of internal door panel by using modelling software.
- To conduct a transient dynamic structural analysis (stress and displacement analysis) of BFREC internal door panel by finite element method
- To use the previously conducted experimental results on BFREC for the FEM analysis.
- To compare the performance of BFREC material with previously recommended materials of internal door panel.

1.5. Scope of the research

In this specific research work, experimental investigations will not be conducted; instead a reasonable data that was already done by appropriate experiments will be taken.

The present research analysis is done by considering only the effect of the shock producing while closing the door. This is the common load mechanism that creates mechanical stress to affect the life of the internal door panel. By considering this loading condition, the paper conducts the transient dynamic analysis of the internal door panel for BFREC material.

The other loading conditions such as, the side crash impact effect, is not considered under this analysis. And it is left for future work.

1.6. Methodology

First of all a relevant data should be collected. Some crucial characteristics of bamboo fiber composite which was done by experimental investigation and the analysis of internal door panel on different materials are collected. In addition to this an actual data has been collected by observing and measuring the specifically selected car door panel.

Modeling of the internal door panel of an automobile has been developed by CATIA V5 R20 modeling software.

The Finite Element Method simulation and analysis were done by using the Finite element analysis software, ANSYS Workbench 15.0.

Finally, conclusion and recommendations for further researches are suggested based on the analysis outcomes.

1.7. Organization of the paper

This thesis is organized in to five chapters. In the first chapter background, statement of the problem, motivation of the research, objectives and methodology of the study are discussed. In chapter two a survey of literatures related to the research have been investigated. The journals, articles and publications that are related to this research work are reviewed. In the third chapter, materials used, the conditions and the methods of analysis are stated. Modeling and FEM methods for static structural analysis have been discussed clearly. In chapter four the FEA results are displayed and an appropriate discussion is performed. The conclusions, recommendations and future work of the research are stated in the last chapter, chapter five.

CHAPTER TWO

LITERATURE REVIEW

The design of vehicle body has evolved from a simple, all steel structure that meets the basic requirement of strength and functionality, to the current day complex and efficient structure. Lightweight composite materials have been used to replace conventional one. This is because composite materials offer significant opportunities for enhancement of product performance in terms of strength, stiffness and energy absorption, combined with weight reduction & space saving. There are many journals, articles, thesis papers, books, conference and published study in the world related to automotive body structure materials and their analysis. These previous works were trying to address different approaches to design and analyze the automotive body parts by using different materials (conventional and composite).

Natural fibers have become popular reinforcement material for fiber reinforced polymer composite developments. The reinforcement can replace the conventional fiber, such as glass, aramid and carbon as an alternative material. [20]

The main advantageous of natural fibers include low cost, fairly good mechanical properties, high specific strength, non-abrasive, & eco-friendly. In spite of impressive specific mechanical properties, the main challenges associated with these reinforcements include severe moisture absorption, fire resistance, mechanical properties and durability, variability, and manufacturing/processing of natural fiber reinforced plastic composites. [30]

2.1. Bamboo Plant and its fiber

Bamboo, which is belonging to the family of the Bambusoideae, encompass approximately 60–90 genera and 1100–1500 species. Bamboo mainly grows in tropical and sub-tropical regions of Asia, Latin America and Africa [17]

Bamboo, itself is very strong in its longitudinal direction due to strong fiber bundles penetration. The strength, however, decreases from the base to the top of the bamboo culm [18].

2.1.1. Bamboo Plants in Ethiopia

Ethiopia has the largest area of bamboo in Africa by constituting 67% of the total bamboo forest area of the continent and about 7% of the world total bamboo resource. The country has nearly 1 million hectares of bamboo reserves, yet the production and consumption of bamboo and bamboo products is very limited, and value addition is minimal due to poor processing technology. [19]

This large resource is dominated by the two indigenous bamboo species; the highland bamboo (*Yushania Alpina*) and the monotypic genus lowland bamboo (*Oxythenantera Abyssinica*), [19]. These resources are distributed in the highlands and lowlands of Ethiopia. Assosa, Injibara, Gimbi, Ambo, Gurage, Bale, Masha, Chenchu and Hagere-Selam are rich in naturally occurred and planted bamboo forests. The largest source of bamboo plant present in Assosa is lowland type which has solid culm at maturing age. [19, 20, 31]

Although bamboo is not an integral part of the economy of Ethiopia, it plays a very important role socially, economically and ecologically in areas where it occurs naturally and where it is planted. It has been used in traditional way in the country side a little bit for the scaffolding, construction of houses, fuel, feed fodder, beehives, hats, mats, baskets, handicrafts, small furniture and other countless products. Recently, a market for bamboo culms and bamboo products has developed. [19, 20, 31].

2.1.2. Bamboo Fiber

Bamboo is an orthotropic material with high strength along axial and low strength transversal to its fibers. This is due to the longitudinally alignment of its fiber to its body while at the same time this is attributed by its polylamellate wall structure that consists of alternating broad and narrow layers with different fibrillary orientation. Furthermore, high cellulose and lignin content and relatively small micro-fibril angle of bamboo plant contribute to this high strength of bamboo fiber [21]. There is a variety between different culms on stiffness, strength and fracture toughness. The structure of bamboo itself is a composite material, consisting of long and aligned cellulose fibers immersed in a ligneous matrix. That means, the culm of a bamboo plant is a ligno-cellulosic natural functionally graded composite material. Fibers are densely located around the outer cortex and similarly on the top of the culm. As a result when we examine bamboo timber; from inner to the outer and from the bottom culm to the top, the mechanical strength of the bamboo is increased. [21, 22].

The chemical constituents of bamboo are primary cellulose, hemi-cellulose and lignin. The bamboo has 60% cellulose and a considerably high percentage of lignin (about 32%).

Table: 2.1. Composition of few commonly used natural fibers [24]

Fiber	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)	Pectin (wt%)	Moisture (wt%)	Waxes
Cotton	85-90	5.7	-	0-1	7.85-8.5	0.6
Bamboo	60.8	0.5	32	-	-	-
Flax	71	18.6-20.6	2.3	2.2	8-12	1.7
Hemp	70-74	17.9-20.4	3.7-5.7	0.9	6.2-12	0.8
Jute	61.1-71.5	13.6-20.4	12-13	0.2	12.5-13.7	0.5
Kenaf	45-47	21.5	8-13	3-5	-	-
Sisal	66-78	10-14	10-14	10	10-22	2
Coir	32-43	0.15-0.25	40-45	3-4	8	
Banana	63-64	19	5	-	10-12	-

The bamboo fiber is often brittle compared with other natural fibers, because the fibers are covered with lignin. Therefore, a devised process should be adopted to extract the bamboo fibers for reinforcement of composite materials. [20].

The bamboo fiber length and fiber wall thickness is increase with increase of age of bamboo plant. Moreover, the strength of bamboo fiber increases with an increment of age. The optimum strength value occurs between 2.5 and 4 years. Then it became to decreases at a later age. However, as age increases the extraction of bamboo fiber from the culm is more difficult. Thus, the good bamboo fiber with easy and minimum extraction cost will be got from the bamboo plant of age 2.5 to 4 years old. [17, 31]

Applications of bamboo fiber and its composites are roof construction, car dashboard, rope, making sheet, paint brush, upholstered furniture, geo-textile, bamboo cycle, computer hardware, bamboo decorative elements, etc. [22]

The bamboo fiber has a comparable property with that of glass fiber. More over the mechanical properties of bamboo fiber are comparable to the mechanical properties of the best among natural fibers. [20]

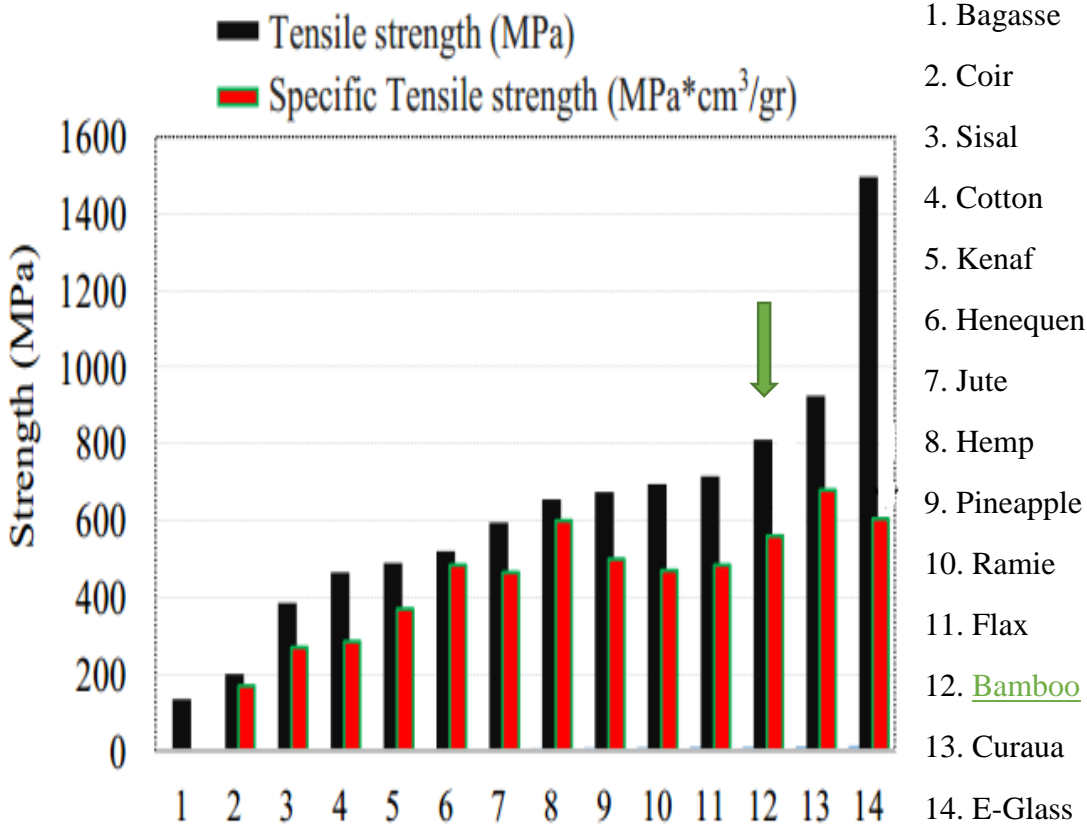


Fig. 2.1. Comparison of Natural fibers strength and specific strength [20]

2.2. Thermosetting Polymer Matrix

Among different types of matrix materials, polymer matrices are the most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared with others.

Polymer matrices can be either thermoplastic or thermoset according to the effect of heat on their properties. The thermoset polymer is frequently used as the matrix material due to some advantages it has over the thermoplastic one. The thermoset polymer matrix materials have overall, better economics and high temperature properties. Good mechanical, wetting and adhesion properties and easy to dispose are also the advantages of thermoset polymers.

The most commonly used thermoset resin materials are epoxy, vinyl ester, polyester and phenolic. Each resin has its own benefits and drawbacks to use as a matrix materials.

2.3. Previous Works

2.3.1. Automotive Body Materials in the Past

Deep drawing steel sheets with good formability were developed in the 1950s, followed by the development of anti-corrosive steel sheets in the 1960s. In this time, mass production technologies were developed because of higher vehicle demand. In the 1970s and 1980s, low fuel consumption was a keen issue because of the oil crises. High-strength steel sheets were developed in response to this issue and have contributed to lightening vehicles by reducing sheet thickness. In the 1990s, safety and environmental issues became primary concerns in the automotive industry, and further work was done on developing technologies for weight reductions. Aluminum alloy sheets were developed in this connection and applied to various body panels such as the engine hood, and have contributed to achieving lighter vehicles [15, 29].

Automobile body panels consist of a double structure with an outer panel and an inner panel. For the outer panels, higher strength materials are especially required to provide sufficient denting resistance. For the inner panels, higher deep drawing capacity materials are especially required to allow the manufacture of more complex shapes. In other words, different properties are required for the outer and inner panels.

New materials for the car body have been developed to improve corrosion resistance and to reduce the dead weight of the vehicle. [29]

Material technologies are also expected to contribute in the improvement of crashworthiness. In order to achieve a safe car body in the event of a collision, deformation of the cabin structure should be minimized to protect the occupants, and the collision energy should be absorbed in a short deformation length within the crushable zones. From the viewpoint of materials, both dynamic strength and static strength are important in designing parts for greater crash safety.

Lightweight composite materials, such as glass-fiber reinforced polymers, have been used to replace traditional steel and aluminum components. This is because composites offer significant opportunities for enhancement of product performance in terms of strength, stiffness and energy absorption, combined with weight reduction and space saving. Today, design procedures of vehicles body that ensures reliability and road worthiness is well established. [15, 29]

By reducing vehicle weight will reduce the amount of energy required for movement, which has major implications on the level of environmental pollution. An obvious way to this is to extend the use of lightweight composite materials with multiple functions in the body structure components without using one material for each of the requirements. Current trends in the field of composite materials, due to environmental and economic considerations, focus on achieving low environmental impact materials and possible usage of waste resulting from other industrial processes.[10, 15]

2.3.2. Automotive door panel materials and analysis in the past

Mr. Sandeep Bundele & Dr. Rupa S. Bindu [1] conducted Automotive Door Design & Structural Optimization of Front Door for Commercial Vehicle with ULSAB Concept for Cost and Weight Reduction. The paper described the drawbacks of existing automotive door structure and suggest design changes to overcome the present drawbacks.

The new front door assembly components with tailor welded blank technology for reducing weight and cost of door assembly was designed. Tailor-welded blanks allow combining different strengths of steel in one part without adding complications at the joints. Weight of a door assembly is reducing by 0.4 kg, by reducing weight of a door inner panel by using less thickness high strength material, reduce cost by replacing molded trim with hard pad.

It was successfully solved water leakage problem by modeling front door inner panel correctly. However, the weight of the door panel can be further reduced by selecting lighter materials than steel and designing accordingly.

O.M. Terciu, I. Curtu, C. Cerbu [2] presented the finite element analysis of an automotive door trim panel made of lignocelluloses composites in order to determine the stresses and displacements in case of a door slam simulation. The research was investigated a new lignocelluloses composites made of polymers reinforced with woven fabrics of natural fibers and wood particles. The FEM results emphasized that the new material improves component stiffness compare with classical materials used.

Comparing the results obtained by finite element modelling can be seen that for an acceleration of the impact of 350 m/s^2 , displacements of the lignocellulosic composite moulded panel are lower by 43% than the plastic moulded panel (polypropylene) and its weight is decreasing by 0.3kg.

Even if the result shows that the newly analyzed material has better performance as compared with the classical one, still a large deformation value is recorded. This can be reduced by assessing the more stiff materials.

