ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

DEVELOPMENT AND CHARACTERIZATION OF MECHANICAL PROPERTIES OF AL6063 ALLOY REINFORCED FLY ASH AND E-GLASS FIBER COMPOSITE

A Thesis Submitted to The Graduate School of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Mechanical Engineering (Manufacturing Engineering)

By: Abebayehu Mulugeta

Advisor: Mesfin Gizaw (PhD)
Co-advisor: Mr. Gezae Abera

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DECLARATION

I hereby declare that this thesis entitled **“Development and Characterization of Mechanical Properties of Al6063 Alloy Reinforced Fly ash and E-Glass Fiber Composite’’** is my original work, with the guidance of my advisors, and that it has not been submitted in whole or in part for a degree in any university/institution and that all resources of materials used for this thesis have been duly acknowledged and a list of references is given.

Abebayehu Mulugeta	________________	________________
Author	Signature	Date
Dr. Mesfin Gizaw	________________	________________
Thesis Advisor	Signature	Date
Mr. Gezae Abera	________________	________________
Thesis Co-Advisor	Signature	Date

APPROVAL PAGE

Addis Ababa University
Addis Ababa Institute Of Technology

School Of Mechanical And Industrial Engineering

This is to certify that the thesis is prepared by **Abebayehu Mulugeta,** entitled: ***Development and Characterization of Mechanical Properties of Al6063 Alloy Reinforced Fly ash and E-Glass Fiber Composite*** and submitted as partial fulfillment for the award of the Degree of Master of Science in Mechanical Engineering (Manufacturing Engineering) complies with the regulations of the university and meets the accepted standards concerning originality, content, and quality.

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Dr. Desalegn Wogaso ________________ ________________

Internal Examiner Signature Date

Dr. Getasew ________________ ________________

External Examiner Signature Date

Dr.Yilma Tadesse ________________ ________________

Dean of SMIE Signature Date

Dr. Ermiyas Tesfaye ________________ ________________

Director of Post Graduate Signature Date

ABSTRACT

Currently, one of the key concerns in automotive engineering is the weight minimization of a part without any reduction in load carrying capacity and stiffness. The present investigation deals with investigating the hardness, compression, and flexural properties of **Al6063/ E-glass fiber/ Fly ash Composite** as a possible replacement to the existing steel outer door panel of the Toyota Hiace four-wheel vehicle. In this study ten composite specimens were prepared as per ASTM standards size by machining operations to conduct flexural, hardness, and compression tests. Comparing the ten composites the result showed the composite with **7% of E-Glass fiber/ 6% fly ash** had the maximum mechanical property of hardness and compression strength with the value of 116.73HRB and 850.31MPa respectively. And maximum flexural strength was found with composite **5% of E-Glass fiber/ 9% fly ash** with the value of 340.1MPa. In this study, a volume fraction of **5% E-Glass fiber with 9% Fly ash** was selected as a composite for the outer door panel because for all mechanical properties listed above it shows a better result. Then this paper effort to attain, designing less deformed and stressed than that of the existing Toyota Hiace vehicle steel outer door panel. The solid modeling of the outer door panel was done on SOLIDWORK 2017 and analyzed using ANSYSR18.1 workbench software. From transient structural analysis, it is seen that weight reduction of the outer door panel is obtained up 66.24% in the case of the composite than structural steel, and the equivalent stress-induced and deformation in the Al6063/E-Glass fiber/ fly ash composite outer door panel is 66.24 % and 26.3 % respectively less than the current steel outer door panel. Lastly, based on this result, the study concludes that the recently designed Al6063/E-Glass Fiber/ Fly ash composite outer door panel has a better presentation than that of the conventional steel outer door panel of the Toyota Hiace Van vehicle.

Keywords: AMMC, Al6063/Fly ash/E-Glass Fiber, Stir casting, FEA.

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LIST OF ABBREVIATIONS AND ACRONYMS

AMMCs	Aluminum Metal Matrix Composites
ASTM	America Society for Testing and Material
CAD	Computer-Aided Design
Eq.	Equation
FA	Fly ash
FEM	Finite Element Method
FEA	Finite Element Analysis
MMCs	Metal Matrix Composites
UTM	Universal Testing Machine
W_c	Weight of Composite (g)
ρ_c	Density of Composite(g/cm^3)
V_m or V_C	Volume of Mold or Volume of Composite
$V'f$	Volume Fraction of Fiber (cm^3)
$V'm$	Volume Matrix of Matrix (cm^3)
Wf	Weight of Fiber (g)
W_m	Weight of Matrix (g)
ρ_m	Density of Matrix(g/cm^3)
ρ_f	Density of Fiber (g/cm^3)
vf	Volume of Fibers, (cm^3)
$V'\ f$	Volume Fraction Fibers
$V'\ m$	Volume Fraction Matrix
σ	Stress (MPa)
ε	Strain (mm/mm)

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CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Starting from the period when human civilization started with the stone age to the current time, this world is both dependent upon and limited by materials. Because of this fact, people across the globe are forced to travel from place to place to accomplish their daily activities within a given period using automobiles. Nowadays due to the high demand for conservation of the environment, weight reduction in automotive engineering applications is mandatory.

A door panel can be taken as one of the core constituents in automobile systems and it could be also a possible constituent for weight minimization in automobiles as it owns weight. In addition to that the main common mechanical stress, which affects the life of the door panels, is the shock produced by closing the door resulting from inertia forces due to its weight [1].

To address this problem recent efforts indicate that a wise material improvement and design are critical mechanisms. One of the approaches is selecting of better material or changing the existing material with a new one is the most known way of weight minimization [2].

Nowadays, metal matrix composite and different reinforcing particles have been used in certain parts of the vehicle and display a decrease in weight without the reduction of the strength. Among the metal matrix composite, aluminum metal matrix reinforced with different kinds of particles has been used as a composite [3], [6].

The application of aluminum metal matrix composite in automotive engineering could fulfill their constant power of economization of energy, preservation of natural sources. In addition to that, it diminishes the environmental effect of the automobiles as well as advances traveling quality by mainly saving some weight from the overall weight of the automotive. From this, various parts of the vehicle like the roof, floor, parts of the engine, and door panels are specific to the application parts of the AMMCs [7].

The automobile body panel comprises a double structure of an outer panel and an inner panel and each panel requires different material properties. Outer panels need higher strength materials for providing sufficient denting resistance while inner panels require materials with higher deep drawing capacity that allows for the manufacturing of more complex shapes [3].

Regarding this point, the foremost intention of this thesis is to investigate the properties of composite material prepared from fly ash and E-glass fiber as reinforcement material and Al6063 as a matrix. Finally, the result found from the experiment, will be replaced with the existing outer door panel. For these purposes, materials are being selected, composites are produced and mechanical properties are also studied. Based on the result obtained, the composite with better mechanical properties was selected. For the selected AMMC, outer door panel has been modeled with the aid of SOLIDWORK 2017 and by using ANSYSR18.1 workbench software finite element analysis (FEA) has been done.

1.2 MOTIVATION

Currently, Ethiopia is importing TOYOTA HIACE four-wheel vehicles its outer door panel is made from steel. But if the steel outer door panel is replaced by lightweight, inexpensive, and locally available materials, we can advance the vehicle performance and simultaneously save foreign currency for the imported one. Thus E-glass fiber and fly ash are abundant resources in Ethiopia and can be the appropriate material for the outer door panel parts of an automotive by reinforcing it with Al6063 alloy.

1.3 STATEMENT OF THE PROBLEM

Nowadays automotive industries are adapted to reducing the weight of the vehicle component by modifying or replacing the existing parts with new or better material. In this connection, currently, automotive industries are producing outer door panels of TOYOTA HIACE four-wheel vehicles from steel. Due to their density, these materials affect the life of the door panels, through increasing the mechanical stress while closing the door. In addition to that these materials affect fuel efficiency, maneuverability, acceleration and braking system of the vehicles. So, it is very essential to decrease the weight of the outer door panels of the vehicle to have a reduced vehicle response time for better control as well as the performance of a vehicle. Therefore, this thesis tries to study the mechanical properties of Al6063/E-glass fiber/fly ash composite with different fiber–matrix volume percentages. Based on the result attained, the composite with better mechanical properties will be selected to reduce the aforementioned problems and become an alternative material for outer door panel application.

1.4 OBJECTIVE

1.4.1 GENERAL OBJECTIVE

The general objective of this thesis is to fabricate Al6063/E-glass fiber/Fly ash composite specimens of different compositions, characterize their mechanical properties (Hardness, compression, and flexural strength). Then, based on the result obtained; the composite with better mechanical properties will be selected as an alternative material for outer door panel application.

1.4.2 SPECIFIC OBJECTIVE

- To fabricate Al6063 reinforced with fly ash and E-glass fiber.
- To evaluate the effect of wt% of reinforcement on the mechanical properties (compression strength, hardness, flexural strength).
- To compare the conventional Al6063 metal and the Al6063 composite.
- To simulate and analyze the suggested composite material for the outer door panels using ANSYSR18.1 software.
- To compare the suggested composite material with currently used material steel outer door panel using ANSYSR18.1 software.

1.5 SCOPE OF THE STUDY

This study conducted fabrication of Al6063/E-glass fiber/Fly ash composite. The study also involves experimental characterization of mechanical properties like flexural strength, compression strength, and hardness of the composite according to ASTM standards. Additionally, the study explored stress and displacement of the outer door panels using the finite element method for the selected application. Neverthless, the study is limited to only the 3D modeling and analysis of the outer door panel. The prototype of the outer door panel was not considered in this thesis.

1.6 SIGNIFICANCE OF THE STUDY

As this study is concerned with the investigation of the effect on Al6063 reinforced with E-glass fiber and fly ash for weight reduction of vehicles and less stressed outer door panel for TOYOTA HIACE four-wheel vehicles, the main significance of the study goes to automotive industries and academician researchers. Also, this study can be used as a reference to B and C Al6063 manufacturing PLC for fabricating additional products to automotive industries in addition to their main product besides it reduces Ethiopia hard currency that spends on importing automotive body parts from abroad and finally this study has the merit of recycling the wastage (FA) into the healthy product.

1.7 RESEARCH QUESTIONS

- What is the effect of different wt% of reinforcement on the mechanical properties (compression strength, hardness, flexural strength) when reinforced with Al6063 alloy?
- Which composition of Al6063/E-glass fiber/Fly ash composite from tested compositions has maximum mechanical property for the application of outer door panel?

1.8 LIMITATION OF THE STUDY

The study of Al6063/E-glass fiber/Fly ash composite material was not simple work. While conducting it there were many obstacles. The majors are few experimental setups not available like experimental setups for developing stir casting machines, unavailability of additive materials within our country for the casting process. Because of the unavailability of testing machines like friction test, only three mechanical properties of the composites are studied towards the use of Al6063/fly ash/E-glass fiber composite for automotive body application; it seems not to provide enough evidence of Al6063/E-glass fiber/Fly ash composite to use as outer door panels.

1.9 ORGANIZATION OF THE THESIS

This study presents how Aluminum Metal Matrix Composite (AMMC) materials can be used to develop outer door panels in automobile engineering through producing as well as mechanical property characterization of the composite. The manuscript is organized into five chapters:

Chapter 1: It is an introductory part, which contains an introduction for the main part of the study, statement of the problem, the objective of the study, scope and limitations and significance of the study, methodology.

Chapter 2: Reviewed all research related to this research such as definitions of composite material, its classifications, previous researches correlated to Al6063, FA and E-Glass fiber, and outer door panels.

Chapter 3: Focused on the detailed explanation of materials used in the study and the methodology followed during the research work. The modeling procedures, the steps, and the conditions of finite element analysis are also discussed in this chapter.

Chapter 4: Delivers the outcomes of both simulation and experimental studies. Meanwhile, it also gives a detailed discussion of the results and compares the experimental results.

Chapter 5: Comprises conclusions of the study as well as directions of future works.

CHAPTER TWO
LITERATURE REVIEW

2.1 COMPOSITE MATERIALS

Conventional monolithic materials have been confined in attaining a good combination of strength, stiffness, toughness, and ductility. To overwhelm these deficiencies and to meet the ever-increasing property demands, conventional monolithic materials are being replaced by the most promising candidate materials called composites. Composite material is a mixture of two or more macro constituents and distinct materials, having a recognizable interface between them and that is insoluble in each other. Constituents that are found in composite materials are the matrix phase and reinforcement phase. The reinforcement is added to the matrix to achieve the desired mechanical properties [4].