M. Grujcic et.al. [3] perform a research on multi-disciplinary design optimization of a composite car door for structural performance, NVH, crashworthiness, durability and manufacturability. In this work, a multi-disciplinary design optimization methodology has been presented and subsequently applied to the development of a light composite vehicle door (more specifically, to an inner door panel). The door design has been optimized with respect to its weight while meeting the requirements /constraints pertaining to the structural and NVH performances, crashworthiness, durability and manufacturability.

For the internal door panel the thermoplastic reinforced material was used in the modeling and the analysis. This makes more expensive to invest on the application of the results due to the manufacturing process of thermoplastic composites. And the non-degradable property of this type of composite will make the disposal of the wastes after use more difficult.

Tan Wei et.al. [4] conducted design of the vehicle door structure based on Finite Element Method. The stiffness, strength, modal characteristic and anti-extrusion of a newly developed passenger vehicle door assembly are calculated and evaluated by several finite element analysis commercial software. The issue in focus was to predict the performance of the door assembly by powerful finite element analysis software, and optimize the structure to meet the design targets. This method can be used to forecast the performance of vehicle door efficiently when it is designed.

The developed methodology in the design of vehicle door is mainly focused on the outer door panel and the side impact beam only; that means this research forgot the significance of the internal door panels.

Tawanda Mushiri and Charles Mbohwa [5] published on design of a vehicle door structure based on Finite Element Method. In this paper, the finite element method was used in the development processes of the door assembly. A popular 3-D nonlinear dynamic explicit finite element code with advanced contact algorithms and material models was used to simulate several types of armors subjected to the impact of projectiles moving at various velocities. This paper also has the same gap as the above literature [4]

Said Darwish et.al. [6] did the Numerical study of automotive doors. Predetermined values from previous works conducted on a similar existing vehicle were used as targets to be achieved by Finite Element Analysis (FEA) of car doors. In this research modal analysis of rear and front doors was in target. For these models both the global stiffness and local stiffness analysis and the vertical displacement analysis were performed.

The research work gave less emphasis for the internal door panel which can play a great role on the weight reduction concept.

M. Raghuvver and Ganti Satya Prakash [7] researched on Design and impact analysis of a car door. The aim of this work was to analyze the car door with existing material and replacing with different composite materials like Carbon Epoxy, S-glass epoxy, and E-Glass epoxy. Impact analysis was conducted on door for different speeds by varying the materials. This work was going to reduce weight of the door by using composite materials replacing with steel and reduce the damage percentage of the car and passenger protection. The Car door was modeled using parametric modeling software Pro/Engineer.

The strength of the door is increased by change of material from steel to E-glass epoxy and S-glass epoxy composites. However the glass fiber is denser than natural fibers, so that the weight of the door panel can be further reduced when we use bamboo fiber composites. Since the bamboo fiber has almost equivalent strength with that of glass fiber [20], we can improve the vehicle by reducing its dead weight.

Mats Hornlund and Alexander Papazoglu [8] conducted the Analysis and measurements of vehicle door structural dynamic response. Basically it was objected to improve the structural dynamic response prediction capability of a vehicle door simulation model in a free-free configuration under steady-state conditions. The actions performed can then be rolled down to: simulate Eigen modes and frequency response, perform hardware measurements, make correlations of simulations versus measurements, using modal assurance criterion, frequency response assurance criterion and sum-blocks, and update simulation model.

Enrico Mangino et.al. [9] researched on The future use of structural composite materials in the automotive industry. This paper reported the findings of a recent European initiative that examined the future use of composite materials in the automotive sector. The principal

technical challenges that must be overcome in different key areas relating to composite usage are reviewed.

As a general conclusion, design procedures of vehicles body that ensures reliability and road worthiness is well established today. However, as a result of advancements in the areas of material, production methods, computational & design tools, optimization technique, etc., further improvement on vehicle structural design is still an active topic of research. When we see all of the revised literatures, they were focused mostly on experimental researches. Moreover, they were targeted on conventional materials. Thus, conducting the analysis of composite materials for automotive body application may be a good researchable idea, especially by using natural fiber (bamboo fibers) composites.

2.3.3. Mechanical characterization of bamboo fiber reinforced composites

S. A. H. Roslan et.al. [21] conducted a review on the natural fiber composites based on bamboo fibers. This paper is to review on the properties of bamboo reinforced composites from numerous characterization studies of bamboo that are available in the literatures. The review is based on characterization studies on several types of bamboo reinforced composites such as laminated bamboo fiber reinforced composite, randomly oriented bamboo reinforced composite, hybrid fiber reinforced composite, bamboo fiber reinforced bio-composite and bamboo fiber sandwiched structure composite. It can be said that the laminated bamboo composite in general gives higher mechanical properties compare to other structural forms of bamboo composite. Even though bamboo bio-composite in general provides low mechanical properties, the properly design unidirectional bamboo bio-composite can also have high mechanical properties that are as good as the laminated bamboo reinforced composite.

S. sreeni vasul u et.al. [22] performed the research on Mechanical properties evaluation of bamboo fiber reinforced composite materials. The research has attempted to explore the potential utilization of short bamboo fiber reinforced polyester composites with different weighting compositions, see the table below.

Table: 2.2. Designation and weighting of Composites [22]

Samples	Compositions
PB-1	Polyester + bamboo Fiber (15 wt%)
PB-2	Polyester + bamboo Fiber (30 wt%)
PB-3	Polyester + bamboo Fiber (45 wt%)
PBA-1	Polyester + bamboo Fiber (45 wt%) + Alumina (0 wt%)
PBA-2	Polyester + bamboo Fiber (45 wt%) + Alumina (5 wt%)
PBA-3	Polyester + bamboo Fiber (45 wt%) + Alumina (10 wt%)

It has been evaluated the Mechanical properties such as Tensile strength, and Flexural strength of short bamboo fiber reinforced polyester composites material.

Table: 2.3. Mechanical properties of bamboo fiber reinforced polyester composites

Composites	Tensile strength (MPa)	Flexural strength (MPa)
PB-1	7.241	29.381
PB-2	8.587	38.989
PB-3	15.601	26.226
PBA-1	17.883	38.109
PBA-2	16.861	45.848
PBA-3	18.767	28.448

The results of this research has been shown that, the mechanical properties of short bamboo fiber reinforced polyester composite material are greatly influenced by the fiber volume fraction and the filler content.

Syed Altaf Hussain et.al., [23] conducted a research titled as Mechanical properties of short bamboo fiber reinforced polyester composites filled with alumina particulate. It was about the evaluation of mechanical properties namely, Tensile strength and Flexural strength, of short bamboo fiber reinforced polyester composites filled with alumina particulates. Specimens were prepared by hand lay-up technique and are cut as per ASTM standards to perform the test. The experimental result reveals that the mechanical properties of the composite material were highly

influenced by the fiber volume fraction (fiber loading). Addition of alumina (Al_2O_3) particulate at various proportions as filler material the mechanical properties i.e., Tensile strength and flexural strength are distinctly improved.

Table. 2.4. Designation and composition of Composites [23]

Samples	Compositions
PB-1	Polyester + Bamboo Fiber (15 wt.%)
PB-2	Polyester + Bamboo Fiber (30 wt.%)
PB-3	Polyester + Bamboo Fiber (45 wt.%)
PBA-1	Polyester + Bamboo Fiber (45 wt.%) + Alumina (5 wt.%)
PBA-2	Polyester + Bamboo Fiber (45 wt.%) + Alumina (10 wt.%)
PBA-3	Polyester + Bamboo Fiber (45 wt.%) + Alumina (15 wt.%)

The test results are summarized according to the following graphical expressions.

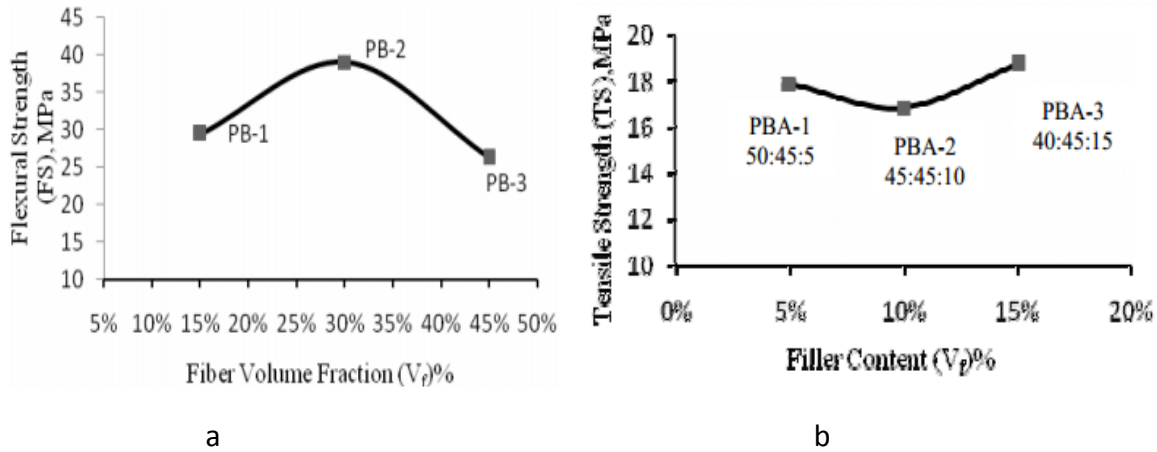


Fig. 2.2: Variation of mechanical properties with respect to the filler content (fiber volume fraction) a. flexural strength, b. tensile strength,

Subhash Kumar Gupta, Prof. Sandhyarani Biswas [24] A study on mechanical behavior of bamboo fiber based polymer composites. It has been investigate the mechanical behavior of short bamboo fiber reinforced epoxy based composites. Bamboo fibers with different length and contents are reinforced in epoxy resin to fabricate composite materials.

The effect of fiber length and content on the mechanical behavior of the composites was studied under this research work.

Table: 2.5. Composition and designation of fiber reinforced composites [24]

Composite	Composition
C-1	Epoxy (90 wt.%) + short bamboo fiber of length 4mm (10 wt.%)
C-2	Epoxy (80 wt.%) + short bamboo fiber of length 4mm (20 wt.%)
C-3	Epoxy (70 wt.%) + short bamboo fiber of length 4mm (30 wt.%)
C-4	Epoxy (90 wt.%) + short bamboo fiber of length 7mm (10 wt.%)
C-5	Epoxy (80 wt.%) + short bamboo fiber of length 7mm (20 wt.%)
C-6	Epoxy (70 wt.%) + short bamboo fiber of length 7mm (30 wt.%)
C-7	Epoxy (90 wt.%) + short bamboo fiber of length 10mm (10 wt.%)
C-8	Epoxy (80 wt.%) + short bamboo fiber of length 10mm (20 wt.%)
C-9	Epoxy (70 wt.%) + short bamboo fiber of length 10mm (30 wt.%)

The study tried to verify the mechanical properties of bamboo reinforced epoxy based composites such as tensile strength, flexural strength, with their varying composition are explained below.

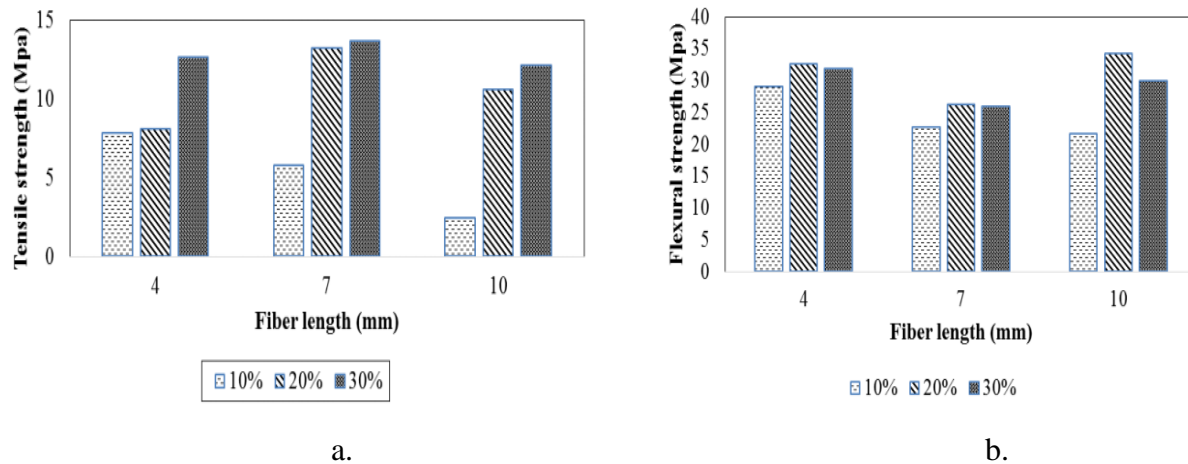


Fig. 2.3: Effect of fiber parameters on the mechanical property of composite: a. tensile strength, b. flexural strength [24]

D. Dash et.al. [25]; Conducted the mechanical characterization of Natural Fiber Reinforced Composites (NFRC) consisting of epoxy resin reinforced with jute fiber and bamboo fiber. Hand lay-up technique was used for fabrication of the composite specimens. The effect of fiber orientation (0/90, 15/-75, 30/-60, and 45/-45) was analyzed and it shows that the fiber orientation of 0/90 provides higher strength and stiffness than other fiber orientations used in this work.

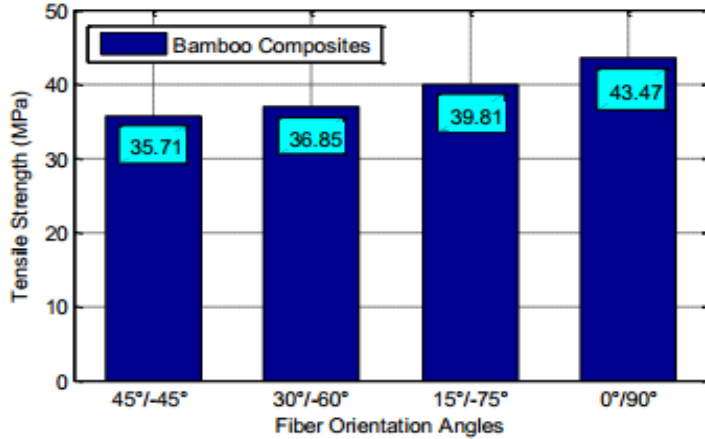


Fig. 2.4: Effect of Fiber Orientation on Tensile Strength of Bamboo Composites.[25]

The natural fiber reinforced composite can be used in places where light load application is important and the economics of natural fiber composite materials is more beneficial as compared to E-glass fiber composites.

Dheeraj Kumar (Asstt. Prof.) [26] Characterization of tensile properties of treated bamboo natural fiber polymer composite. The paper tried to show the practical observation which includes characterization of mechanical properties of potential bamboo fiber. The fabrication of the samples were made by hand lay-up technique.

Table: 2.6. Sample Composition

Designation	Composition	No. of Samples
B	Pure Epoxy	5+5+5 = 15
B1	Epoxy (95%) + Bamboo Fiber (5%)	5+5+5 = 15
B2	Epoxy (90%) + Bamboo Fiber (10%)	5+5+5 = 15
B3	Epoxy (80%) + Bamboo Fiber (20%)	5+5+5 = 15
B4	Epoxy (75%) + Bamboo Fiber (25%)	5+5+5 = 15
B5	Epoxy (70%) + Bamboo Fiber (30%)	5+5+5 = 15

The Result shows the variation in tensile strength in respect with the variation in fiber content (%). The tensile strength of bamboo-epoxy composite increases to the certain level of fiber loading and then starts decreasing on further fiber loading.

Table: 2.7 Tensile strength of bamboo fiber polymer composite with random orientation [26]

Designation	Fiber Content (%)	Orientation (Degree)	Tensile Strength (MPa)
B	0	-	18.16
B1	5	Random	26.22
B2	10	Random	37.98
B3	20	Random	45.28
B4	25	Random	53.61
B5	30	Random	46.91

The result shows that the tensile strength of bamboo-epoxy composite increases to the certain level of fiber loading and then starts decreasing on further fiber loading. The maximum value of tensile strength is obtained at 25wt% of fiber loading

Vivek Kumar, Sanat Mohanty [27] Researched on High Performance Moldable Bamboo Fiber-Epoxy Composites. For development of the composites, woven bamboo mats were used where the bamboo was stripped into narrow strips, about 4.25mm wide and about 0.5 mm in thickness.

The composites contained between 30-40 wt.% fibers, although up to 60 wt. % fiber can be used. Fillers such as carbon black and fly ash can also be added to these composites. The composites exhibit tensile strengths of 140MPa, flexural strengths of 160 MPa and notched Charpy Impact strengths of 60 kJ/m². These composites were molded into auto body parts (dashboard, doors, and panels) and are under test with an auto-rickshaw manufacturer

Fekadu Tarekegne and Philip Conze [19] Researched on the study of Ethiopia high land bamboo composite for structural materials. The main objective of the study was to introduce the industrial application of bamboo to bamboo sectors of the country by investigate the performance of bamboo fiber composite. The experimental analysis was carried out by using a short bamboo fiber reinforced epoxy composite (with bamboo fiber content of 25 wt. %) to evaluate its mechanical properties. The fiber was extracted from a two years old highland bamboo (bamboo from Injibara). This experimental results were summarized by the following table, (Table 2.9)

Table 2.8 Mechanical properties of bamboo fiber reinforced epoxy composites [19]

Mechanical Properties	Values	Tests Standards
Tensile Strength	187.73MPa	ASTM D638
Flexural Strength	190.32MPa	ASTM D790
Compressive Strength	114.13MPa	ASTM D695
Shear Strength	18.18MPa	ASTM D638
Water Absorption	2-3%	24 hour submersion
Young's Modulus	3852	-
Shear Modulus	1580	-

From these results the researchers concluded that the analyzed BFREC material has an attractive mechanical properties which can replace the current structural materials.

The research was commissioned by Fortune Enterprise P.L.C collaborated with GTZ on a public private partnership project (PPP). The PPP has the objective of establishing a sustainable production of high value composite bamboo materials, and promote industrial production

Generally to summarize this chapter, several experimental investigations were done to characterize the mechanical properties of the bamboo fiber reinforced composite materials. As we have seen from the above reviewed literatures, the bamboo fiber reinforced composites have mechanical properties comparable to currently used engineering plastics and are appropriate for application in automotive body parts.

CHAPTER THREE

MATERIALS, CONDITIONS AND METHODS

3.1. Materials

As we have seen from different literatures (previous chapter), bamboo fiber has better mechanical properties as compared with other natural fibers. Therefore, using this plant fiber as a reinforcement in composite materials for different structural components by replacing the currently used conventional materials will have a competence advantages.

In this analysis the bamboo fiber/epoxy composite materials with a considerable composition are used as the materials of internal door panel of an automotive.

Bamboo Fiber

From the fact that, the availability of large amount of bamboo plant resources in Ethiopia attracts for the relying on this plant for different studies in the past. Especially the highland bamboo (*Yushania Alpina*) species is given more focus from the researchers and it is suitable for different applications

Epoxy Resin

The choice of a resin system for the use of most composite structural component depends on a number of its characteristics, such as: adhesive properties, mechanical properties, and degradation from water ingress.

The most commonly used thermoset resins are epoxy, vinyl ester, polyester and phenolic. Among these thermoset matrix materials, the epoxy resins are being widely used for many advanced composites due to their valuable advantages such as excellent adhesion to wide variety of fibers, good performance at elevated temperatures and better mechanical and electrical properties. In addition to that they have low shrinkage upon curing and good chemical resistance. It has very low viscosity, long average pot life at room temperature, consistent performance and doesn't contain any hazardous dilutes or extenders.

Moreover, epoxies generally out-perform most other thermosetting resins in terms of mechanical properties and resistance to environmental degradation, (has superior tensile strength, bond strength, adhesive characteristics, fatigue resistance and resistance to water degradation).

Mechanical Characterization of BFREC

The mechanical properties of most reinforcing fibers are considerably higher than those of the resin systems. Therefore; the fiber/resin composite properties are dominated by the contribution of the fiber to the composite. The main factors that govern the fiber's contribution are the basic mechanical properties of the fiber itself, the surface interaction of fiber and resin (the 'interface'), the amount of fiber in the composite ('Fiber Volume Fraction') and the orientation of the fibers in the composite.

Mechanical properties of a designed bamboo composite depend on how bamboo fibers are extracted from the bamboo trees, the form of bamboo fibers and eventually the types of bamboo composites, the treatments on the fibers and the polymers and the fabrication process used to produce the composite. [21]

The fiber length, diameter, orientation, amount and properties of the constituents (fiber and matrix materials), and the bonding between them have also the effect on the composite properties. Fiber dimensions are characterized by the aspect ratio (their fiber length and diameter ratio, l/d , where l is the fiber length and d is the fiber diameter). The strength improves when the aspect ratio is large. Fibers often fracture because of surface imperfections. Making the diameter small reduces its surface area, which has fewer flaws.

Long fibers are preferred because the ends of the fiber carry less of the load. Thus the longer the fiber, the fewer the ends and the higher the load carrying capacity of the fiber reinforced composites.

Epoxy has low strength. It doesn't support any load. So, the main purpose of epoxy is to transfer loads to the fiber. As a result, the length and orientation/ angle of the fibers in the composite determines the strength of the composite materials.

More over the manufacturing methods used to produce the final product is very important as it dictates the type of properties as well as the quality of the product.



Fig.3.1: Forms of bamboo being used as composite reinforcement (a) long fibers (b) flake (c) short fibers (d) sliver (e) strips and (f) powder. [21]

Fiber and matrix volume content of the composite

The relative proportions of fiber and matrix have a significant influence on the mechanical properties of composite materials. These proportions can be expressed either as volume fractions, or as mass fractions. While mass fractions are easier to obtain during fabrication of composites, volume fractions are handier in theoretical analyses of composites.

The ratio of the resin to the fiber can be determined through experience. The formula used to calculate the weight fraction and volume fraction of fiber and matrix was discussed below according to [12, 15].

i. Fiber and matrix weight fraction (WF, WM)

$$\text{Fiber weight fraction} = \frac{\text{Weight of fiber}}{\text{Total Weight}}$$

$$\text{WF} = \frac{W_f}{W_f + W_m} \quad (3.1)$$

$$\text{Matrix weight fraction} = \frac{\text{Weight of matrix}}{\text{Total Weight}}$$

$$\text{WM} = \frac{W_m}{W_f + W_m} \quad (3.2)$$

$$W_f + W_m = W_c$$

$$\text{WF} + \text{WM} = 1 \quad (3.3)$$

ii. Fiber and matrix volume fraction (VF, VM)

Volume of fibers, matrix and composite is given by

$$V_f = \frac{W_f}{\rho_f} \quad V_m = \frac{W_m}{\rho_m} \quad V_c = V_f + V_m \quad (3.4)$$

$$\text{Fiber volume fraction} = \frac{\text{Volume of fiber}}{\text{Total Volume}}$$

$$\text{VF} = \frac{V_f}{V_f + V_m} = \frac{V_f}{V_c} \quad (3.5)$$

$$\text{Matrix Volume fraction} = \frac{\text{Volume of Matrix}}{\text{Total Volume}}$$

$$\text{VM} = \frac{V_m}{V_f + V_m} = \frac{V_m}{V_c} \quad (3.6)$$

$$\text{VF} + \text{VM} = 1 \quad (3.7)$$

$$\text{VF} = \frac{W_f \times \rho_m}{W_f \times \rho_m + W_m \times \rho_f} \quad (3.8)$$

$$\text{Similarly; } \text{VM} = \frac{W_m \times \rho_f}{W_f \times \rho_m + W_m \times \rho_f} \quad (3.9)$$

iii. Mass density of the composite (ρ)

$$\begin{aligned}\rho &= \frac{\text{Total Weight}}{\text{Total Volume}} = \frac{\text{Weight of fiber}}{\text{Total Volume}} + \frac{\text{Weight matrix}}{\text{Total Volume}} \\ &= \frac{\text{Volume of fiber}}{\text{Total Volume}} \rho_f + \frac{\text{Volume of matrix}}{\text{Total Volume}} \rho_m \\ \rho &= \rho_f \times VF + \rho_m \times VM\end{aligned}\tag{3.10}$$

In general, some simple properties of composite materials can be estimated from the contribution of each part of the composite. This method is referred to as the rule of mixtures. Based on this rule a composite property, P_C , can be estimated by:

$$P_C = P_f \times VF + P_m \times VM;\tag{3.11}$$

Where P_f & P_m = the property of fiber and matrix, respectively.

Material selection

As we have seen from the literatures there are a variety materials of bamboo fiber reinforced composites. Researchers did the characterization of these composites by using the experimental methods with different fiber and matrix compositions. Not only the composition, but also the extraction mechanisms of the fiber and the manufacturing methods of the composite were different from researcher to researcher. Thus, selecting the material which will feat our requirements is essential.

During selecting the material, the characteristics of the composite, the ways of fiber extraction, the ease of the manufacturing process, the types of the matrix used for the composite and some other criteria are taken into consideration. In addition to this, the selection of the material for this specific research work is basically focusing on the Ethiopian bamboo fiber and the researches which has previously done on it.

Based on these measures, the composite with a one to four (1:4) composition of fiber and matrix (25% bamboo fiber and 75% epoxy resin) is selected. This was done by the researcher Fekadu Tarekegne and Philip Conze under the title of “Study of Ethiopia high land bamboo composite for structural materials” In the research, the two years old highland bamboo was used for fiber

extraction and the fabrication of the sample was made by hand lay-up technique, which has the advantages of high flexibility and the simplicity of the process and the cheap tooling. [19]

Now by using this information, the above equations (equations 3.1-3.10) and the weight fraction of the composite, the total weight of the panel can be calculated.

For the internal door panel of front door: (see fig 3.2)

From the geometry modeling, the total surface area of the panel is 3989 cm².

Total volume of the panel = Area of the panel * thickness of the panel = 1196cm³.

The weight of the bamboo fiber needed per panel = 337.8 gram = 0.3378 kg

The weight of the epoxy resin needed per panel = 1013.2gram = 1.0132 kg

Thus, the total weight of the panel can be 1340 gram = 1.34 kg.

The density of the bamboo fiber reinforced epoxy composite can be 1.12g/cm³.

For the internal door panel of rear door:

From the geometry of the model, the total surface area of the panel is 3560 cm².

Total volume of the panel = Area of the panel * thickness of the panel = 1067cm³.

The weight of the bamboo fiber needed per panel = 301 gram = 0.301 kg

The weight of the epoxy resin needed per panel = 903gram = 0.903 kg

Thus, the total weight of the panel can be 1195 gram = 1.20 kg.

3.2. Modeling of internal door panel

Modelling and numerical simulation are essential aspects of today's automotive sector. They are necessary in order to reduce the time-to-market for new products and the costs associated with experimental testing.

In the early days of composite use, there was often a big gap between the expectations of the vehicle designers and those of the composite manufacturers, and this often resulted in the poor use of materials and delays in production. Today, a major challenge relating to automotive

composite design is the poor availability of simulation tools and a general lack of composite material characterization [9, 32].

In vehicle design, the automotive sector has been undertaking structural analyses (static, dynamic, safety, noise and vibration, handling, etc.) for many years.

With time, models have increased in their precision and accuracy, but until recently they have only involved metals and a few polymer components. The polymer components, in the majority of cases, have only been modelled as isotropic materials. However, as the use of structural composite materials in the automotive sector has increased, it has now become necessary to model composites more rigorously. [9]

It is also desirable to be able to integrate design and process analyses in order to be able to verify a product's performance in relation to its manufacturing and vice versa. This is especially critical for designers seeking extreme light weighting whilst maintaining the necessary structural characteristics.

Light weighting is one of the major drivers for the use of composites in the automotive industry. However, the benefits of light weighting are different for different categories of vehicle. Light weighting in trucks allows for payload increases whilst maintaining the same overall mass. In mass production vehicles, the most important driver for light weighting is the reduction of fuel consumption and the associated reduction of CO₂ and other emissions in order to reduce environmental hazards.[9]

Fuel economy can be improved by reducing aerodynamic drag and increasing the thermodynamic efficiency of the engine, however remarkable gains can also be achieved by reducing vehicle weight. For this purpose, advanced materials with high specific stiffness and strength properties are adopted into the automotive applications. According to the research study [32], every 10% of weight reduced from the average new car or light truck can decrease fuel consumption by 6.9%.

Overall, there is no doubt that the importance of modelling and simulation in the automotive sector will continue to increase time to time. In terms of composite materials, the focus for continued development will be the improvement of failure theories, damage modelling, and fatigue life prediction whilst achieving reasonable solution times.[33]

3.2.1. Geometrical modelling of the internal door panel

The 3D Modeling is a geometrical representation of a real object without losing information the real object would have. It has volume and therefore, if someone provides a value for density of the material, it will have mass and inertia.

In this specific research, the 3D modelling of the front internal door panel is done by using CATIA V5 R20 modeling software. This is done by taking the actual data from a selected type of vehicle.

The Toyota Corolla DX model vehicle is selected for this purpose. This vehicle is selected due to some reasons; such as,

- Toyota Corolla DX model vehicle are old enough to need spare parts for the replacement of their parts; such as internal door panel. Thus it will be feasible to implement the findings of this research on the selected vehicle.
- It is easy to take the necessary data due to its availability.