Composite should also have properties that are better than the properties of the individual constituents that make up the composites such as low specific gravity, superior strength, and modulus [5].

2.2 CLASSIFICATION OF COMPOSITES

One way of classifying composite is based on a matrix. Matrix has the function of binding the reinforcement constituent together and protecting the reinforcement from structural damage and chemical attacks [6], [7]. Based on matrix composite can be categorized in the following groups:

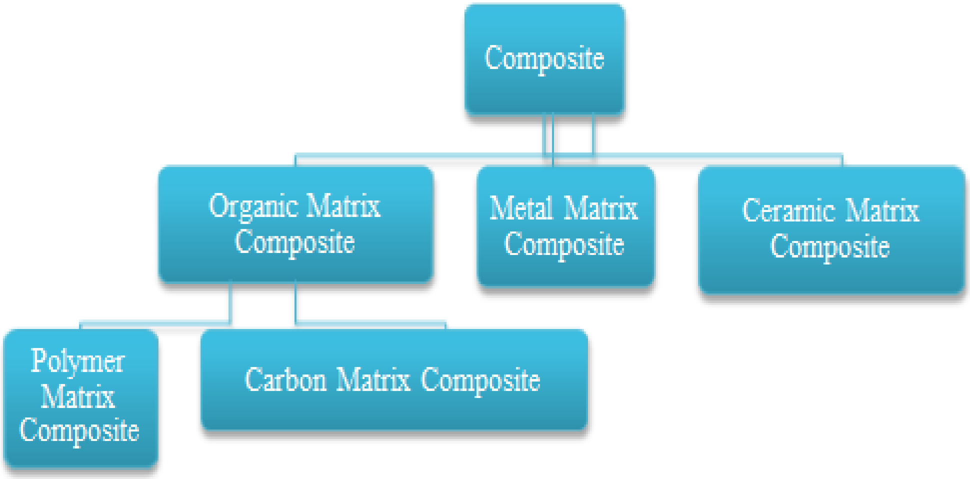


Figure 2. 1 Composite materials classification based on matrix [6].

2.2.1 METAL-MATRIX COMPOSITES (MMCS)

Metal matrix composite is one of the types of composite in which the matrix phase is a ductile metal or metal alloy which acts as a bonding element to transfer and distribute the load to the reinforcing materials. MMCs have an attractive combination of superior properties such as high strength, enhanced elevated temperature properties, wear resistance, high stiffness, high electrical and thermal conductivity greater resistance to corrosion, oxidation, and wear when compared to the base material [7]. Because of these attractive properties, MMCs are gaining wide popularity in several sectors, especially in applications where weight and strength are of prime importance like in space shuttles, commercial airliners, electronic substrates, bicycles, automobiles, and golf clubs [8].

The most commonly used metal matrix material are Zn, Fe, Al, Cu, Ni, Mg, Ti, and Pb but the most widely used are Al, Mg, and Ti are widely used. Mg and its alloys are the lightest materials for practical use as a matrix phase in MMCs which is around 35% lower than Aluminum. However, Mg alloys are not good competitors for Aluminum alloys in terms of absolute strength. The main reason for aluminum being better than magnesium is, due to the design flexibility, good wettability, and strong binding at the interface [9].

Aluminum alloys are the most using nonferrous materials which are selected in engineering applications as a matrix as it consists of desirable properties like high strength-to-weight ratio, controlled coefficient of thermal expansion, increased fatigue resistance, and superior dimensional stability at elevated temperatures [5]. Because of these attractive properties, AMMCs are gaining widespread acceptance for automobile, industrial, and aerospace applications.

2.2.2.1 CLASSIFICATION OF ALUMINUM

There is an extensive range of aluminum alloys and due to that; a classification method has been established for them. Depending on the processing operated to produce the material there are two main types of aluminum alloys [10].

i. Wrought alloys
ii.Cast alloys.

Wrought alloys are one classification of aluminum alloy that is manufactured by casting plus deformation it might be in the form of extrusion, forging, or rolling. Wrought alloys are favored for most load applicability structures in aerospace applications as they have advanced strength and damage tolerance. Numerous wrought aluminum alloys are accessible depending on alloy compositions, processing, and heat treatment. Due to that, wrought alloys have various designation systems than cast alloys.

Whereas cast alloys are prepared by casting and no deformation is applied on the material because of that they have limited strength and ductility. The main importance of cast aluminum alloys is that they can be used for the production of intricately shaped parts which are challenging to produce by wrought processing.

As it is designed by International Alloy Designation System, wrought aluminum alloys have a four-digit number and sometimes there can be a further letter and number to indicate temper and condition developed by the Aluminum Association. In Table 2.1 and 2.2, the designation system for wrought aluminum alloys and cast aluminum alloy is shown respectively.

The first digit mentions the main alloying element, the second digit refers to a modification of the original alloy or impurity limits and the last two digits refer to the specific aluminum alloy. For example, the 6xxx series alloys contain silicon and magnesium as main alloying elements and manganese and iron may as additional alloying elements.

Table 2.1 Aluminum alloy designation system for wrought alloys [11].

Four Digit Series Alloys	**Major Alloying Elements**	**Application Area**
1xxx series	99% Aluminum	Electrical and chemical industries.
2xxx series	Copper (most also contains Magnesium	Aircraft.
3xxx series	Manganese	Architectural applications and various products.
4xxx series	Silicon	Welding rods and brazing sheet.
5xxx series	Magnesium	Boat hulls, gangplanks, and other products are exposed to marine environments.
6xxx series	Magnesium and Silicon	Used for architectural extrusions and automotive components.
7xxx series	Zinc (most also contains Magnesium and Copper)	Used in aircraft structural components and other high-strength applications
8xxx series	Others including Li and Fe	

As shown in Table 2.2 the designation system for the cast aluminum alloys uses a three-digit system. The first digit denotes the major alloying element, and the second two refer to a specific composition. The zero after the decimal point shows casting and other numerals indicate ingots. For instance, 5xx.0 series alloys have magnesium, 3xx.x series alloys have silicon as the foremost alloying element with magnesium and/or copper as additional alloying elements.

Table 2. 2 Aluminum alloy designation system for cast alloys [11].

Three-digit series	**Major alloying elements**
1xx.0	99.00% minimum Al
2xx.0	Copper
3xx.0	Silicon with added Cu or Mg
4xx.0	Silicon
5xx.0	Magnesium
6xx.0	Unused
7xx.0	Zinc
8xx.0	Tin
9xx.0	Others

Aluminum alloy Al6063

From the enormous varieties of aluminum alloys, 6xxx are the ones containing silicon and magnesium as an alloying element. 6xxx series are usually used as medium strength structural alloys having the advantage of good weldability, corrosion resistance, and immunity to stress corrosion cracking [12]. Al6xxx series could be used in the automotive industry to make light load components, hydraulic, oil and fuel system components [13]. Among 6xxx series types of aluminum alloy that could be used as a matrix for the composites is the Al6063 alloy. Al6063 is the best common alloy used for aluminum extrusion [14]. It permits intricate shapes to be formed with very smooth surfaces fit for and it is common for visible architectural applications such as frames of doors and windows, roofs, and sign frames [15]. Al6063 has characteristics of good corrosion resistance, medium strength, high thermal conductivity, heat treatable, good weldability, lower melting point, low coefficient of thermal expansion, medium machinability, good wear resistance.

Table 2. 3 General Properties of Al6063 [16].

Characteristics	**Appraisal**
Strength	Medium
Corrosion Resistance	Good
Weldability	Good
Machinability	Fair
Workability	Good

Table 2. 4 Physical Properties of Al6063 [17].

Property	6063-T5		6063-T6		6063-T832	
Density	2.70g/cc	0.075lb/in^3	2.70g/cc	0.0975lb/in^3	2.70 g/cc	0.0975 lb/in^3

Table 2. 5 Mechanical Properties of Al6063 [18].

Property	6063-T5		6063-T6		6063-T832	
Tensile Strength	186 MPa	27000psi	241MPa	35000psi	290MPa	42000 psi
Yield Strength	145 MPa	21000psi	214MPa	31000psi	269 MPa	39000 psi
Modulus of Elasticity	68.9 GPa	10000psi	68.9 GPa	10000ksi	69.0 GPa	10000ksi

Another way of classifying composite materials is focusing on the type of reinforcement of the composite. Reinforcing materials afford strength, stiffness and support the structural load [6], [8]. Because of this, the selection of reinforcement is a critical issue to obtain the required finished product with desired properties. Based on reinforcement composite can be categorized in the following groups:

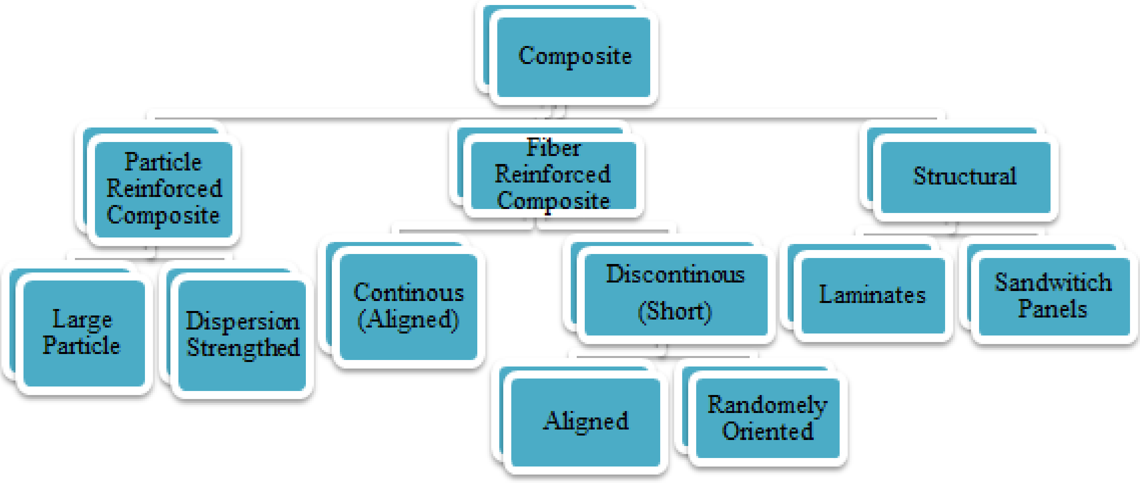


Figure 2. 2 Composite materials classification based on reinforcement composite [6].

2.2.3 PARTICLE REINFORCED

In recent years, fiber and particulate reinforced MMCs have found special interest due to their specific strength, specific stiffness, their low cost with advantages like isotropic properties, and their potential to replace their monolithic counterparts primarily in the automobile and energy sector [2]. The main concept here is, continuous fiber-reinforced composite has better strength but their manufacturing processing is highly expensive, anisotropic properties of the resultant composite make it unaccepted. In addition to that, they don't permit secondary forming such as extrusion, rolling, and forging. Because of these drawbacks, new energies on the study of discontinuous reinforcements have been used [18].

Fly ash is among the numerous discontinuously dispersed solids used, fly ash is the lowest density and most inexpensive reinforcement which can be generated in the combustion of waste by-products in thermal power plants.

It is known the constituents of the fly ash produced differ extensively, but all fly ash covers SiO_2, Al_2O_3, and Fe_2O_3 as major constituents and oxides of Mg, Ca, Na, K, etc. as minor constituents.

Fly ash reinforcing particles are mostly spherical ranging from less than 1 μm to 100 μm and a specific gravity of vary in the range of 0.6-2.8 gm/cm^3 [19].

The inclination to use fly ash as reinforcement in metal matrix composite is that it can be found abundantly as a solid waste by-product in thermal power plants at fewer costs since much of this is presently landfilled. Nowadays the use of MMC has partial applications due high cost of reinforcing particles. Therefore, the costs of composites can be reduced significantly by incorporating fly ash into the matrixes. In addition to that replacement of aluminum with fly ash can decrease the need for energy almighty aluminum, resulting in energy savings [20].

Fly ash as a reinforcing particle in AMMCs increases hardness, stiffness and decreases density. It can also improve maintainability, damping capacity and coefficient of friction, etc. which are the main parameters that are needed in automotive industries [10]. As the fabrication of aluminum is condensed by the consumption of fly ash reinforcing particles, this can decrease the formation of greenhouse gases as they are produced during the bauxite processing and alumina reduction.