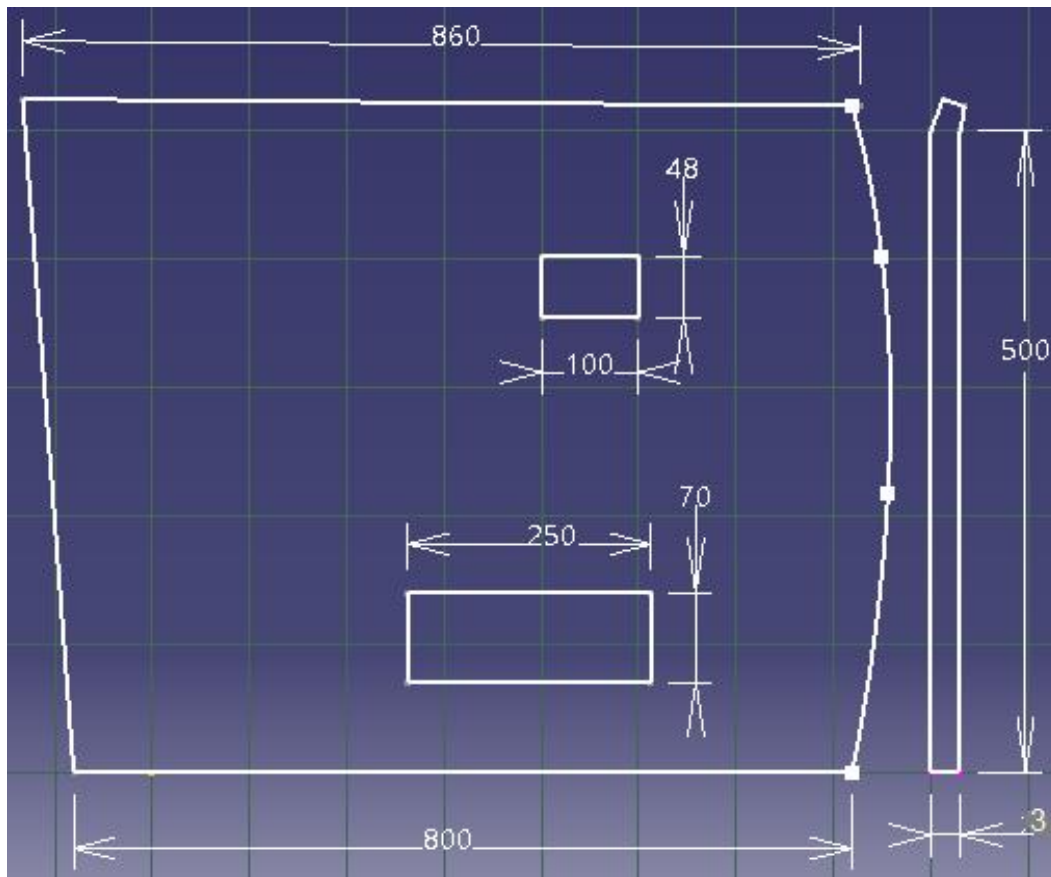


Fig. 3.2: The 2D drawing of the internal door panel (all dimensions are in mm)

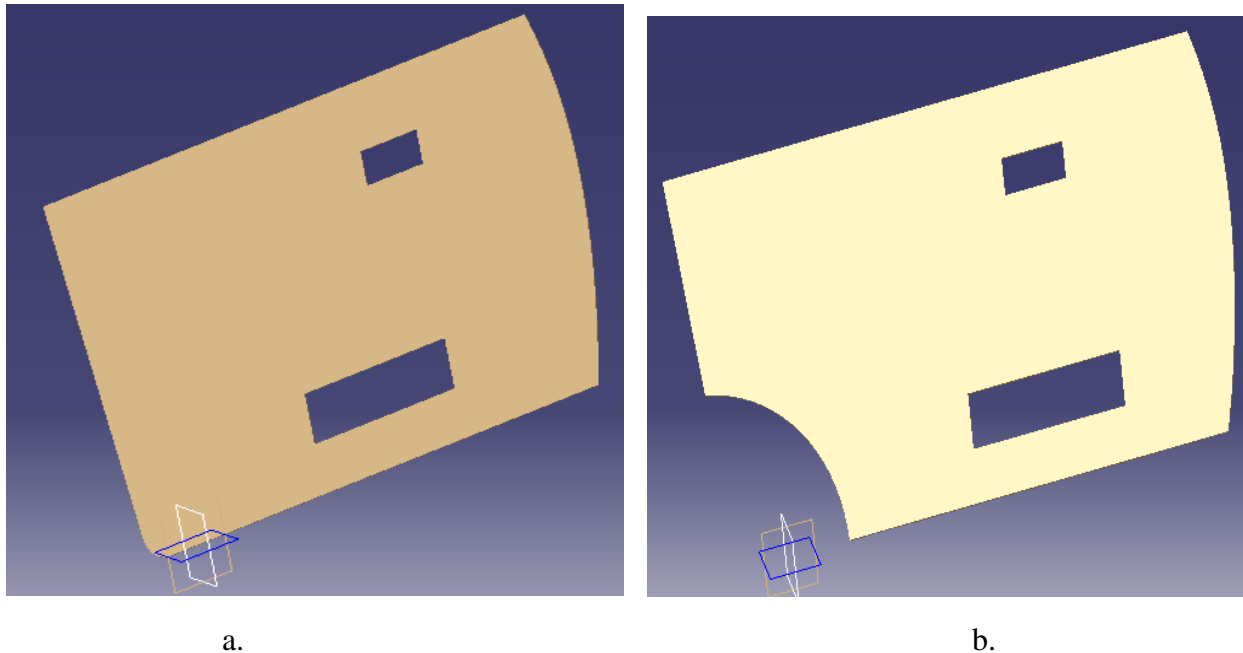


Fig. 3.3: The 3D modeling of the internal door panel; *a. front left door panel; b. rear left door panel*

3.2.2. Mathematical modeling

The mathematical modeling is a crucial task to understand or predict the real situation of the designed components. In this case different loads or stresses which would be applied on the internal door panel could be considered.

According to the literature the main common mechanical stress, which affects the life of the door panels, is the shock produced by closing the door. In this case the internal door panel is loaded with an acceleration field resulting from inertia forces due to its own weight [2].

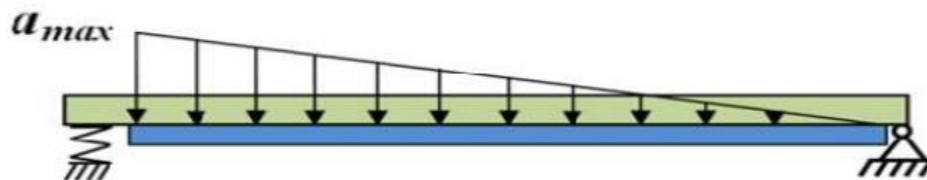


Fig. 3.4: Acceleration field resulting from inertia forces due to its own weight

According to Newton's law of inertia, the generalized inertia load is equivalent to the acceleration multiplied by mass (inertia). Thus, the inertia load distribution has a transient (time dependent) characteristics.

are then globally assembled through their common nodes into an overall system matrix. Applied loads and boundary conditions are then specified and through matrix operations the values of all unknown displacement degrees of freedom are determined. Once this is done, it is a simple matter to use these displacements to determine strains and stresses through the constitutive equations of elasticity.[33]

An establishment of appropriate finite element model for an actual practical problem depends to a large degree on the understanding of the physical problem including a qualitative knowledge of the structural response to be predicted, the knowledge of the basic principles of mechanics and the good understanding of the finite element procedures available for analysis. [33]

Discretization of the domain into finite elements is the first step in the finite element method. This is equivalent to replacing the domain having an infinite number of degrees of freedom by a system having finite number of degrees of freedom. The shape, size, number and configuration of elements have to be chosen carefully so that the original body or domain is simulated as closely as possible without increasing the computational effort needed for the solution. [33]

Before meshing of the body it is necessary to add the material properties, external loads, and apply the boundary conditions. In order to start of the problem, only parameters of the calculation regime should be added to the input file.

Assumptions

It is known that automotive components are geometrically complex; consequently, some assumptions and approximations need to be made in order to make the simulation more practical. Thus; we can consider the following assumptions for the entire FEM analysis.

- The whole parts of the internal door panel have uniform element and material properties throughout the model.
- The modeling and the analysis is done only for the left internal door panel, (both for the front and rear door panels).
- Since the inertial effects are a significant factor, transient structural analyses are needed to evaluate the response of the panel structure to the applied loads and boundary conditions.

3.3. Methods of Finite Element Analysis

The establishment of the finite element model and the finite element analysis of this thesis work were conducted through the software package, ANSYS. ANSYS is a combined interactive/batch type computer –aided design software package, which contains many mechanical analysis programs developed, commercialized and marked by ANSYS.inc. ANSYS is the name commonly used for ANSYS mechanical, general-purpose finite element analysis (FEA) computer aided engineering software tools. ANSYS mechanical is a self-contained analysis tool incorporating pre-processing such as creation of geometry and meshing, solver and post processing modules in a unified graphical user interface. ANSYS is a general-purpose FEM package for numerically solving a wide variety of engineering problems. [34, 35].

In general, a finite element solution may be broken into the following three stages. This is a general guideline that can be used for setting up any finite element analysis. [35, 36]

Preprocessing: it is about defining the problem which will be analysed by FEM. The element type, material/geometric properties and Meshing are also defined under this section.

Solution: in this section assigning loads, constraints and solving the resulting set of equations the given problem are performed.

Post processing: further processing and viewing of the results; in this stage one may wish to see nodal displacements, Element forces and moments, Deflection plots, Stress contour diagrams.

Dynamic structural Analysis

Transient dynamic analysis (sometimes called time-history analysis) is a technique used to determine the dynamic response of a structure under the action of any general time-dependent loads. One can use this type of analysis to determine the time-varying displacements, strains, stresses, and forces in a structure as it responds to any combination of static, transient, and harmonic loads. The time scale of the loading is such that the inertia or damping effects are considered to be important. Transient structural analyses are needed to evaluate the response of deformable bodies when inertial effects become significant. If inertial and damping effects can be ignored, consider performing a linear or nonlinear static analysis instead. On the other hand, if the loading is purely sinusoidal and the response is linear, a harmonic response analysis is more

efficient. In all other cases, transient structural analyses should be used, as it is the most general type of dynamic structural analysis. [41]

The following steps are used in the solution procedure using ANSYS Workbench software for transient structural Finite Element Analysis of a mechanical problem. [37]

1. The geometry of the panel to be analyzed is imported from modeling software to the ANSYS Workbench in an acceptable format.
2. The material type and its properties are specified.
3. Meshing the imported panel model.
4. The boundary conditions and external loads are applied.
5. The solution is generated based on these input parameters.
6. Finally, the solution can be displayed.

Importing the model geometry

The mechanical geometry model of the panel is done by CATIA V5 R20 modeling software. For the finite element analysis, it should be imported to the ANSYS Workbench 15.0 in an IGES format which is compatible with the ANSYS software package.

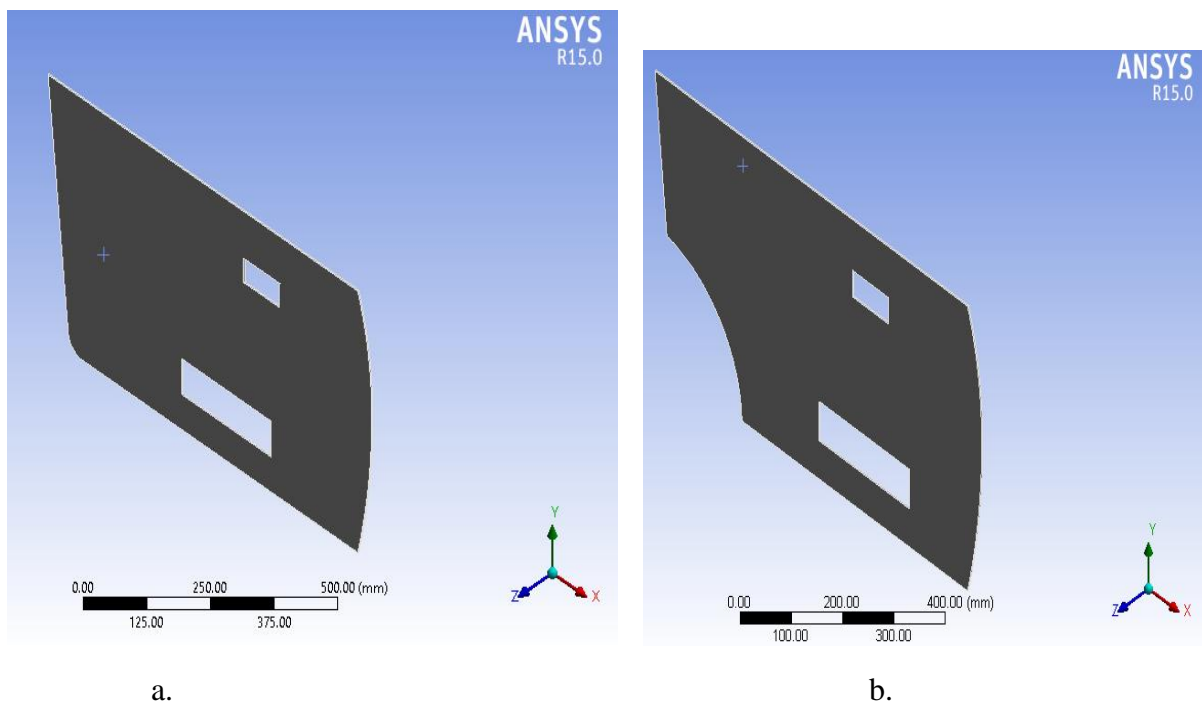


Fig. 3.5: Imported 3D model from CATIA V-5 R-20 to ANSYS Workbench 15.0; *a. front left door panel; b. rear left door panel*

Input the material type and properties

The material type and its properties such as density, strength, Young's modulus shear modulus and Poisson's ratio are specified under the project model geometry system. The material applied for this purpose is bamboo fiber reinforced epoxy composite (BFREC) material. The engineering data helps to input the mechanical properties of the material (Bamboo fiber reinforced Epoxy composite). The material properties can be altered or edited in this system.

The important material properties are taken from the experimental investigations of previously conducted researches [19]. Since the fibers are short and randomly dispersed, the reinforcement composite will be almost isotropic. Whilst deformation of homogeneous, isotropic materials can be described relatively simply by using the Young's and Shear moduli. [13]

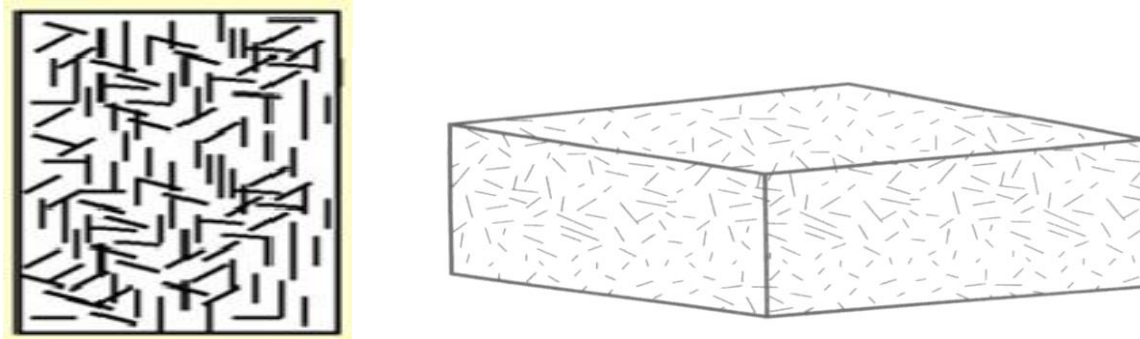


Fig. 3.6: Randomly dispersed short fibers composites materials [13]

The Cartesian strains resulting from a state of plane stress ($\sigma_z = \sigma_{xz} = \sigma_{yz} = 0$) are

$$\begin{aligned}\epsilon_x &= \frac{1}{E}(\sigma_x - \nu\sigma_y) \\ \epsilon_y &= \frac{1}{E}(\sigma_y - \nu\sigma_x) \\ \gamma_{xy} &= \frac{1}{G}\tau_{xy}\end{aligned}\quad (3.13)$$

Using matrix notation, these relations can be written as $\mathbf{1}/G$

$$\begin{pmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{pmatrix} = \begin{pmatrix} 1/E & -\nu/E & 0 \\ -\nu/E & 1/E & 0 \\ 0 & 0 & 1/G \end{pmatrix} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix}\quad (3.14)$$

In the above relations there are three elastic constants: the Young's modulus (E), Poisson's ratio (ν), and the shear modulus (G). However, for isotropic materials only two independent elastic constants are needed, and the third constant can be obtained from the relation of:

$$\nu = \frac{E}{2G} - 1 \quad (3.15)$$

The specific material property of the selected bamboo fiber reinforced epoxy composite material are stated in the table below.

Table: 3.1: mechanical properties of Bamboo fiber reinforced epoxy composite [19]

Material Property	Values
Density (ρ)	1.12 g/cm ³
Tensile Strength	187.73MPa
Flexural Strength	190.32MPa
Compressive Strength	114.13MPa
Shear Strength	81.18MPa
Young's Modulus	3852
Shear Modulus	1580

Table: 3.2: Workbench BFREC mechanical property specification

Properties of Outline Row 3: Bamboo Fiber Reinforced Epoxy Composite				
	A	B	C	E
1	Property	Value	Unit	<input checked="" type="checkbox"/> <input type="checkbox"/>
2	Density	1.12	g cm ⁻³	<input type="checkbox"/> <input type="checkbox"/>
3	Isotropic Elasticity			<input type="checkbox"/> <input checked="" type="checkbox"/>
4	Derive from	Shear Modulus and You...		
5	Young's Modulus	3852	MPa	<input type="checkbox"/>
6	Poisson's Ratio	0.21899		<input type="checkbox"/>
7	Bulk Modulus	2.2846E+09	Pa	<input type="checkbox"/>
8	Shear Modulus	1580	MPa	<input type="checkbox"/>
9	Tensile Ultimate Strength	187.73	MPa	<input type="checkbox"/> <input type="checkbox"/>
10	Compressive Ultimate Strength	114.13	MPa	<input type="checkbox"/> <input type="checkbox"/>

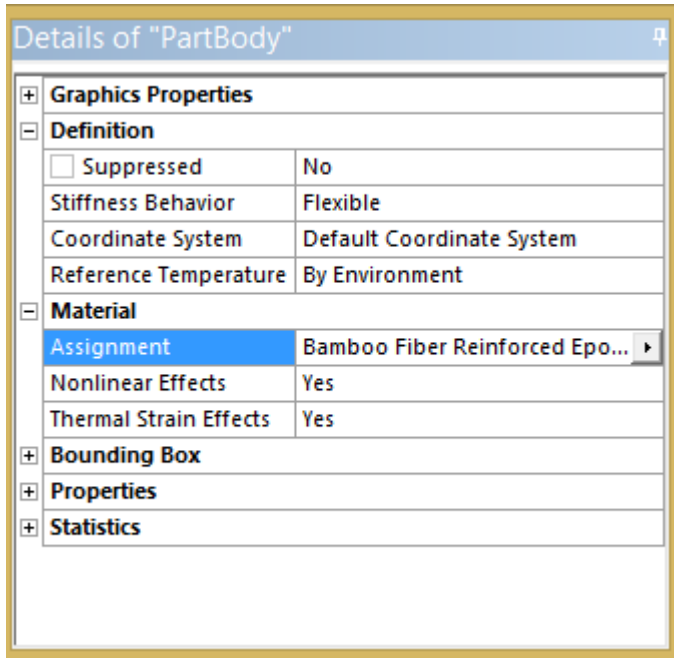


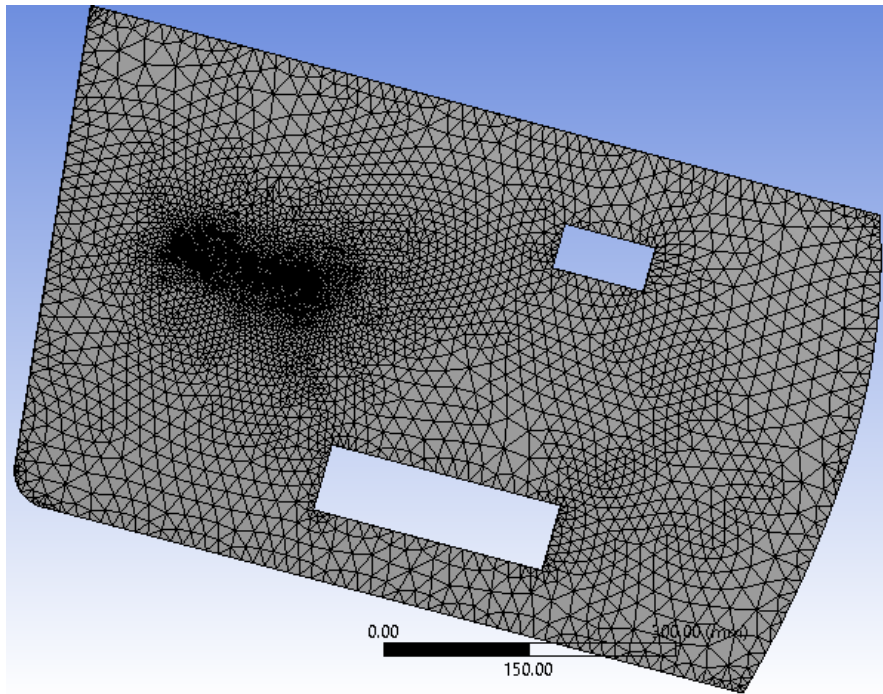
Fig. 3.7: Assignment of the material to the model on ANSYS workbench.

Meshing the imported 3D model.

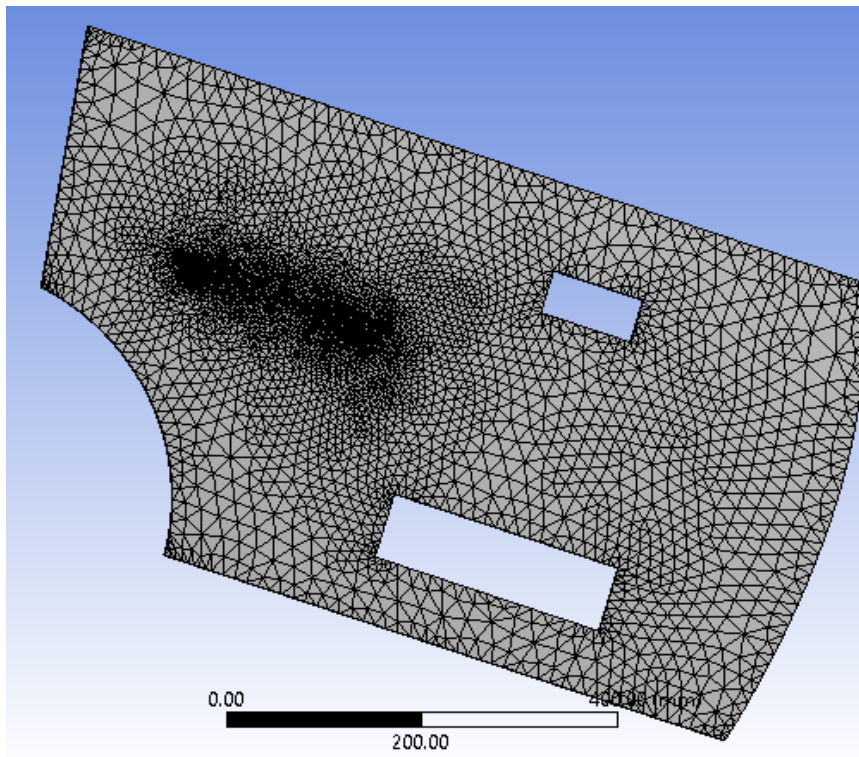
In the finite element analysis the basic concept is to analyze the structure which is an assembly of discrete pieces called elements which are connected together at a finite number of points called nodes. A network between these elements is known as meshing. This is the step that divides the complex geometry model into small elements that become solvable in an otherwise too complex situation. The meshing of the geometry under consideration may be generated directly, i.e., generation of nodes and elements, one at a time. Solid Modeling constitutes a part of the finite element analysis. Thus, the sole purpose of Solid Modeling is to create the mesh of the geometry, as conveniently and efficiently as possible. The meshing process can be performed only after the specification of element type. ANSYS offers several convenient options to assist in meshing. These include Automatic Meshing, Smart Sizing, and Mapped Meshing. [35]

One of the most powerful features of ANSYS is automatic mesh generation. ANSYS meshes the solid model entities up on execution of an "appropriate" single command. With automatic meshing, the user can still provide specific preferences for mesh density and shape. If no preferences are specified by the user, ANSYS uses the default preferences. [35]

In this specific research work, Meshing is done by using this automatic meshing generation method and the refinement is done, specifically for areas at which high stress concentrations will occur.



a.



b.

Fig. 3.8: Geometric Meshing of the model on ANSYS Workbench;
a. front left door panel; b. rear left door panel

The general mesh statistical data of the internal door panels after meshing of the imported models are summarized in the table below.

Table: 3.3: General statistics of meshing of the panel

	Front door	Rare door
Number of nodes	47136	41751
Number of elements	22785	20015

Application of boundary conditions and external loads

The next step of finite element analysis involves applying appropriate boundary conditions and the proper loading mechanism. There are two ways to apply the boundary conditions and loading to the model in ANSYS; either apply the conditions to the solid model (key point, lines and areas), or the conditions can be directly imposed on the nodes and elements. In this research work, the first approach is preferable; because if it is decided to change the meshing, there will not need to reapply the boundary conditions and the loads to the new finite element model. [36]

The internal door panel has several areas where constraints are applied as follows:

- Upper part rests on a metal door structure, thus blocking shifting on the y direction (U_2)
- In screw mounting areas shifting are blocked on all three directions (U_1 , U_2 and U_3)
- On clips systems panel mounting metal structure areas, shifting are blocked on all the three directions (U_1 , U_2 and U_3);

Where, U_1 , U_2 and U_3 are the displacements in x, y and z directions, respectively.

These boundary conditions and constraints can be applied on the imported model in ANSYS Workbench as shown in fig 3.9.

The main goal of a finite element analysis is to examine how a structure or component responds to certain loading conditions. Specifying the proper loading conditions is, therefore, a key step in the analysis. Loads can be applied on the model in a variety of ways in the ANSYS program. Also, with the help of load step options, one can control how the loads are actually used during solution.

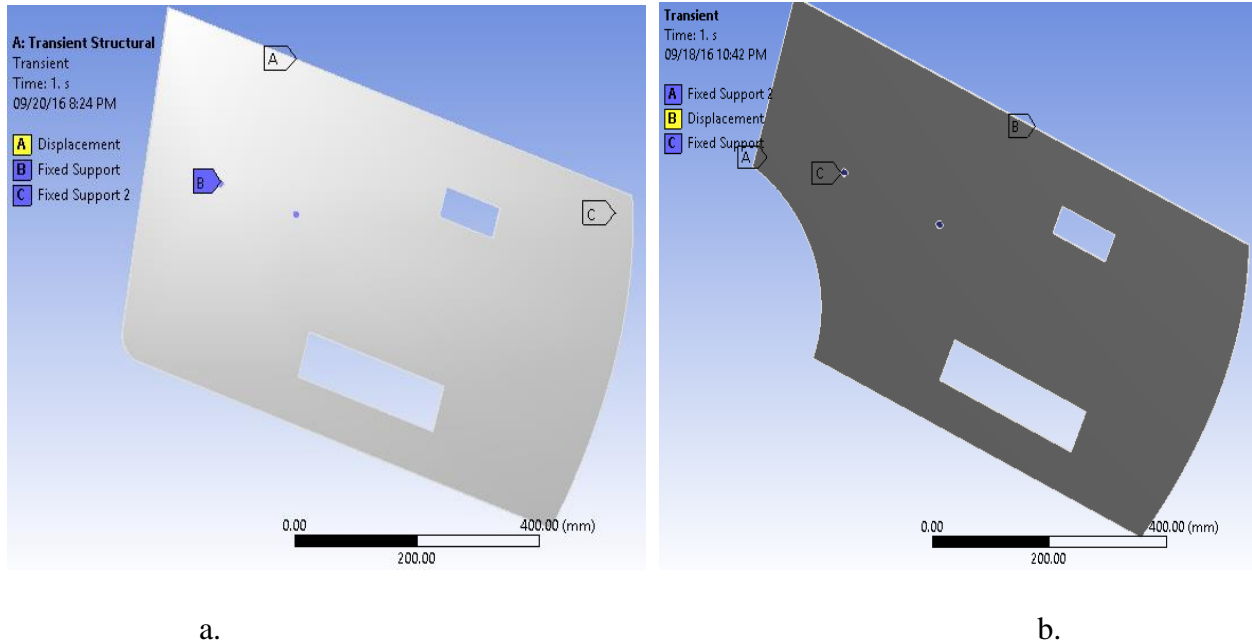


Fig. 3.9: Applying boundary conditions on ANSYS Workbench; *a. front left door panel; b. rear left door panel*

In this specific research, the load to be applied for the analysis purpose is the inertial load due to the acceleration field intensity during closing the door. According to the researches [2], the maximum acceleration value during closing the door is 350m/s^2 . Thus, this value is used for the analysis purpose in this research work.