2.2.4 FIBER REINFORCED COMPOSITE

Glass fiber is the supreme common reinforcing fiber for polymeric matrix composites (PMCs) [21]. Glass fibers are produced by a spinning process, in which molten thin strands of silica-based or other formulation glass are pulled out through a nozzle and changed into fine fibers.

There are two kinds of glass fibers mainly used in the fiber-reinforced plastics industries; S-glass and E-glass. S-glass (high strength), has better mechanical properties than E-glass fiber [22] but is higher in cost. The 'E' in E-glass refers to 'electrical' and that indicates the material had low electrical conductivity [23]. E-glass is the most commonly used fiber because it is the cheapest and also it can be produced at lower temperatures combined with high tensile strength, compressive, and modulus, with individual filament about 3500 MPa, 5000MPa, and modulus around 80GPa respectively [24]. It has a density of 2.6 gm/cm^3 and a melting temperature of around 1000-1400^{0}C [25].

2.3 AUTOMOTIVE BODY MATERIALS IN THE PAST

Steels were the historic choice in automotive industries because their inherent stiffness, strength and cost-benefit, however, it has a disadvantage of relatively high density (7550 to 8050 kg/m3) [26]. In the 1950s and 1960s, because of higher vehicle demand, deep drawing steel sheets, and anti-corrosive steel sheets and with good formability were developed. In the 1970s and 1980s, weight reduction of cars in terms of fuel efficiency was a great concern to manufacturers. With this concern steel sheets were established and had paid to reduce automobiles by minimizing the thickness of the sheet [27]. During the 1990s, harmless environmental subjects control the main alarms in the vehicle industry due to that additional effort was used on increasing technologies for weight minimization by replacing traditional materials, such as mild steel, with lightweight materials, like aluminum alloy, and composite. In this connection, aluminum alloy sheets were developed and applied to various body panels to achieving lighter vehicles [28].

Materials that are used for body panels are also estimated to donate a harmless vehicle body through the occasion of a crash and also the collision energy should be minimized and controlled in a small distortion length within the attacked area.

An evident way to achieve this easily is to outspread the usage of lightweight composite materials with numerous tasks in the body structure components without consuming one material for each of the requirements [29].

2.3.2 E-GLASS FIBER AND FLY ASH REINFORCED WITH AL ALLOYS USING STIR CASTING METHOD

Ramakrishnaiah [30] tested the mechanical properties of Al2219 aluminum alloy matrix reinforced with E-glass fiber and fly ash processed by using the stir casting method. The properties comparison was made with the parent metal. It was found that the improvement in mechanical properties of Tensile strength, compressive strength, and hardness.

Ghadge [31] reported research on Al8011 alloy and AMMCs reinforced with fly ash and E-glass fiber through the stir casting method. They measure a mechanical property of aluminum alloy and AMMCs and they found that mechanical properties of Al8011 like compressive strength and tensile strength with different percentages of 2%, 4%,6%,8% and 1%, 3%, 5%, 7% fly ash, and E-glass fiber respectively and finally observed that tensile strength and compressive strength decreases with increasing E-glass fiber.

Arun [32] evaluated the mechanical properties of Al6061 alloy reinforced with particles having 2 wt%, 4 wt%, 6wt%, and 8wt% of fly ash, and 2 wt% and 6wt % of E-glass fiber were fabricated by stir casting method. The result shows that a significant enhancement in tensile properties, compressive strength, and hardness are noticeable as the wt % of the fly ash increases.

Ganeshkumar [33] studied that by separating Al6063 from e-waste material for the handling of the composite to make aluminum founded E-glass and fly ash hybrid using stir casting method. Samples were machined as per ASTM standards to test hardness, tensile, and compression strength. Finally it was observed, when the percentage of E-glass fiber & fly ash is more, hardness, tensile, and compression strength increases.

2.3.3 Al6063 REINFORCED WITH DIFFERENT REINFORCING PARTICLES USING STIR CASTING METHOD

Venugopal [34] evaluate the experimental investigation of Al6061 aluminum alloy matrix reinforced with SiC processed by using the stir casting method. The properties comparison was made with the parent metal. It was found that the improvement in mechanical property flexural strength.

Venkatesulu [35] studied the production and estimation of mechanical properties by reinforcing boron carbide (B_4C) into the base metal of the Al6063 alloy matrix using stir casting techniques. B_4C of 2, 3.5, 5, and 6.5 wt. % was added to the base matrix. The mechanical properties and microstructure study was done using an optical microscope. The result revealed that impact strength and tensile strength have been increased with weight percentages 2, 3.5, and 5 of B_4C in the matrix metal. The hardness of the Al6063/ B4C is greater than the conventional, this is due to the addition of the weight percentages of B_4C. Microstructural observations display that B4C particles with weight percentages 2, 3.5, and 5 are well distributed in the matrix material (Al6063) and have good bonding between them.

Ajay [36] presented a metal matrix composite of Al6063 reinforced with fly ash particles is fabricated by using a stir casting process. By varying temperature, the weight of fly ash and stirring speed using Taguchi method (L9 array) mechanical properties of Fatigue strength and Vickers hardness for the fabricated samples were detected by Vickers hardness tester and fatigue testing machine respectively. Finally revealed the maximum value of hardness found at 9% fly ash composition at 720ºC at 400 rpm and also stated that due to significant reduction in fatigue strength fly ash composition of near about 9% at 720ºC with 400rpm stirring speed is not suggested for fabrication.

Jims [37] develop and characterize aluminum-based hybrid composite using a constant 84 vol% Al6063, fly ash and Borosilicate reinforcements varied in the proportions of 2%, 4% 8%, and 14% using the stir casting method. It is observed that both the reinforcements used in this study, increased the tensile and wear resistance of the alloy and recommended that this metal matrix composite of Al6063 reinforced with fly ash and Borosilicate reinforcements can be used in automobile, aerospace, and structural applications where to wear resistance and tensile properties are mostly required.

2.3.4 EFFECT OF HEAT TREATMENT OF ALUMINUM ALLOY AL6063

Abdalla [38] shows the consequence of solid solution temperature, aging time, and the aging temperature on the mechanical properties of tensile and impact toughness of Al6063 alloy. The prepared samples were homogenized at 560 ºC for 2h, and then they were solution heat-treated at various temperatures (500, 530,560) ºC for 1 h and then quickly quenched in water at room temperature. After quenching the specimens were aged at (150,175, and 200)ºC for different periods. Finally, it was observed the maximum value of the tensile strength and yield stress are (288.6 and 264.5) MPa respectively at a solution treatment temperature of 530ºC and the best aging temperature of 175ºC for 6h. Whereas the maximum value of impact toughness is 24.6J in samples aged at 175ºC for 2h.

The aforementioned literature indicates a significant change in mechanical properties. However, the reinforcing materials are higher in cost and density, also not easily available especially for our country and finally, it was better if the researches show as the microstructural characterization of their specimens for better understanding.

Joseph [39] studied the effect of solidification rate and stress-release or stress relief annealing on the mechanical properties of Al6063 after being melted and cast using a metal mold and sand mold. After that, the cast samples were heat treated and then cooled in natural air and then mechanical properties like impact test, tensile test, hardness test, and microstructural analysis were carried out on the samples. Finally found a significant change in the mechanical properties of the specimens. When annealing is carried out on the specimens, the yield strength, ultimate tensile strength, and hardness percentage elongation of cast Al6063 and reduced by 10.3% and 7.5% for the respective molds. Whereas the recorded values before annealing was an ultimate tensile strength of 146.7 MPa and 163.5 MPa were noted for sand mold and metal mold samples. However, the values of impact strength and percentage elongation of cast Al6063 matrix upgraded with the increase in thermal conductivity of casting method and annealing operation. After being annealed, the ductile increased by 51.01% and 45.82% for sand mold and metal mold samples, respectively. Moreover, microstructural analysis of cast Al6063 discovered a fine-grained structure with an increase in thermal conductivity.

2.3.5 AUTOMOTIVE DOOR PANEL MATERIALS AND ANALYSIS IN THE PAST

Grujicic [40] studied weight reduction for inner door panels by reinforcing carbon fiber with epoxy matrix composite. Finally found a 5% weight reduction. However, since thermoplastic reinforced material was used for internal door panels which leads it is more costly to finance. Furthermore because of the non-degradable feature of this composite will make it removal of the waste next usage tougher. Finally, this research mainly focuses on the internal door panel that means this study overlooked the significance of the outer door panels.

Terciu [41] studied the property of the inner door panel which is fabricated from woven fabrics of natural fibers and wood particles. Next to that analyzed the displacements and stresses in a situation of a door slam simulation using finite element analysis for this composite and they compare the results obtained with plastic molded panel (polypropylene) inner door panel. For both cases using an acceleration of the impact, 350m/s^2 was used for the FEA. Finally, the FEA result underlined that the newly designed material advances component stiffness compare with classical materials used. The displacement of the fresh composite was lesser 43% than the polypropylene and its weight is reduced by 0.3kg.

Though the result displays that lignocelluloses composites have improved performance as related with the classical one, still there is a possibility of gaining less deformation by assessing the more stiff materials.

Sandeep [2] showed the one way of minimization in cost and weight reduction of a vehicle door with ULSAB (ultra-light steel auto body) Concept. The study pronounced the shortcomings of the present vehicle door structure and endorses design variations to solve the current problem. Tailor welded blank technology was used for decreasing weight. Tailor-welded blanks technology permits joining dissimilar strengths of steel in one part without adding complications at the joints. So, by reducing the weight of a door panel like using less thickness high strength material, reduce cost by replacing molded trim with hard pad finally found that a reduced weight of door assembly about 0.4kg. Also, there was a magnificently answered water drip tricky by modeling the front door panel appropriately. However, the weight of the door panel can be additionally reduced by selecting lighter materials than steel and designing accordingly.

Denanto [42] this study analyzed the effect of bamboo fiber reinforced with polyester composite materials with different orientations (0 and 0/90. Based on the result ‘0’ orientation was selected and recommend bamboo fiber reinforced with polyester composite materials with a strength of 160MPa is suitable for new external structural automotive door panel of three-wheel Bajaj. It is known that natural fibers are biodegradable, recyclable, and good for weight reduction but not recommended for external body panels like conventional materials especially for automotive parts because they are highly deformed during a collision.

2.4 SUMMARY OF LITERATURE REVIEW

From the literature, today’s requirement of manufacturing industries is to make the automobile's fuel-efficient. Additionally, it has been proven that AMMCs are widely used than other conventional materials, due to the inherent property they possess like good strength to weight ratio, adequate wear resistance and economic. E-Glass fiber and fly ash are compatible reinforcing particles with aluminum metal matrix. Healthier mechanical properties like hardness test, tensile strength, flexural strength, and compressive strength can be found when the fiber volume ratio is 2% to 9% with a particle size of $\leq$ 75µm beyond this the matrix loses its property because if the volume fraction of reinforcing particles increase there is a possibility of formation of agglomeration retards the ability the matrix to transfer load. Heat treating AMMCs makes them more useful by changing or restoring their mechanical properties. For annealing 298 ^{0}C to 410^{0}C for homogenizing from 482.22 ^{0}C to 537.77^{0}C, for solution heat treatment 440 ^{0}C to 526 ^{0}C ±10 and for artificial aging 150 ^{0}C to 200 ^{0}C ±5. The reinforcing particles have their feature in composite materials. This study is different from previous work related to AMMCs by the types of reinforcing particles and their volume fraction and also by the method of heat treatment used. Moreover, this study differs from others by its application area which is for the automobile door panel.

2.5 GAPS IDENTIFIED

From the above literature, it has been shown that the addition of fly ash and E-glass fiber into aluminum casting alloy has a direct effect on the features of mechanical properties. However, if the researchers were using preheat treatment and post heat treatment they may get a better result than the current one.

The aforementioned literature indicates a significant change in mechanical properties. However, the reinforcing materials are higher in cost and density, also not easily available, especially for our country.

From the literature of automotive door panel materials and analysis, researchers are focused only on the internal door panel.