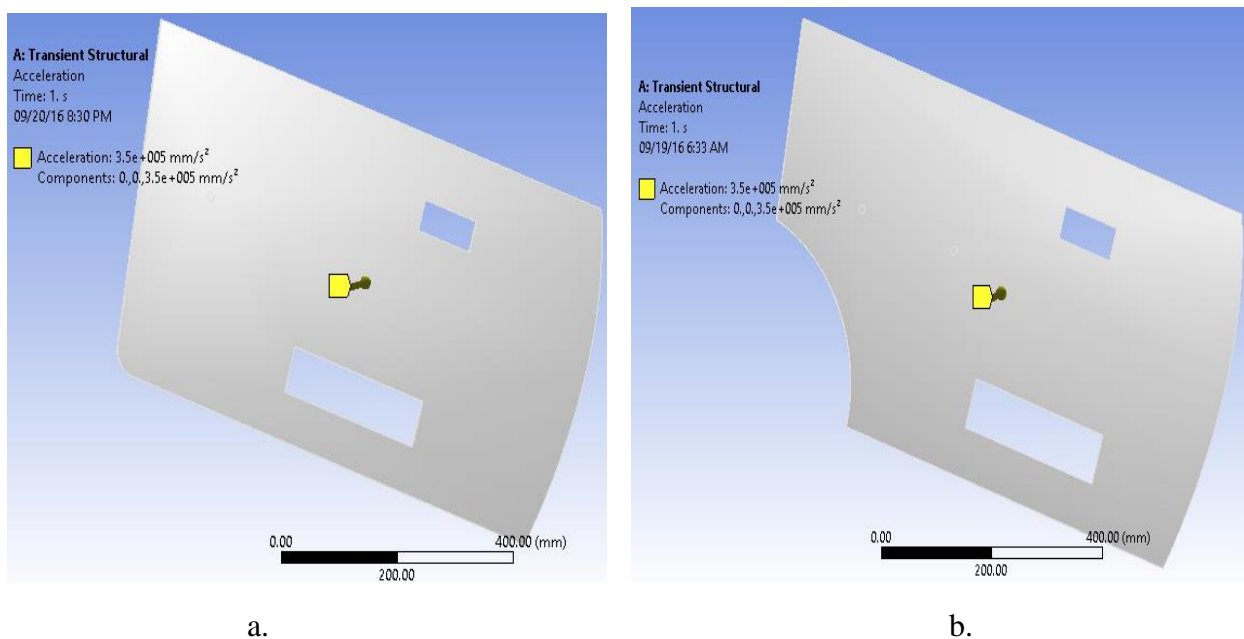


Fig. 3.10: Application of acceleration field due to inertial load on ANSYS Workbench; *a. front left door panel; b. rear left door panel*

Generate solutions

The solution is generated based on the above input parameters. The total deformation and the equivalent (Von Mises) stress are the basic variables to be solved by this software analysis.

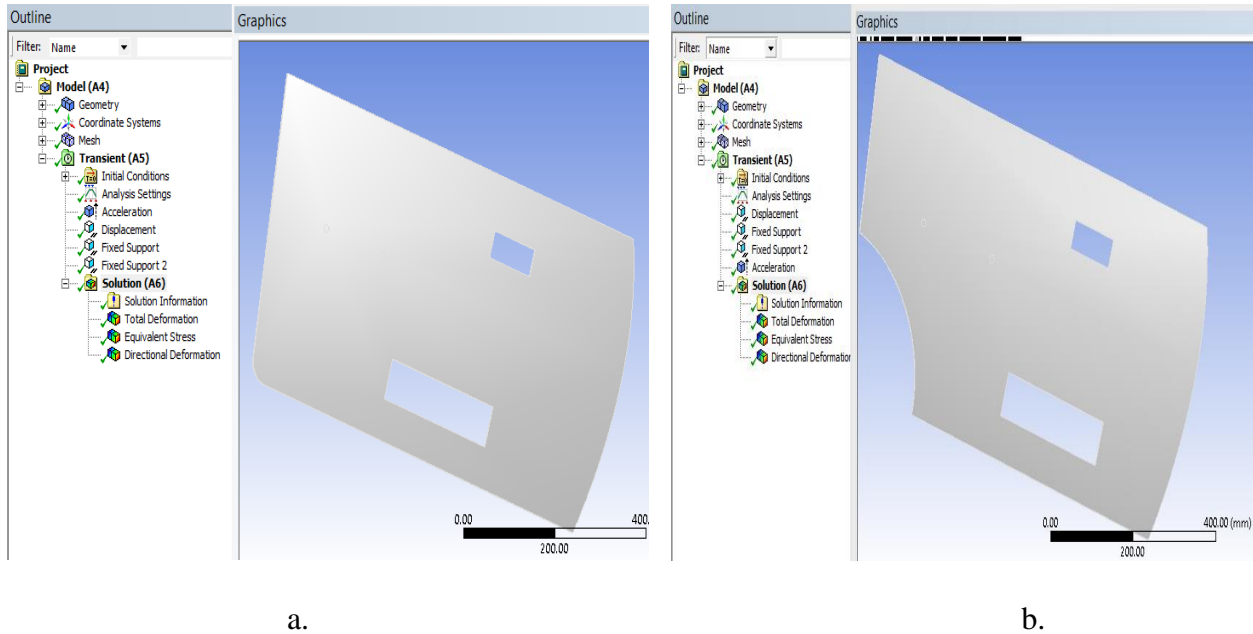


Fig. 3.11: Generating the solution; a. front left door panel; b. rear left door panel

Finally, the solution of each dependent parameter can be displayed one by one. Once the solution is generated, each dependent parameter is solved and ready to be seen and interpreted. This will be clearly discussed in the next chapter.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter describes results obtained from the transient structural dynamic analysis of the door panel during the present study. After completion of the transient structural dynamic analysis in ANSYS Workbench, results were reviewed by result report. Basically, the two significant types of results were recorded from this analysis of the imported model. The results are presented for both categories namely: equivalent stress (von Mises stress) and total displacement. The most important step of finite element analysis procedure is the physically realistic interpretation of the results by the analysis. Since finite element analysis procedures are invariably accompanied by an extensive output of data, it is extremely important that we interpret the results correctly.

4.1. Analysis

The panel model and analysis is performed using finite element method with the software ANSYS Workbench 15.0 that consist of a transient structural (ANSYS). This is for the purpose of getting the maximum and minimum equivalent stress and displacement on the structural model. The transient structural dynamic analysis determines characteristics of the stress and deformation of the structures (the panel) caused by the applied loading systems and boundary conditions. The following typical transient structural analysis system of Ansys Workbench 15.0 could be performed one by one to complete the analysis and get an appropriate solutions of the problem.

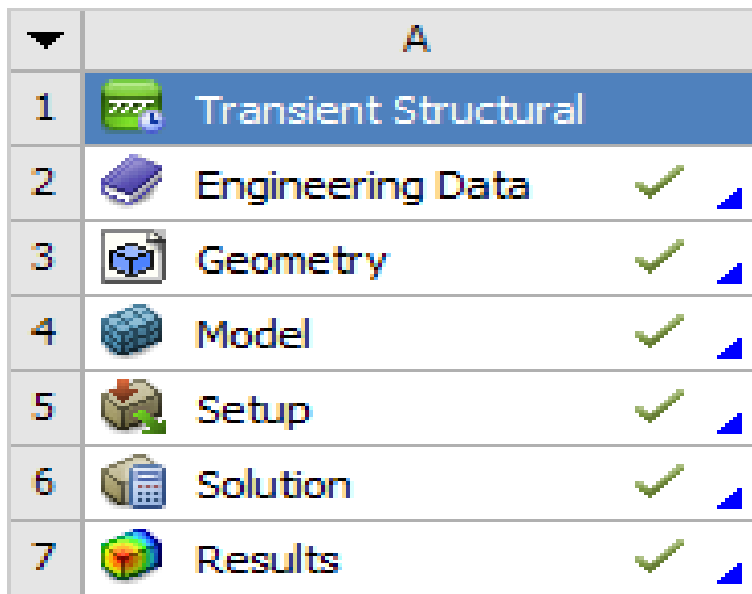


Fig. 4.1: ANSYS Workbench transient structural analysis system

4.2. Results

Equivalent (Von-Mises) stress

The equivalent (Von Mises) stress values of both the front and the rear internal door panels of FEA are shown in the following figures.

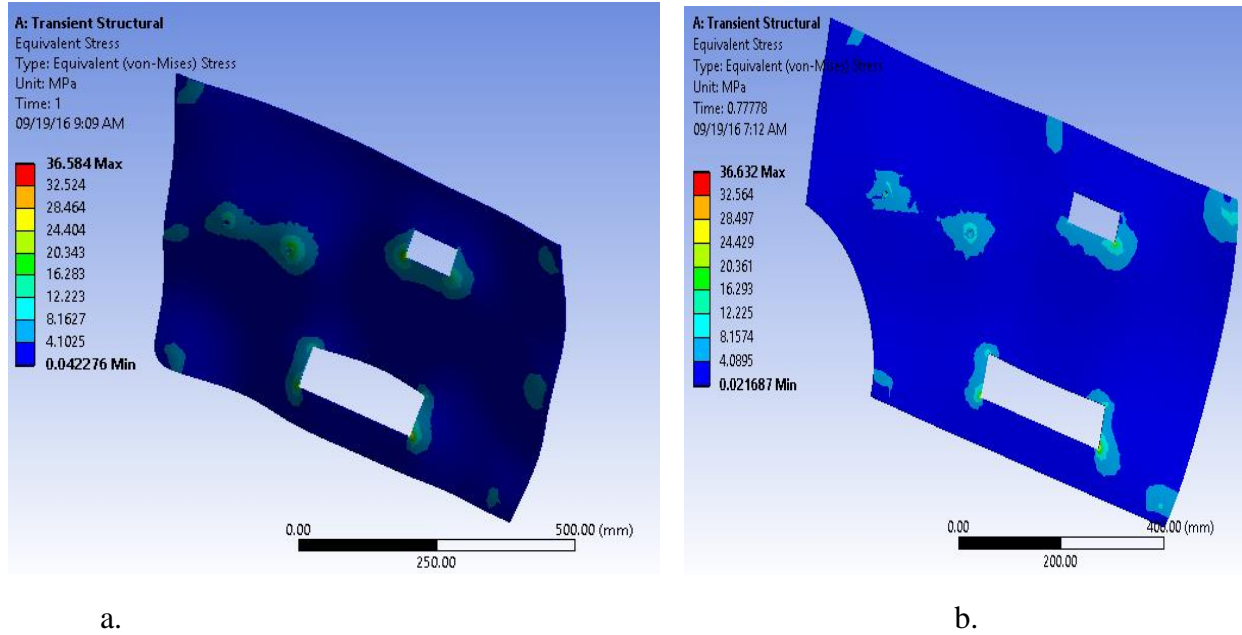


Fig. 4.2: Equivalent (Von Mises) stress; a. front left door, b. rear left door

Displacement

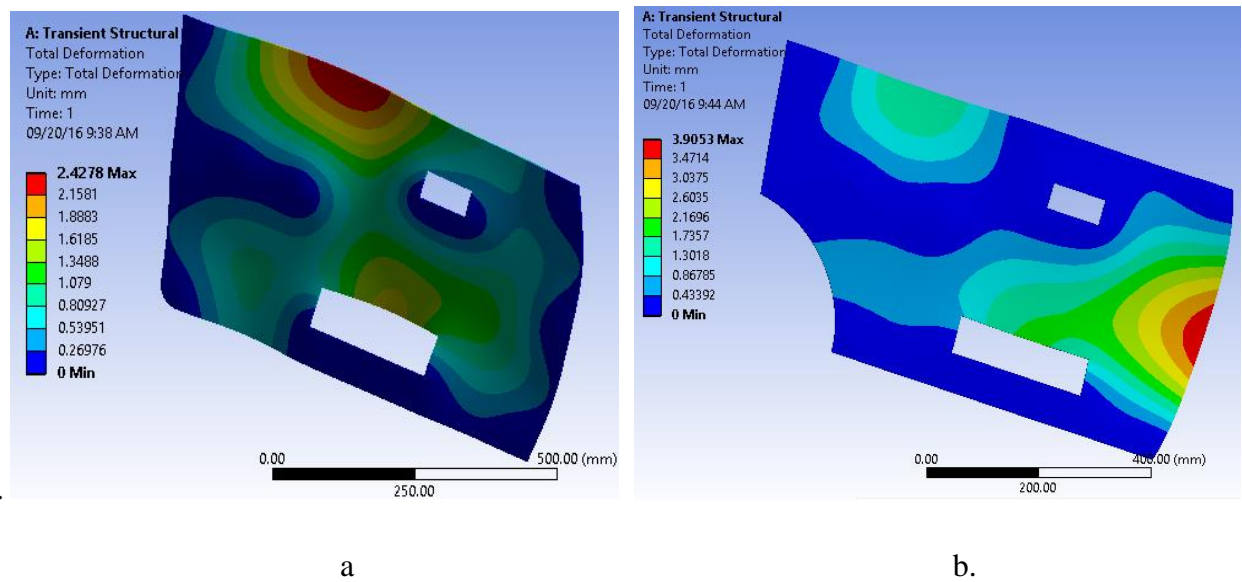


Fig. 4.3: Displacement; a. front left door, b. rear left door

4.3. Discussions

This transient structural dynamic analysis of the internal door panel of a vehicle using BFREC was performed for self-weight inertial load intensity of the shock produced while closing the door.

Comparing the results obtained by FEA of the bamboo fiber reinforced epoxy composite panel with the panels of other previously recommended materials (lignocellulosic composite and polypropylene plastic composite materials) is important to see the improved achievement.

In this specific research the comparison between the results of the FEA of these materials is carried out by making everything the same, except the material properties; i.e. at the same acceleration field, in the same model and the same method of FEM analysis. The results of the FEM analysis for the lignocellulosic composite and polypropylene materials are displayed in the appendix part of this specific research work document.

Stress

External loads applied to a structural model in equilibrium is reacted by internal forces set up within the material. Stress is defined as the average force per unit area that some particle of a body exerts on an adjacent particle, across an imaginary surface that separates them. [32]

Equivalent (Von-Mises) stress

Equivalent (Von Mises) stress, which arises from distortion energy failure theory, is widely used by designers to check whether their design will withstand a given load condition.

Using the ANSYS Workbench 15.0 software, along with the given boundary conditions and applied loads we got a value for this load, the values equivalent (von-Mises) stress. Then the maximum equivalent (Von-Mises) stress values are noted (See Table 4.1).

The results of this analysis shows that the equivalent (Von-Mises) stress of the BFREC panel is the smallest one as compared to that of the lignocellulosic composite and polypropylene panels under the same applied load and boundary conditions. This implies that BFREC material is less stressed and thus, has a better performance.

Displacement

According to the literature [2], the same structural analysis was done from two types of structural materials, lignocellulosic composite moulded panel and plastic moulded panel. And displacements of lignocellulose materials internal door panel obtained by FEM for an acceleration field of 350 m/s^2 , are smaller by 43% than those of polypropylene panel. The paper also concluded that the mass of the internal door panel was decreasing from 1.81kg to 1.49kg by using the lignocellulosic composite material instead of polypropylene plastic one. [2]

This analysis shows that, the maximum displacements of the bamboo fiber reinforced epoxy composite panel has the lowest value. It is lower by about 34% than the lignocellulosic composite panel and 50% of the polypropylene panel. This values displacements decrease is due to the greater rigidity of bamboo fiber reinforced epoxy composite material. (See the Appendix)

Moreover, the mass of bamboo fiber reinforced epoxy composite panel is reduced by 6% and 8% than that of lignocellulosic composite and polypropylene materials respectively.

The smaller mass of the bamboo fiber reinforced epoxy composite panel helps to make the vehicle lightweight, so that the efficiency and fuel economy of the vehicle is improved by reducing its dead weight.

Table 4.1: Comparing the FEA results of the panel of different materials at an acceleration of 350 m/s^2

<i>Internal door panel</i>	<i>Equivalent Stress (MPa)</i>		<i>Maximum Displacement (mm)</i>		<i>Mass(kg)</i>	
	<i>Front</i>	<i>Rear</i>	<i>Front</i>	<i>Rear</i>	<i>Front</i>	<i>Rear</i>
Polypropylene panel	44.13	46.31	4.80	7.35	1.45	1.29
Lignocellulosic composite	42.23	44.93	3.66	5.90	1.42	1.27
BFREC panel	36.58	36.63	2.43	3.91	1.34	1.20

The charts plotted below will show the comparisons of these values clearly for both front and rear door panels. The results are the values obtained at an acceleration field of 350 m/s^2 applied on the panel.

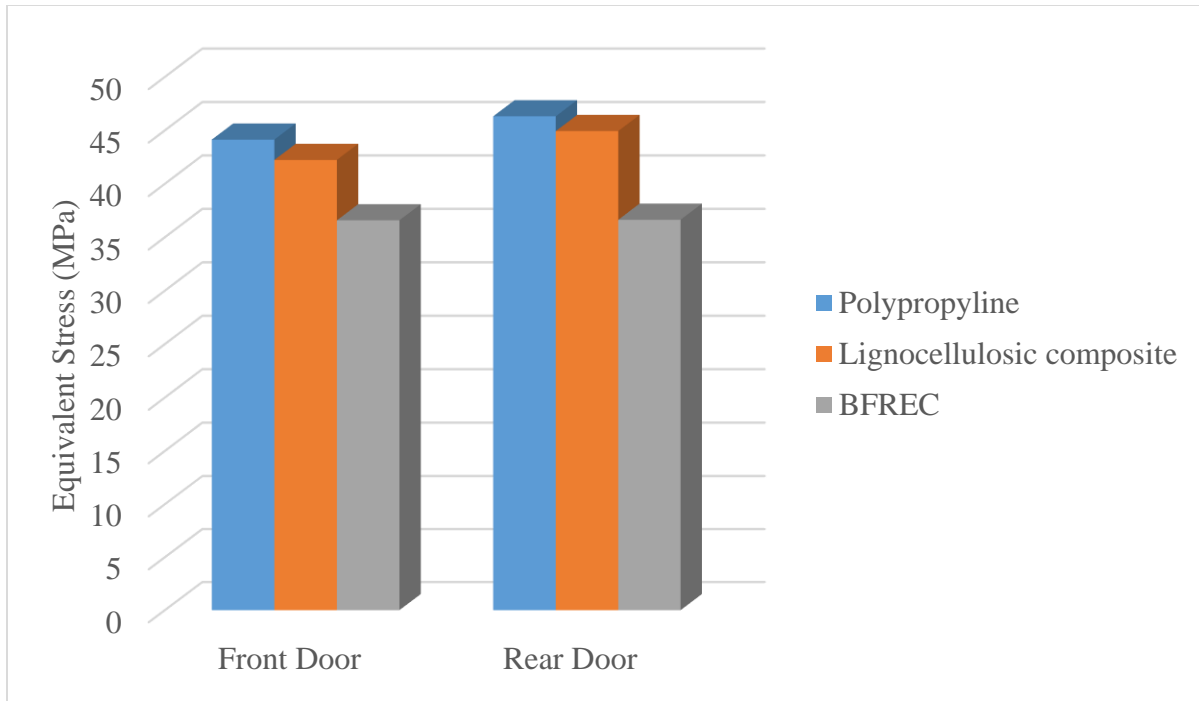


Fig. 4.4: Comparison of equivalent stress of a panel of different materials

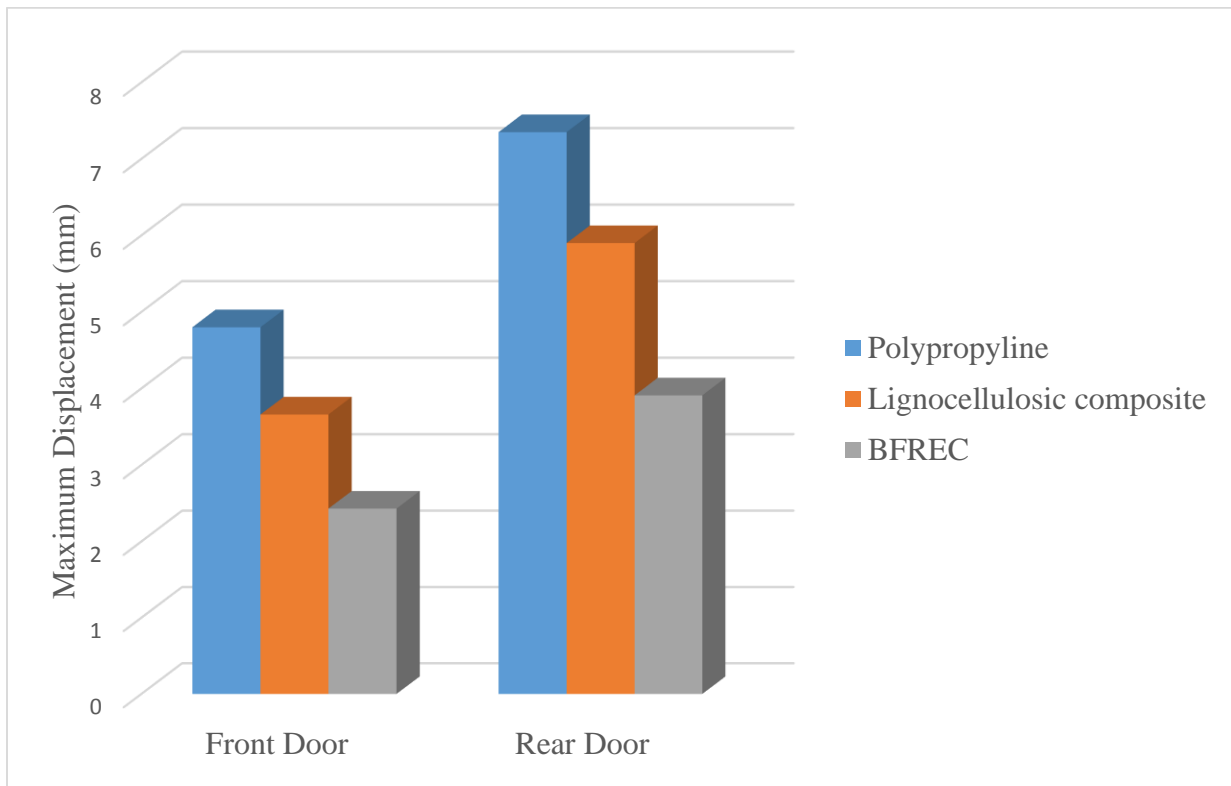


Fig. 4.5: Comparison of displacements of a panel of different materials

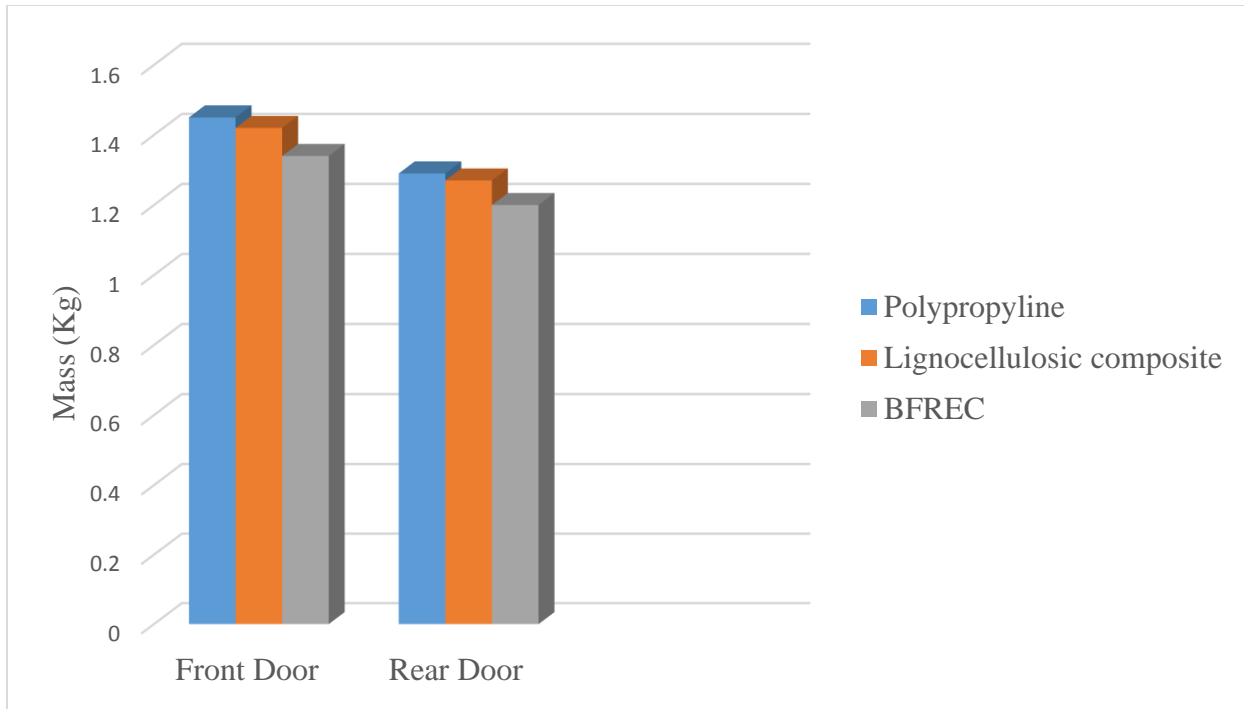


Fig. 4.6: Comparison of weight of the panel of different materials

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The finite element analysis (FEA) is a powerful computational tool for analyzing complicated structures like doors. It can reduce prototype parts' producing and the number of physical tests to shorten the development cycle and reduce the development investment; i.e., it saves much time, effort and costs.

In order to achieve the goal of this study, different tasks were performed and the following conclusions are drawn.

- ✓ The transient structural dynamic analysis of the modeled panels were performed by ANSYS Workbench 15.0 analysis software.
- ✓ Under the same applied load and boundary conditions, the smallest equivalent (Von-Mises) stress is recorded on BFREC panel as compared to the lignocellulosic composite and polypropylene panels. Thus, BFREC panel performs in a better way at a given loading condition.
- ✓ Displacements of BFREC materials internal door panel obtained by FEA are smaller by 34% and 50% than that of the lignocellulosic composite and polypropylene plastic materials respectively.
- ✓ Small values of displacements resulting for BFREC component are due to the high rigidity and also low weight material component given its lower thickness of the panel.
- ✓ Moreover, the mass of the newly modeled panel is reduced by 6% and 8% than that of lignocellulosic composite and polypropylene materials respectively.

5.2. Recommendation

The properties of composite materials, like high specific strength and high specific stiffness are attractive for the construction of lightweight, fuel efficient and environmental friendly vehicle structures. The energy absorption capability of the composite materials in general offers a unique combination of reduced weight and improves failure of the vehicle structures. The fuel efficiency of the vehicle directly depends on the total weight of the vehicle.

The FEA result obtained from ANSYS Workbench 15.0 of this study shows that BFREC has much better performance than the lignocellulosic composite and polypropylene materials. Moreover, the weight of the panel is reduced in a very much amount; this intern reduces the overall dead weight of the vehicle. Thus, applying the results of this research work will improve the efficiency and the fuel economy of the vehicle.

Finally, it is recommended that bamboo fiber reinforced with epoxy composite materials are suitable for internal structural automotive door panel applications.

5.3. Future Work

From different aspects, working on natural composite materials have several advantages. From this point of views, regarding BFREC several things can be made and improved in the future in which this study didn't address.

Therefore; the following research areas are recommended for future studies.