CHAPTER THREE

MATERIALS, CONDITIONS, AND METHODS

3.1 METHODOLOGY

This chapter presents the method employed, to achieve the research objective mentioned in Chapter one. Fig: 3.1 show the schematic diagram of the framework of the applied methodologies:

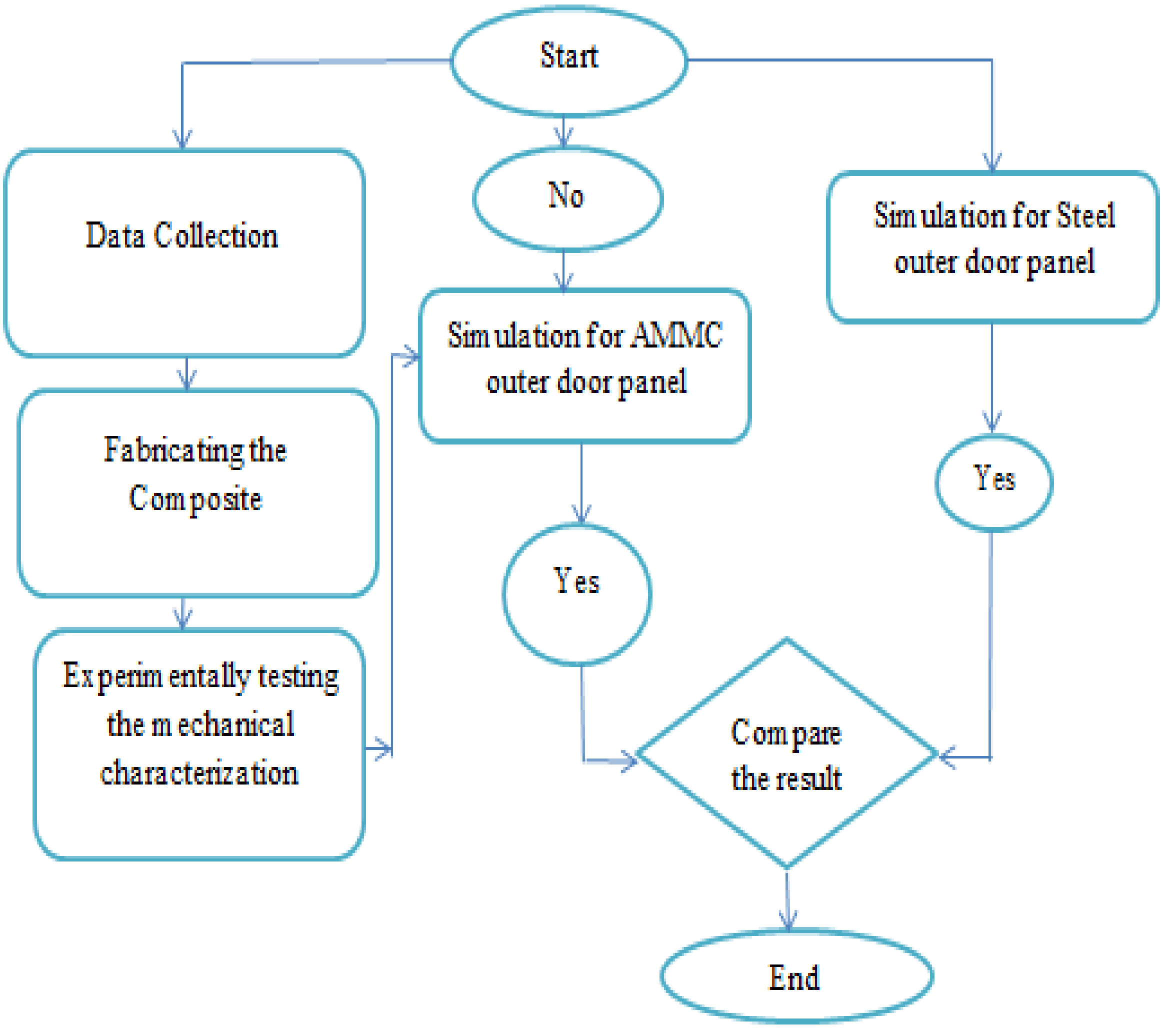


Figure 3. 1 Methodology

3.2 MATERIALS USED

Aluminum alloy of 15-kg Al6063 ingot with 98.21 wt% commercial purity as a matrix material, and 2-kg fly ash and 2-kg E-glass fiber were used as reinforcement. Al6063 ingot is supplied by the B&C aluminum manufacturing company, the fly ash was from Ethiopian waste to the energy power plant and the E-glass fiber from the local market around gurd shola.

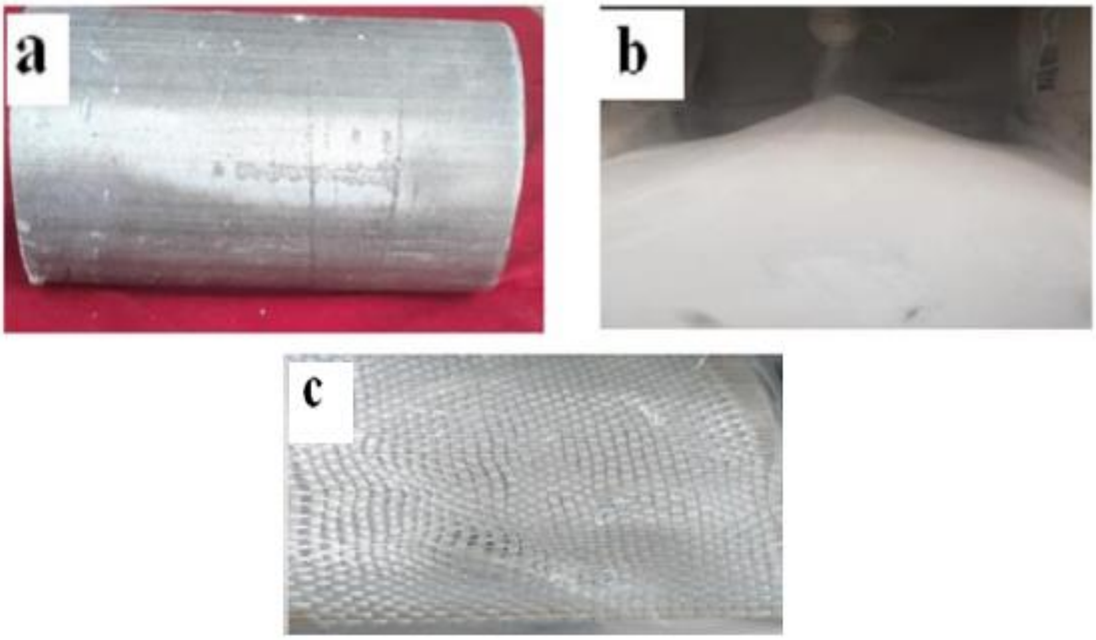


Figure 3. 2 Materials used for the composite

a) Al6063 ingot, b) Fly ash, c) E-Glass Fiber

Table 3.1 shows the chemical compositions of the Al6063. It has main constituents of Si (0.431%) and Mg (0.477 %). As an additional alloying element it contains Fe (0.283%) and Mn (0.150%).

Table 3. 1 Chemical composition of Al6063 alloy matrix - wt % (from supplier).

	Al	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Ni**	**Zn**	**pb**	**Sn**	**Ti**	**V**	**Zr**
1.	98.15	0.460	0.279	0.020	0.140	0.450	0.055	0.058	0.046	0.140	0.096	0.021	0.038	0.072
2.	98.23	0.417	0.298	0.100	0.150	0.480	0.069	0.065	0.044	>0.160	0.103	0.026	0.036	0.056
3.	98.24	0.417	0.272	0.016	0.160	0.500	0.067	0.071	0.043	>0.170	0.148	0.018	0.037	0.062
Avg	**98.21**	**0.431**	**0.283**	**0.045**	**0.150**	**0.477**	**0.063**	**0.065**	**0.044**	**>0.157**	**0.116**	**0.022**	**0.037**	**0.063**

Table 3.2 shows the chemical compositions of the E-glass fiber. It has the main constituents of SiO_2 (52-56 %), Al_2O_3 (12-15%) and CaO (21-23%).

Table 3. 2 Chemical composition of E-glass Fiber - wt % [20].

Material	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	B_2O_3	Na_2O+K_2O
E-glass Fiber	52-56	12-15	21-23	0.4-4	0.2-0.4	4-6	<2

Table 3.3 shows the chemical compositions of the fly ash. It has the main constituents of SiO_2 (57.95 %) and Al_2O_3 (28.15%).

Table 3. 3 Chemical composition of Fly ash - wt % using XRD (from AAU 4killo branch chemistry department).

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O	Others
Fly ash	57.95	28.15	4.75	3.74	1.73	0.93	0.62	2.13

3.2.1 ADDITIONAL ALLOYING MATERIAL

Magnesium Powder

When reactive elements (magnesium, calcium, titanium, or zirconium) are added to the composite it is possible to get a good wetting which leads to better bonding between the reinforcement and the matrix, through lessening the surface tension of the molten metal [43]. Among the different reactive elements listed above magnesium is a very suitable reactive element for incorporating reinforcement particles in the melt, improving the distribution of the reinforcements in AMMC than others elements (titanium, or zirconium) [44].

The other function of magnesium in casting is due to its high powerful scavenge to oxygen it will react with the oxygen that is found on the surface of the particle and makes thinning the gas layer which leads to reducing of the propensity of agglomeration and an increase in the surface energy of the particles. For example in the composite of Al356 with SiC the addition of magnesium helped in thinning the gas layer which is present over the silicon carbide particles [45].

But during the process of adding magnesium to the melt, it is essential to use the optimum value unless it will result in the formation of agglomerates of reinforcement particles and their non-uniform dispersion in the melt.

Figure 3. 3 Magnesium metal powder

3.3. VOLUME FRACTION OF THE FIBER AND THE MATRIX CONTENT OF THE COMPOSITE

The volume of the composite was done by adding the volume of each part that was found in the mold such as the volume of pouring, the volume of a riser, and the volume of each specimen. After getting the volume of the composite, the density of the composite was found by a method of rule of law of mixture. Add the multiplication of density and volume fraction of aluminum, E-glass fiber, and fly ash for each specimen as shown in eq (3.7). Then the mass of the composite was calculated by multiplying the density of the composite by the volume of the composite eq (3.8). The mass of each component of the composite was found by multiplying the density of the reinforcing materials with their volume as shown in eq (3.9) and eq (3.10). The density of aluminum is 2.7 g/cm^3 from the supplier, the density of E-glass fiber 2.6 g/cm^3 [22] and the specific gravity of fly ash was measured in the AAiT chemical department by using the following procedure:

W1 = weight of empty bottle……………….……………………………………..3.1

W2 = Weight of bottle + Weight of fly ash…………………………….…….…3.2

W3 = Weight of bottle + weight of fly ash + kerosene ……………….…………..3.3

W4 = Weight of bottle + Weight of kerosene ....………3.4

W5 = $\frac{w2-w1}{(w2 - w1)-(w3-w4)*0.79}$………………………………………………….............3.5

Specific gravity of kerosene = 0.79 g/cm^3

Sample1. W1= 28.5341g, W2= 37.2908g, W3= 73.7377g, W4= 67.8865g

$$W5 = \frac{37.2908g-28.5341g}{(37.2908g-28.5341g)-(73.7377g-67.8865g)*0.79}$$

$= 2.119\ g/cm^3$

Sample 2. $=2.1\ g/cm^3$

Sample 3. $= 2.12\ g/cm^3$

Average = 2.11 g/cm^3

3.3.1 CALCULATION TO FIND VOLUME FRACTION OF THE REINFORCING PARTICLES AND THE MATRIX CONTENT OF THE COMPOSITE

Based on literature the volume fraction of E-glass fiber is 2%, 5%, 7% and fly ash is 3%, 6%, 9% beyond this percentage the ability of the aluminum for transferring load to the reinforcing particles decreases. Therefore the AMMC can't resist the applied load and failure will happen [34].

Table 3. 4 Total matrix and reinforcing materials ratio.

Samples	**% of Fly ash**	**% E-glass fiber**	**% Al6063 alloy**
Sample 1	0	0	100
Sample 2	3	2	95
Sample 3	6	2	92
Sample 4	9	2	89
Sample 5	3	5	92
Sample 6	6	5	89
Sample 7	9	5	86
Sample 8	3	7	90
Sample 9	6	7	87
Sample 10	9	7	84

For Specimen 1:

Weight of Composite (W_c) = Density of Composite (ρ_c) * Volume of Mold (V_m or V_C)

Volume of Mold (V_m or Vc) = 500 cm^3

$V'_{Al} = 100 = 1$

$V'_{FA} = 0 = 0$

$V'_{EG} = 0 = 0$

$V_{Al} = V'_{Al} * V_C$ ……………………………………………………………………..…...3.6

$V_{Al} = 1 * 500\ cm^3 = \underline{500\ cm^3}$

$V_{FA} = 0 * 500\ cm^3 = \underline{0}$

$V_{EG} = 0 * 500\ cm^3 = \underline{0}$

Volume of Mold (V_m or Vc) = $V_{Al} + V_{FA} + V_{EG} = \underline{500\ cm^3}$

$\rho_c = \rho_f V'_f + \rho_m V'_m$...……………………………………………..……….......3.7

$\rho_c = \rho_f V'_f + \rho_g V_g{}' + \rho_{Al} V'_{Al}$

$\rho_c = 2.11*0 + 2.6*0 + 2.7*1 = 2.7 g/cm^3$

Weight of Composite (W_C) = Density of Composite (ρ_c) * Volume of Mold ($V_m$or V_C)…………………………………………………………………….……….....3.8

Weight of Composite (W_C) = 2.7 g/cm^3 * 500 cm^3 = $\underline{1350\ g}$

$W_f = \rho_f * V_f$ ……………………………………………………………………...3.9

$W_m = \rho_m * V_m$ …………………………………………………………….....3.10

$W_{FA} = \rho_{FA} * V_{FA}$

$W_{FA} = 2.11\ g/cm^3 * 0 = \underline{0}$

$W_{EG} = \rho_{EG} * 0 = \underline{0}$

$W_{EG} = 2.6\ g/cm^3 * 0 = \underline{0}$

$W_{Al} = \rho_{EG} * V_{Al}$

$W_{Al} = 2.7\ g/cm^3 * 500cm^3 = \underline{1350g}$

<u>For Specimen 2:</u>

Volume of Mold (V_m or Vc) = 500 cm^3

$V'_{Al} = 0.95$

$V'_{FA} = 0.03$

$V'_{EG} = 0.02$

$V_{Al} = V'_{Al} * V_C$

$V_{Al} = 0.95 * 500\ cm^3 = \underline{475\ cm^3}$

$V_{FA} = 0.03 * 500\ cm^3 = \underline{15\ cm^3}$

$V_{EG} = 0.02 * 500\ cm^3 = \underline{10\ cm^3}$

Volume of Mold (V_m or Vc) = $V_{Al} + V_{FA} + V_{EG} = \underline{500\ cm^3}$

$\rho_c = \rho_f V'_f + \rho_g V_g' + \rho_{Al} V'_{Al}$

$\rho_c = 2.11*0.03 + 0.02*2.6 + 2.7*0.95 = \underline{2.680\ g/cm^3}$

Weight of Composite (W_C) = Density of Composite (ρ_c) * Volume of Mold (V_m or Vc)

Weight of Composite (W_C) = 2.680 $g/cm^3 * 500\ cm^3 = \underline{1340\ g}$

$W_{FA} = \rho_{FA} * V_{FA}$

$W_{FA} = 2.11\ g/cm^3 * 15\ cm^3 = \underline{31.65g}$

$W_{EG} = \rho_{EG} * V_{EG} = 0$

$W_{EG} = 2.6\ g/cm^3 * 10\ cm^3 = \underline{26g}$

$W_{Al} = \rho_{Al} * V_{Al}$

$W_{Al} = 2.7g/cm^3 * 475\ cm^3 = \underline{1282g}$

Using the same method, from casting 3-10 is given in the table below:

Table 3. 5 Volume Fraction of the Matrix and the Reinforcing particles.

Casting	$V_{Al} = V'_{Al} * V_{mold}$	$V_{FA} = V'_{FA} * V_{FA}$	$V_{EG} = V'_{EG} * V_{EG}$	$\rho_c = \rho_f V'_f + \rho_g V_g' + \rho_{Al} V'_{Al}$	$W_{Al} = \rho_c * V_{Al}$	$W_{FA} = \rho_c * V_{FA}$	$W_{EG} = \rho_c * V_{EG}$
3	460 cm^3	30 cm^3	10 cm^3	$\rho_{c3} = 2.11*0.06+2.6*0.02+2.7*0.92 = \underline{2.662\ g/cm^3}$	1242 g	63.3 g	26 g
4	445 cm^3	45 cm^3	10 cm^3	$\rho_{c4} = 2.11*0.09+2.6*0.02+2.7*0.89 = \underline{2.644\ g/cm^3}$	1201.5 g	94.95 g	26 g
5	460 cm^3	15 cm^3	25 cm^3	$\rho_{c5} = 2.11*0.03+2.6*0.05+2.7*0.92 = \underline{2.677\ g/cm^3}$	1242 g	31.65 g	65 g
6	445 cm^3	30 cm^3	25 cm^3	$\rho_{c6} = 2.11*0.06+2.6*0.05+2.7*0.89 = \underline{2.659\ g/cm^3}$	1201.5 g	63.3 g	65 g
7	430 cm^3	45 cm^3	25 cm^3	$\rho_{c7} = 2.11*0.09+2.6*0.05+2.7*0.86 = \underline{2.6419\ g/cm^3}$	1161 g	94.95 g	65 g
8	450 cm^3	15 cm^3	35 cm^3	$\rho_{c8} = 2.11*0.03+2.6*0.07+2.7*0.90 = \underline{2.675\ g/cm^3}$	1215 g	31.65 g	91 g
9	435 cm^3	30 cm^3	35 cm^3	$\rho_{c9} = 2.11*0.06+2.6*0.07+2.7*0.87 = \underline{2.657\ g/cm^3}$	1174.5 g	63.3 g	91 g
10	420 cm^3	45 cm^3	35 cm^3	$\rho_{c10} = 2.11*0.09+2.6*0.07+2.7*0.84 = \underline{2.639\ g/cm^3}$	1134 g	94.35 g	91 g

3.4 EXPERIMENTAL WORK

3.4.1 PREPARING SAND MOLD AND PATTERNS

Sand casting is the most frequently used casting process that consumes expendable sand molds to make complex metal geometries. Sand casting needs destroying of the sand mold for removing the part [46]. It involves the use of a furnace, metal, pattern, and sand mold. In this research silica sand of 200-250 mesh sieve size that was received from Mojo River was used as the principal molding material with additional binding materials like molasses, graphite powder, and water. 90% of silica sand was placed in the laboratory sand mixer and mixed for five minutes. Additionally, 1 % of molasses and 9% of water were added to the mixer and further mixed continued for 5minute. It was done for each casting.

Preparation of Sand Molding

The mold-making process mainly includes locating the pattern, packing the sand, and eliminating or removing the pattern. The patterns were prepared from wood according to ASTM standards of the composite specimens by adding an allowance of 3mm for each specimen. To make sand casting first, two molds (cope part and drag part) made from wood and metal were prepared. The patterns will be positioned in the drag part and graphite powder scattered over it to simplify the removal of the patterns from the packed sand easily. Then the mixed sand packed on this half of the mold. This packed sand is an imitation of the external shape of the casting. The sand-packed mold is reversed upside down and the cores are positioned and the two half molds clamped to each other securely to prevent the loss of any material and the same method was done which is done in the drag part of the mold like dispersing graphite and packing sand. While finishing these cores were removed to pour and rise. Vents were made that are used to escape gases during pouring time which prevents the casting from porosity.

Finally, the cope part of the mold was disassembled from the drag part and each pattern was removed. When the pattern was eliminated, the cavity that will form the casting remains. Then for each cavity gates were prepared that allows the casting to flow from the pouring gate into each cavity. Lubrication was functional to the surfaces of the mold cavity to improve the flow of the molten composite and the surface finish of the casting. Since the casting process was done in winter the prepared sand molds were dried for two days by atmospheric temperature before being used.

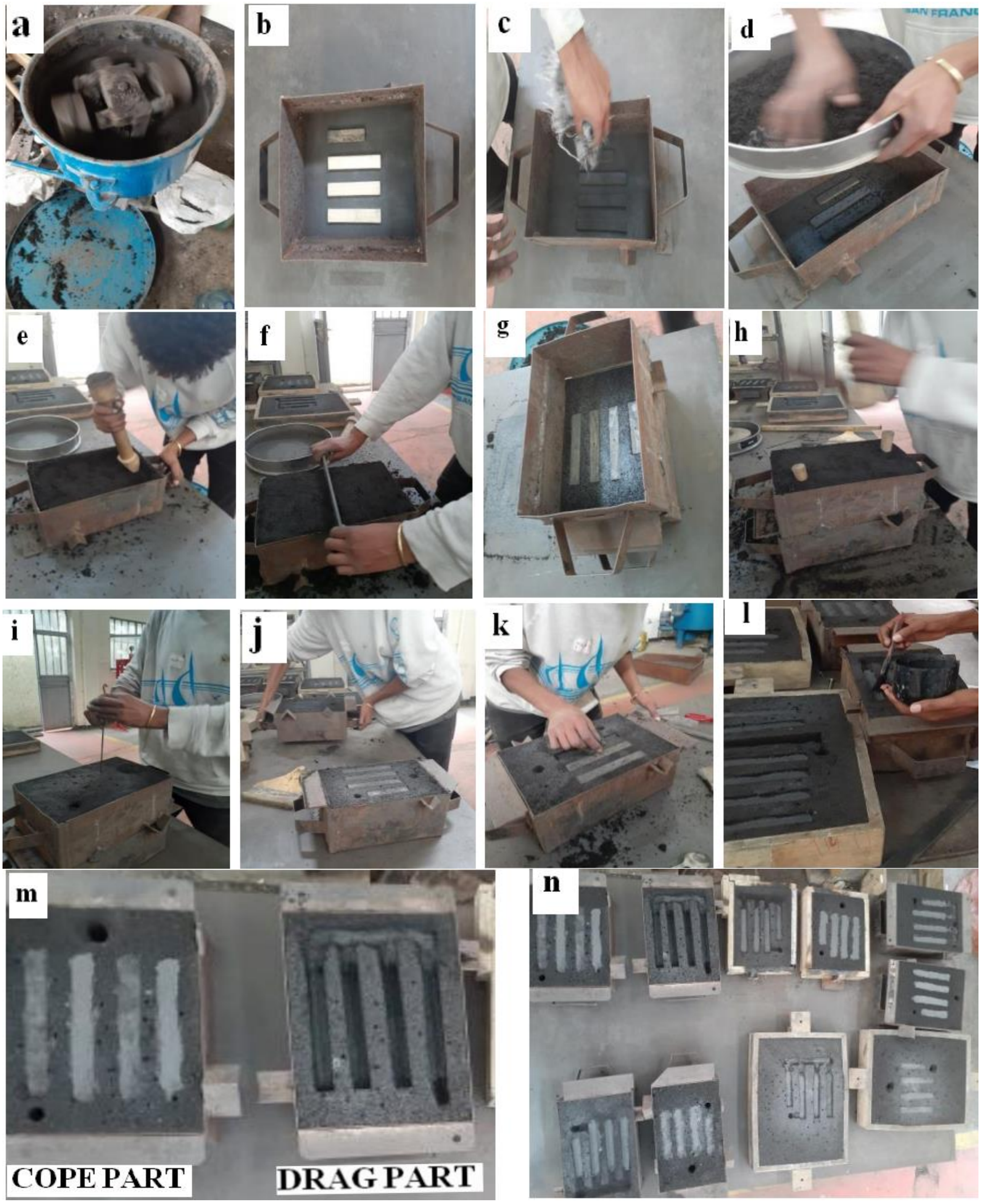


Figure 3. 4 Preparation of Sand molding

a) Sand mixer
(b&c) Positioning patterns & dispersing graphite on it
d) Scattering the mixed sand in the mold
e) Ramming the mixed sand vigorously
f) Making flat the packed sand
g) Clamping the cope over the drag
h) Putting cores & fill them with mixed sand
i) Removing cores & making vents
j) Disassembling the cope from the drag
k) Removing the patterns
l) Lubricating the cavities
m&n) Prepared sand molds

3.4.2 TREATMENT OF THE MATRIX AND REINFORCING PARTICLES

To minimize the dwelling time or to make the alloy melt faster the ingot is cut into small pieces by using a lathe machine, hack saw and hand saw with a cutting grade HSS to get small pieces of aluminum. To avoid any overheating of the ingot the cutting process was with a continuous flow of coolant.