- Applying of BFREC on other internal parts of the vehicle such as, Dashboards.
- Structural analysis optimization of the door panels
- Repeat the analysis by using other forms bamboo fiber composite to increase its performance.
- Do the analysis by assessing other cause of failure of the door panel, such as side impact crash

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APPENDIX

A. Mechanical Properties of Materials

Table A-1: Material properties of Lignocellulosic composite and polypropylene material [2]

Materials	Density (ρ) [g/cm ³]	Young's Modulus (E) [MPa]	Poisson's ratio (ν)
Lignocellulosic composite	1.19	3041	0.37
Polypropylene material	1.21	1300	0.35

Table A-2: Workbench Lignocellulosic composite mechanical property specification;
a. Lignocellulos, b. polypropylene

Properties of Outline Row 5: Lignocellulosic Composite

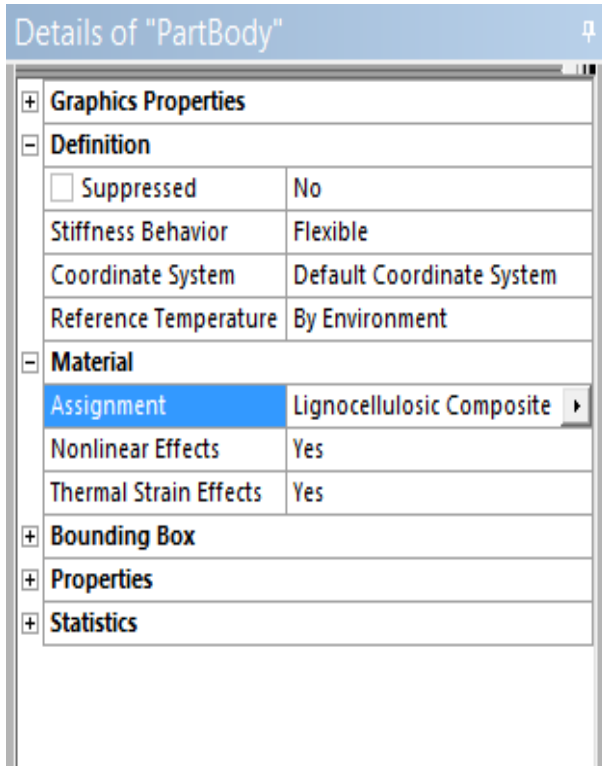
	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1.19	g cm ⁻³		
3	Isotropic Elasticity				
4	Derive from	Young's Modulus and P...			
5	Young's Modulus	3041	MPa		
6	Poisson's Ratio	0.37			
7	Bulk Modulus	3.8987E+09	Pa		
8	Shear Modulus	1.1099E+09	Pa		

a.

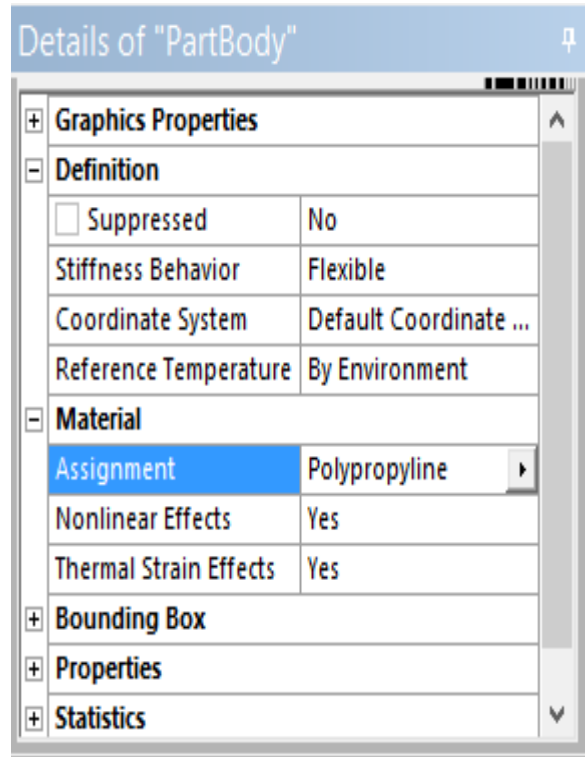
Properties of Outline Row 6: Polypropylene

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1.21	g cm ⁻³		
3	Isotropic Elasticity				
4	Derive from	Young's Modulus and P...			
5	Young's Modulus	1300	MPa		
6	Poisson's Ratio	0.35			
7	Bulk Modulus	1.4444E+09	Pa		
8	Shear Modulus	4.8148E+08	Pa		

b.



a.



b.

Fig. A-1 Assignment of the material to the model on ANSYS workbench;
a. Lignocellulos, b. polypropylene

B. FEA results of lignocellulosic composite and polypropylene panels

Equivalent (Von-Mises) stress

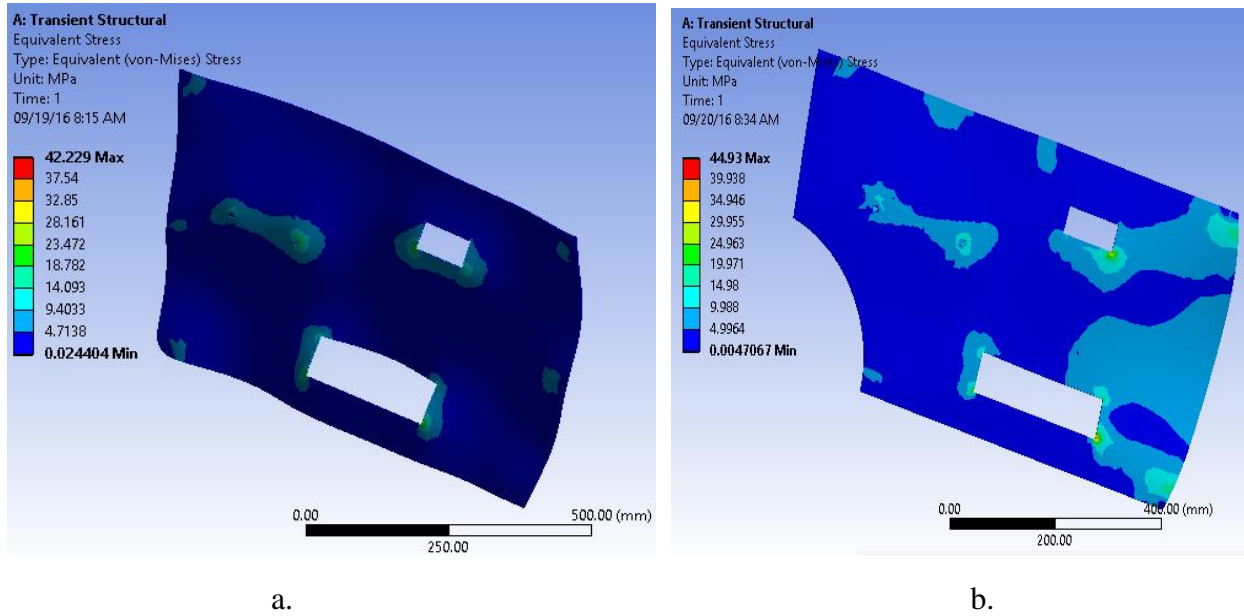


Fig. A-2: Equivalent Stress of lignocellulosic composite panel; a. Front left door, b. rear left door

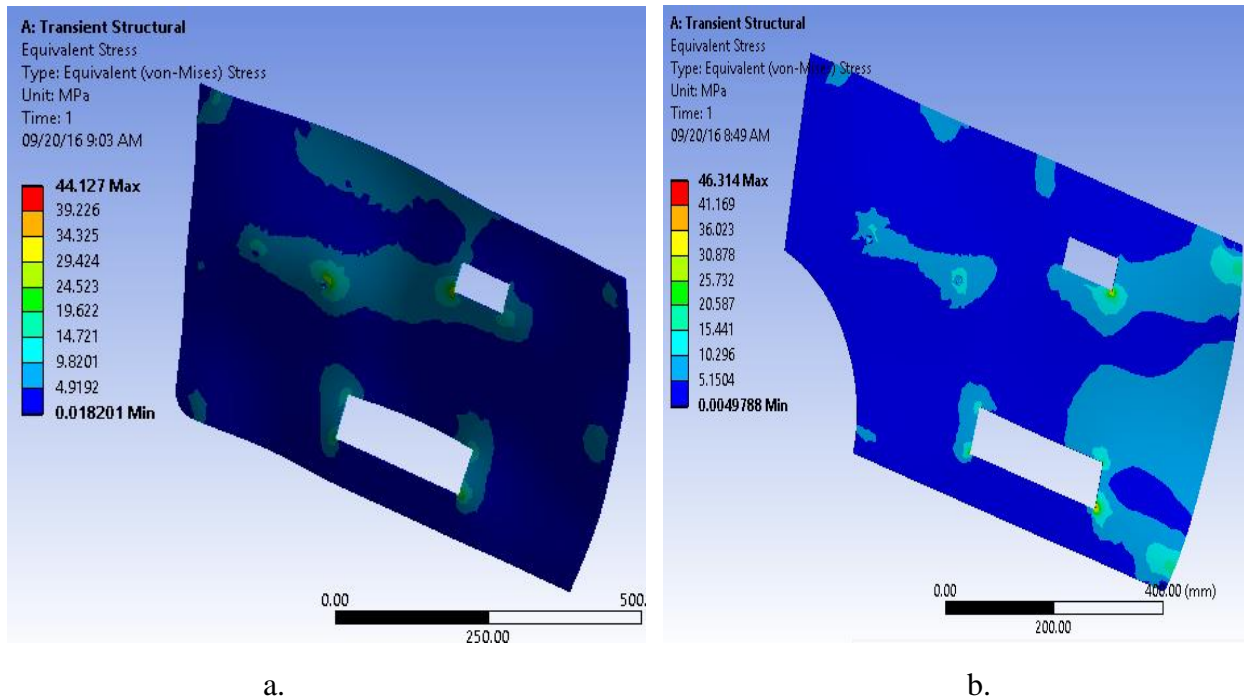


Fig. A-3: Equivalent Stress of polypropylene composite panel; a. Front left door, b. rear left door

Total Displacement

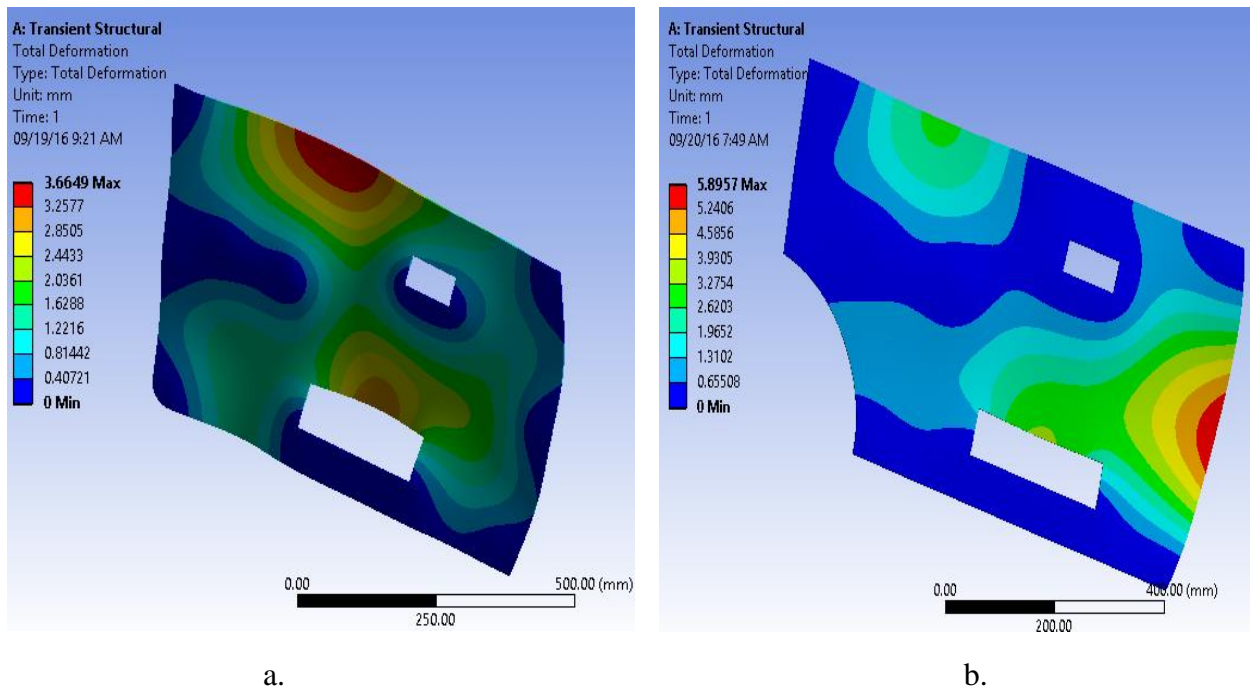


Fig. A-4: Total displacement of lignocellulosic composite panel; a. Front door, b. rear door

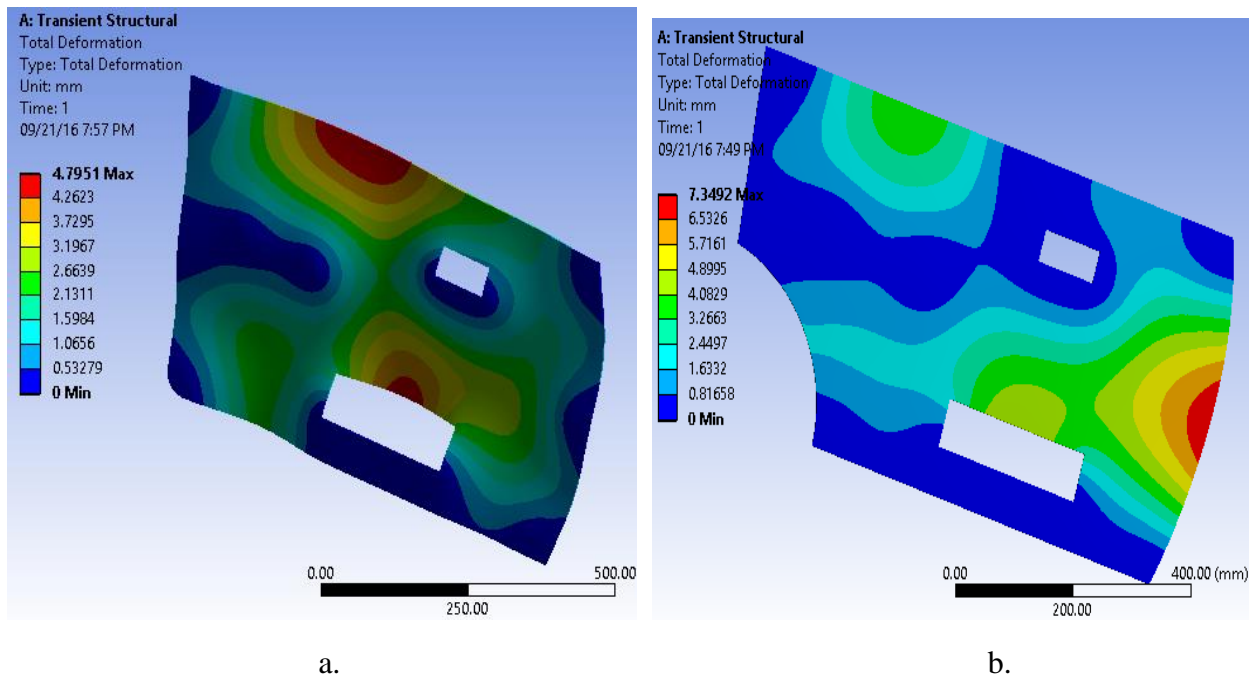


Fig. A-5: Total displacement of polypropylene plastic composite panel; a. Front door, b. rear door