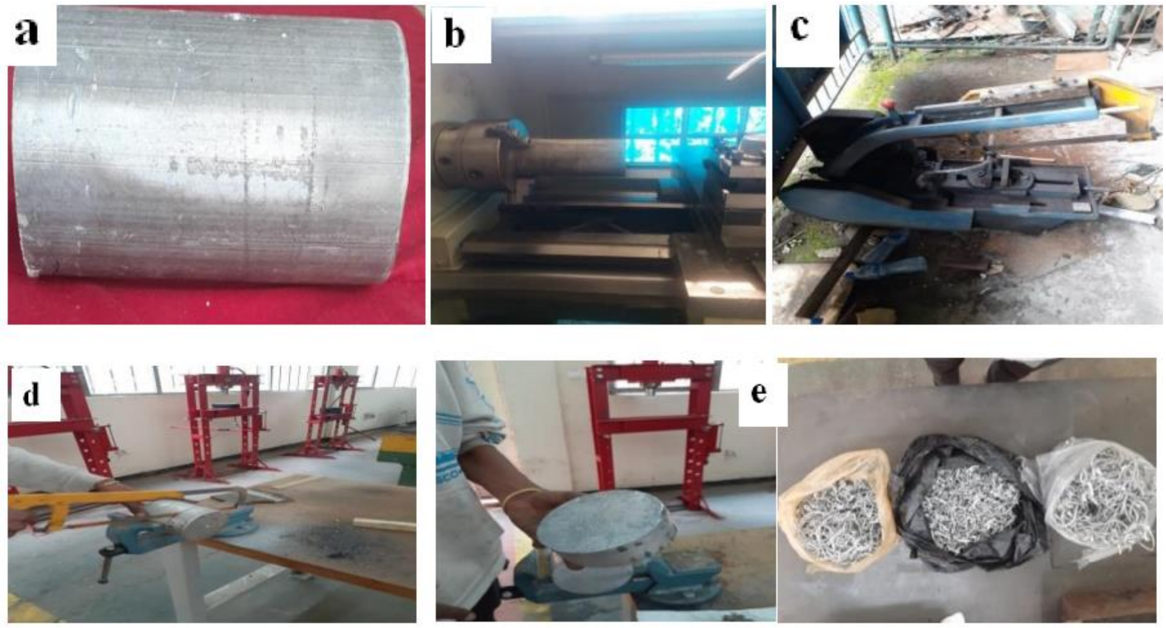


Figure 3. 5 Treatment of the matrix

a) Al6063 ingot (c& d) Cutting the ingot on Hack saw and hand saw
b) Cutting the ingot on lathe machine (e) Al6063 small pieces after cutting

Among different kinds of particle treatments, ultrasonic techniques, various etching techniques and heating of particles are the most known. For this research heat treatment of particles was conducted before inserting it into the molten metal matrix. Its main function is to remove gasses and impurities from the surface of the particles that help the reinforcements to transfer easily in the molten metal matrix and improve the wettability of the molten composite [10].

For treating the reinforcing particles initially, the FA dried in the furnace for 2 hours at 400^0C then using sieve shaker FA powder of $\leq$45μm are separated finally preheated for 1 hour by using the same furnace at a temperature of 300^0C. The E-glass fiber is cut into small pieces of 2-5 mm for a better stirring process and to easily melt it in the slurry and also preheated for at 900^0C for 2hr.

Figure 3. 6 Treatment of the reinforcing particles

a) Heat treating

b) Sieving FA

c) Sieved FA (≤ 45µm)

d) Before heat-treating FA the

e) After heat treating FA the

f) Chopped E-glass fiber

g) Preheating E-Glass Fiber

h) After E-Glass Fiber Preheated

3.4.3 MELTING AND CASTING

Theoretically, the Al6063 matrix alloy melts completely at about 670°C. But before placing the matrix in the furnace, the furnace is preheated at 300^0C for 20min for the safety of the machine. Then weighted the small pieces of Al6063 were placed in the induction furnace of charging medium graphite crucible at 700^0C. It is above the melting point of the matrix because there is a possibility of the formation of the slag at higher temperatures [35]. With this temperature, soaking continued for 45min and before the reinforcing particles were added to the slurry and the stirring started, the top layer of the melt is skimmed off.

This is because the top surface always contains an oxidation and slag layer. This layer retards the movement of reinforcing particles into the molten metal matrix easily. The melt temperature was maintained at 680°C during the addition of fly ash which was already preheated to a certain temperature and chopped E-glass fiber and the reinforcing particles were introduced into the furnace at a small amount rate. The next step is stirring. During this operation, the speed of the impeller and its duration need suitable selection. If the speed of the impeller and its duration is too much, there is a possibility of the formation of porosity and if it is too slow the reinforcing particle will not be wetted by the molten matrix. The temperature of the furnace is maintained at 680°C and stirring is continued for a specified time of about 5minutes and this was done three times a total of fifteen minutes at an impeller speed of 450 rpm, before being poured into a sand mold [36]. 1% Magnesium was added to increase the wettability of the reinforcing particles [10].

After stirring vigorously the molten composite, the next step is pouring. Before pouring the molten metal, the mold has been clamped and put 1.20 meters from the furnace and the ladle has been heated on the top of the furnace using the maintained temperature of about five minutes to facilitate the pouring process. The pouring was performed manually at a temperature of 700^0C. The last operation of stirring was performed during this time. Once the molten composite is poured into the mold and inters the cavities will begin to solidify and finally after 1hr the casting is removed by simply breaking the sand mold. During cooling, there are excess parts that are solidified like: gates of pouring and riser parts, and also the removed casting samples had some sand on their surface. These unnecessary parts were trimmed by sawing and file for reducing the roughness of the casting.

Figure 3. 7 Process of Melting and Casting

a&b) Inserting pieces of Al into the furnace

c) Soaking the Al6063 pieces for a45min

d) Skimming the slug from the top surface of the melt

e) Two blade stainless steel stirrer

f) Addition of reinforcing particles

g) Stirring the slurry

h) Addition of Magnesium powder

i&j) heating ladle &Pouring into a sand mold

j) After poured

k) Removing the cast

l) Removed cast parts

m) Trimmed cast parts

n&o) Specimens after machining

3.4.4 HEAT TREATING THE COMPOSITE

Next to remove the unwanted parts of the casting heat treating of the composite was performed. Heat treating is a method of heating and cooling metals in a series of specific operations for making the metals more useful by changing or restoring their mechanical properties like hardening the metal, making it stronger and more resistant to impact. The heat-treating process can also be used to make metals softer and more ductile. During heat treating of metals, only microstructural modifications result because the temperature used for heat treatment is lower than the melting point of components of the composites so don’t allow the reinforcements to react with each other.

In this research three steps were followed for the heat-treating process. The first was solution treatment at 530ºC for 1hr. This is used to redistribute the components of composite more evenly. Following solution treatment, the next process was quenching. The main objective of quenching is to preserve the dissolved elements or “freeze” the trapped elements in place that they occupied before. The quenching media used is water at room temperature of as shown in figure 3.8b. In this way, it is possible to attain a super-saturated solution, which will be modified consequently by other heat treatment called artificial aging treatment (T6 treatment) at 175 ºC for 4hr [39]. Finally to get the desired ASTM standard size of the specimens lathe machine and milling machines were used.

Figure 3. 8 Heat treating the composite

a) Solution heat treatment b) Quenching in water c) Artificial aging

3.4.5 MECHANICAL TESTING OF COMPOSITE SPECIMENS

3.4.5.1 INTRODUCTION OF TEST APPARATUS

The experimental specimens were fabricated from Al6063/ E-glass/Fly ash fiber composite for different tests and were machined using ASTM to found the essential dimensions for the study of their properties.

Universal Testing Machine (WP 310 UTM) is fast, accurate, & easy to operate. It is named because of the wide range of tests it can accomplish over different kinds of materials. Like tension test, flexural test, compression test, shear test, etc. It has a digital system that displays load and displacement in its particular engineering units.

UTM has two main parts: The first one is the Loading Unit in which the effort of the load and preparation of the test specimen is held. The other one is Control Unit here the distinctions in the application of the load and the corresponding test result are gained.

The loading unit of a UTM consists of three components. Load Frame, Upper crosshead and Lower crosshead, and Elongation Scale. The loading frame has a table where the specimen is positioned for the compression test), upper crosshead, and lower crosshead. The upper crosshead has the purpose of clamping one end of the test specimen whereas the lower crosshead is the movable crosshead whose screws can be untied for height adjustment and tightened. Both crossheads have a tapered slot at the center that has a pair of racked jaws which is planned to grasp and hold the tensile test specimen. The elongation scale measures the relative movement of the lower and upper tables.

The control unit contains three main components: Hydraulic Power Unit, Load Measuring Unit, and Control Devices. Hydraulic Power Unit contains an oil pump that delivers constant oil flow into the main cylinder of the load unit which aids in the smooth application of load on the specimen. Load Measuring Unit has a pendulum dynamometer unit that has a small cylinder with a piston that goes with the constant oil flow. The pendulum is coupled to the piston by pivot lever and the pivot lever glances based on the load applied to the specimen. Then this deflection is changed to the load pointer and shows as the load on the dial. Electric control devices are used to switch on/off the movement of the crossheads. The hydraulic control device has two valves. A right control valve is used for applying load on the specimen and the left valve is used for releasing the load application.

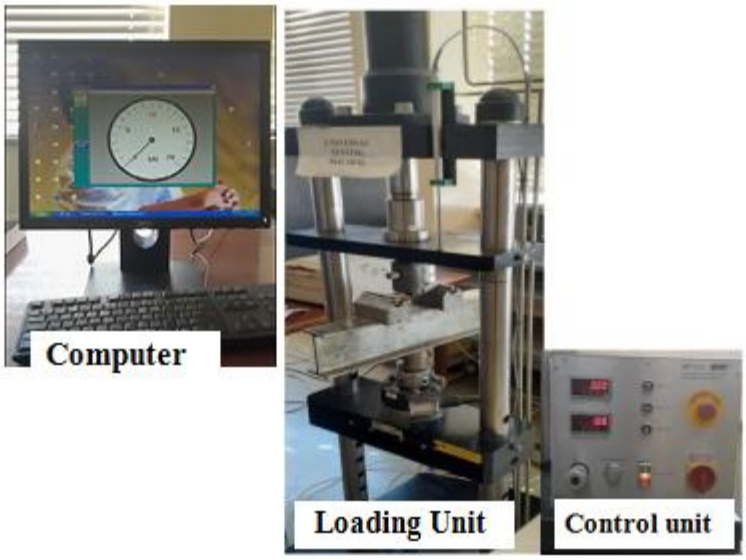


Figure 3. 9 WP 310 UTM in Defense University Engineering College

3.4.5.2 HARDNESS TESTING

Hardness is the capability of a material to resist deformation, which is determined by a standard test where the surface resistance to indentation is measured. There are three most frequently used hardness testing machines: Vicker's test, Brinell test, and the Rockwell test. Among these machines, in Rockwell hardness the test is fast, cheap, and relatively non-destructive, leaves only a minor indentation on the specimen. Rockwell test method can be used in all metals except where there is the indentations would be too large for the specimens or when the shape of the specimen prohibits its use. The basic components of the Rockwell hardness test are crank anvil a device that is used for placing the specimen that is going to be tested. Elevating screw is also one component of the Rockwell hardness test which has the function of moving the specimen by using the handle. There is a screen that displays the result of the test. Rockwell hardness test is also simple to operate. However it needs some precautions like good surface finish of the specimens for more accurate and reproducible will be the results, the bottom side of the specimens must securely contact the anvil without interference from debris or other loose material and the specimens should be held stably during the test unless the specimen can affect the result. Usually, the Rockwell hardness test has an indenter that is made from either a steel ball or a diamond. The values of Rockwell hardness are conveyed as a combination of a hardness number and a scale symbol that represents the indenter and the major and minor loads. The hardness number of any material is expressed by the symbol HR and the scale designation.

In this research for hardness testing, polished specimens were tested using ASTM E-18 (15x15x5 mm^3) and INDENTEC Rockwell hardness testing machine with diamond indenter at a load of 100kg for a period of 15seconds was used to examine the hardness strength of the composite samples. The test was taken at three different locations of the composite specimens and the average value was recorded as the hardness of the composite specimens. It was performed in Defense Engineering College.

In each testing procedure, two loads were applied. First, the Rockwell hardness test machine that consists of a diamond indenter is forced into the composite specimen as a minor load and its depth recorded. While this process going additional load is applied called major load that increases the depth of penetration on the sample. Then the major load is removed and the force on the composite specimen and is returned to the minor load. Finally, the increased depth of penetration due to the major load is used to calculate the Rockwell hardness test value and its result was received from the digital display of the machine.

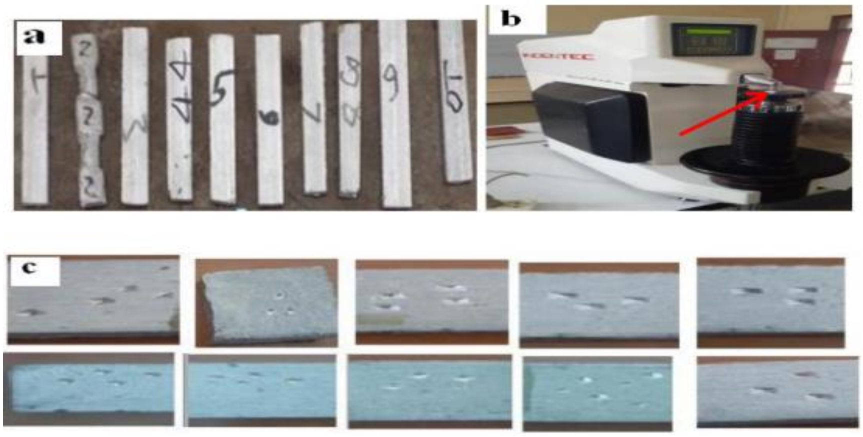


Figure 3. 10 Hardness testing machine& specimens for hardness test

Specimens of Hardness test before being cut into ASTM standard, (b) Typical specimen under Hardness test after preparation of ASTM standard c) Specimens after deformation.

3.4.5.3 COMPRESSION STRENGTH TEST

Compression testing is a very communal fundamental type of mechanical testing that is used to define the behavior material when the material experiences opposing forces that push inward upon the specimen from opposite sides. In this research, the compression test machine was configured by adding compression plates to a universal test machine. Next, the tests were done by loading the test specimen between two plates or griper and then by moving the upper crossheads, the force was applied until the specimen fails. During the test, compressive stress, load, and displacement (elongation) were recorded by the software from the given test. The compressive test specimens are produced according to the specification of the ASTM Standard E9-89; the dimensions of the composite specimen are diameter 10mm and length 8mm. Here also, for each composition three specimens are taken and a total of thirty specimens were tested in this machine.

Figure 3. 11 Compression testing

a) Specimens before deformation, b) Typical specimen during deformation c) Specimens after deformation.

3.4.5.4 FLEXURAL TEST

The flexural test is one of the simplest bending tests that combine both tensile and compressive tests for determining the flexural strength of a material. Flexural Strength is the measure of maximum force that a material withstands before it breaks or yields or it is the capacity of the material to resist bending loads applied perpendicular to its longitudinal axis. A flexural test was performed by a universal testing machine maintaining crosshead velocity of 6mm/min at room temperature, found in Defense University Engineering College Lab.

ASTM E290-14 was followed while preparing the 3-point bending test specimens composite material test. According to this standard, the dimension of each specimen was 145x18x3mm^{3}of size length, width, and thickness respectively. The experimental setup and the composite specimens for the 3-point bending test are shown in figure 3.12 (a), (b) (c), and (d). For each composition, three specimens are taken to show the repeatability of the results through which minimizing the experimental errors. Thirty specimens were tested in this machine.

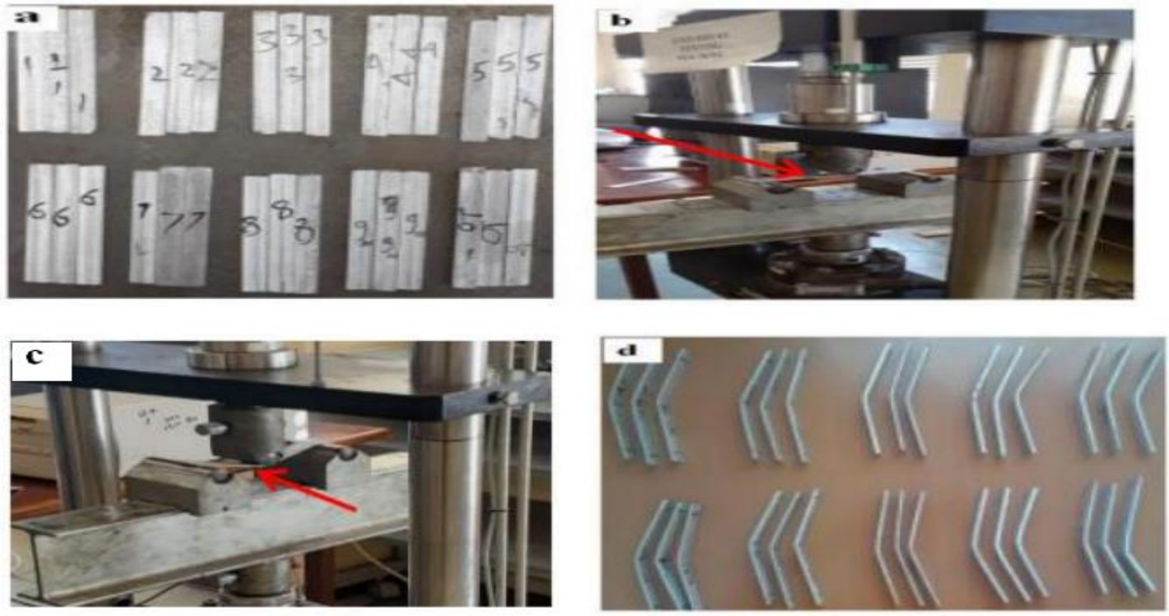


Figure 3. 12 Flexural testing

a) Specimens before deformation, b) Typical specimen during deformation c) Specimens after deformation.

3.5 SPECIFICATION/DIMENSION OF OUTER DOOR PANEL

3.5.1 ANALYTICAL DATA

Considering the current steel outer door panel of the Toyota Hiace van model KG-LH172V-RBPBS car and standing from this, the intention of this study paper is dynamic analysis and testing mechanical properties as per ASTM standard of Al6063/E-Glass Fiber/Fly ash composite outer door panel using FEA and experimental technique for this car, which will have a high strength to weight ratio and lower stress than that of the current steel outer door panel.

Toyota Hiace van model KG-LH172V-RBPBS vehicle is selected for this research. This vehicle is selected due to some reasons;

- Toyota Hiace van model KG-LH172V-RBPBS is one type of vehicle that is used as a public transport in our daily activities. However, it needs a replacement of some parts such as the outer door panel which is made from steel. Thus it will be possible to implement the findings of this study on the selected vehicle. It is easy to take the necessary data due to its availability.

- It is easy to take the necessary data due to its availability.

Table 3. 6 Mechanical properties of structural steel [47]

No.	**Mechanical**	**Values**	**Units**
1	Density (ρ)	7850	Kg/m^3
2	Young modulus (E)	207	GPa
3	Poisson’s ratio (v)	0.3	-
4	Shear modulus (G)	76.9	GPa
5	Tensile yield strength (σt)	250	MPa
6	Compressive yield strength (σc)	250	MPa
7	Ultimate yield strength (σy)	460	MPa
8	Behavior	Isotropic	

Table 3. 7 Technical Specification of Toyota Hiace [1]

Specification		**Standard Model**
Body Features	Standard Model	
	Length	4690 mm
	Width	1690 mm
	Height	1980 mm
Features	External body part	Structural Steel
	Brand	Toyota Hiace Van
	Model	KG-LH172V-RBPBS
	Seats	12
	Weight	1250 kg
	Doors	4
	The thickness of the outer door panel	0.7 mm (Direct measurement)
Engine transmission	The volume of the outer door panel	= Area of the panel * thickness of the panel= 745.71 cm^3
	Position of engine	
	Fuel supply system	Distributor Injection Pump (Bosch-type Jerk-type)
	Valve train	OHC
	Number of cylinders	4

	Position of cylinder	Inline
	Fuel type	Petrol /gasoline
Chassis	Wheel drive	2WD, rear-wheel
	The size of front Tyre size	195R15−6PRLT
	The size of rear Tyre size	195R15−6PRLT
	Front brake	Disk
	Rear brake	Drum

3.5.2 MODELING OF OUTER DOOR PANEL

After collecting the necessary data which are discussed in section 3.1 up to section 3.4, the next step is the modeling of the outer door panel. In automotive industrial sector modeling and numerical simulation are essential aspects because it reduces the time for fresh design [48]. So if one product is modeled and simulated in design and analysis it will deliver many advantages like minimizing product manufacturing time, material scrap, and material cost.

3.5.3 2D SKETCHING AND 3D MODELING OF OUTER DOOR PANEL

SOLID WORK 2017 is mechanical design software that is used to design 3D prototypes and evaluate products or systems before manufacturing and saving a significant production time and cost. This software is an easy-to-use parametric design modular which means no problem with it editing the design at any stage in the design process. Generally, solid work is software that supports the traditional 2D processes and provides design engineers to easily develop manufacturing drawings, assembly drawings, and manufacturing documentation with ease.

Figure 3.13 shows the 2D sketching of steel and Al6063/E-Glass Fiber/Fly ash composite outer door panel and fig 3.14 shows the 3D modeling of steel and Al6063/E-Glass Fiber/Fly ash composite outer door panel.

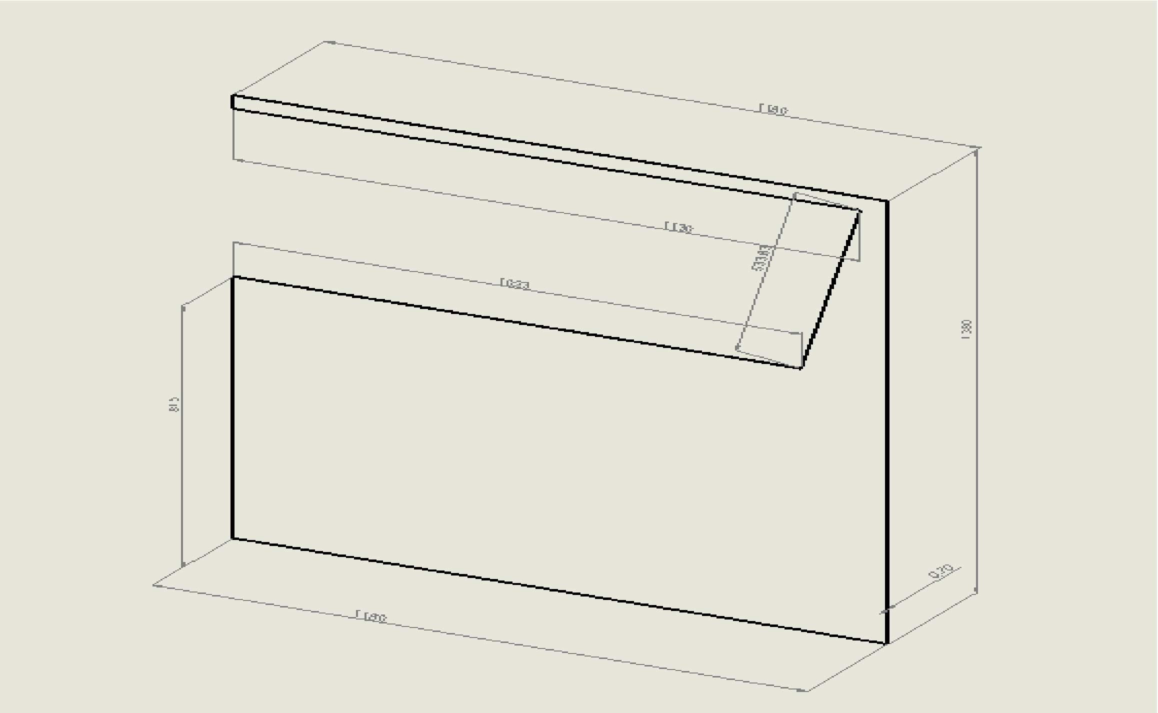


Figure 3. 13 2D drawing of steel and Al6063/E-Glass Fiber/Fly ash composite outer door panel using SOLIDWORK 2017.

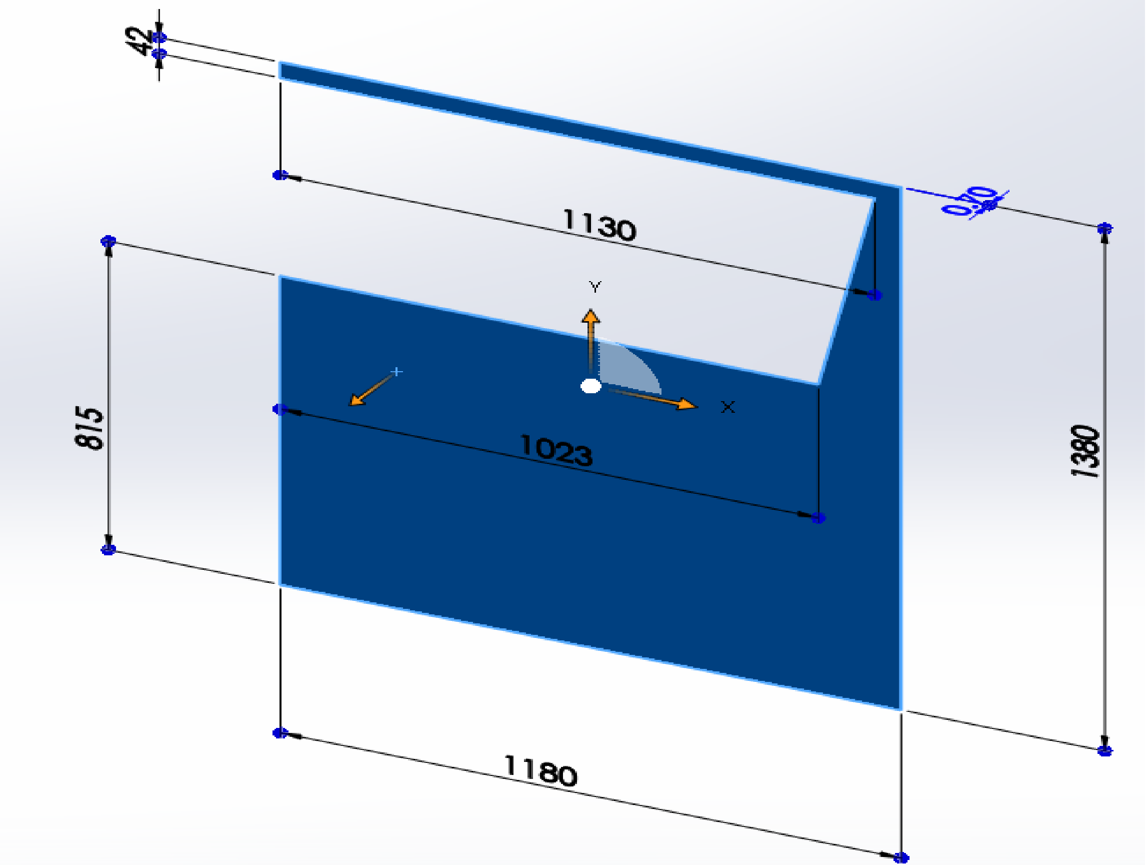


Figure 3. 14 3D drawing of steel and Al6063/E-Glass Fiber/Fly ash composite outer door panel using SOLIDWORK 2017.

3.6 FINITE ELEMENT MODELING AND ANALYSIS

Usually, analytical solutions are not appropriate because of the complexity of the material properties. In such cases, FEM and FEA are used to give engineers awareness of the structural behavior of certain designs and can determine weak points and progress them.

Finite element analysis (FEA) is a mathematical equation that is performed to form a simulation for providing a structural analysis of how a specific design would react under stress in the tangible world [49].

3.6.1 METHODS OF FINITE ELEMENT ANALYSIS

The creation of the finite element analysis (FEA) and Finite Element Method (FEM) of this study was accompanied using ANSYS. ANSYS is one type of CAD software package which comprises several mechanical analysis programs. It is used in different application areas like industries of automotive, nuclear and manufacturing, etc. From the stage of the design concept to the performance validation of the product development cycle ANSYS brings fast, economical, and cost-efficient development [50].

3.6.2 DYNAMIC STRUCTURAL ANALYSIS

Dynamic structural analysis or Transient dynamic analysis is a method that helps to define the dynamic response of a structure of any general time-dependent loads. These dynamic responses can be displacements and stresses due to the loads [51].

GENERAL ASSUMPTION FOR ANALYSIS

Since automotive parts are geometrically complex; approximations and general assumptions are essential to be made to make the simulation more practical without any affection for the result. The assumptions were considered through analysis of both for conventional outer door panel materials and Al6063/E-Glass Fiber/Fly ash composite outer door panel, to be harmonious with the modeling of the outer door panel. Here are the assumptions that were developed for the entire FEM analysis.

- Since the inertial effects are an important factor, dynamic structural analyses are needed to calculate the response of the outer door panel structure to the applied loads and boundary conditions.

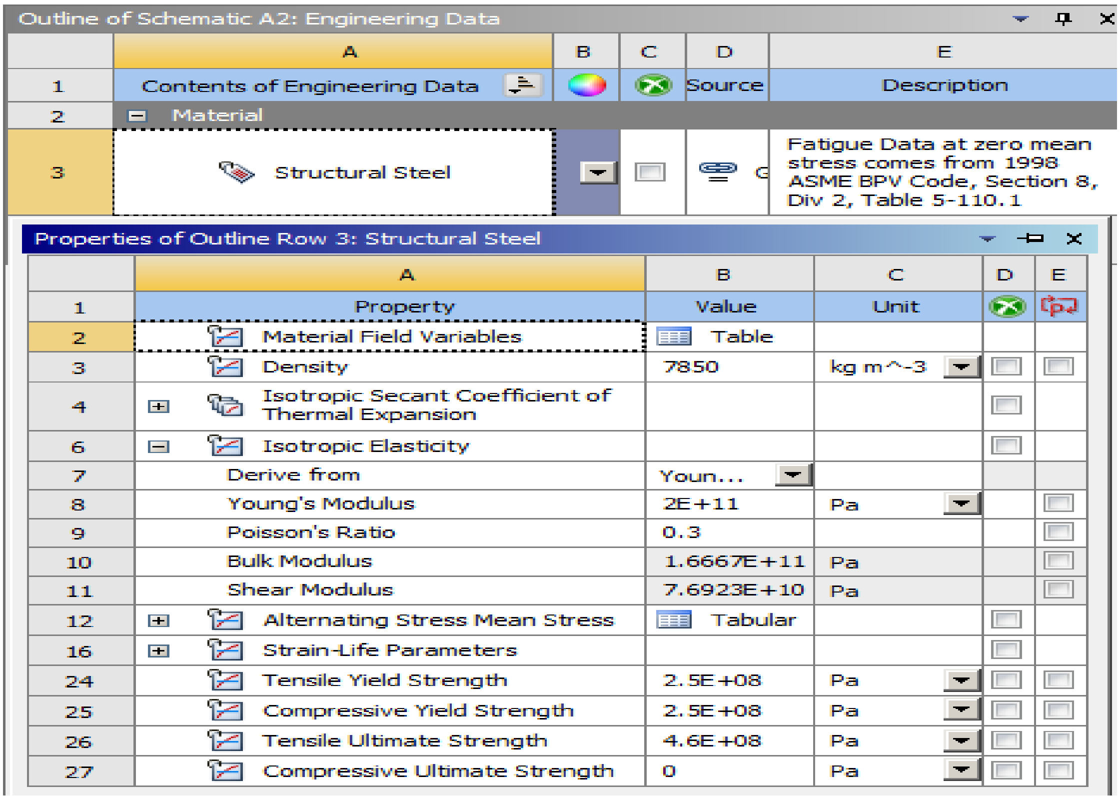
- The entire parts of the outer door panel have uniform element and material properties throughout the model and the grooved parts are assumed as a flat surface.
- The analysis and modeling were applied only for the back outer door panel in which passengers enter and exit through the vehicle.

3.6.2.1 DYNAMIC ANALYSIS OF STEEL OUTER DOOR PANEL AND AL6063/E-GLASS FIBER/FLY ASH OUTER DOOR PANEL

Basic steps for doing transient (dynamic) analysis of a material:

DEFINE ENGINEERING DATA

Defining Engineering data helps to input the mechanical properties of the material (Al6063/E-Glass Fiber/Fly ash composite). It can be applied by choosing the Engineering Data from the analysis tab of the ANSYS Workbench and introducing the equivalent values. The basic corresponding values or material properties are taken from the experimental investigations which are discussed in the previous section. The particular material property of the designated steel and Al6063/E-Glass Fiber/Fly ash composite material is identified in figure 3.15 and 3.16 respectively:



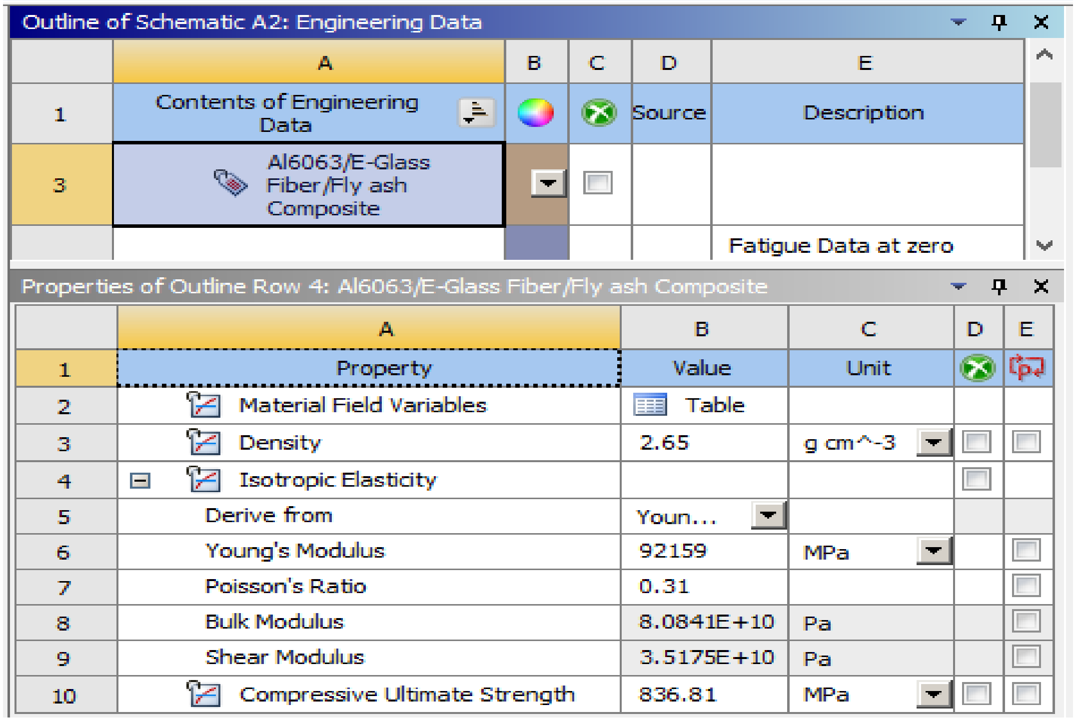
Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Structural Steel		☐		Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1

Properties of Outline Row 3: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7850	kg m^-3	☐	☐
4	Isotropic Secant Coefficient of Thermal Expansion			☐	
6	Isotropic Elasticity			☐	
7	Derive from	Youn...			
8	Young's Modulus	2E+11	Pa		☐
9	Poisson's Ratio	0.3			☐
10	Bulk Modulus	1.6667E+11	Pa		☐
11	Shear Modulus	7.6923E+10	Pa		☐
12	Alternating Stress Mean Stress	Tabular		☐	
16	Strain-Life Parameters			☐	
24	Tensile Yield Strength	2.5E+08	Pa	☐	☐
25	Compressive Yield Strength	2.5E+08	Pa	☐	☐
26	Tensile Ultimate Strength	4.6E+08	Pa	☐	☐
27	Compressive Ultimate Strength	0	Pa	☐	☐

Figure 3. 15 Workbench material properties of steel



Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
3	Al6063/E-Glass Fiber/Fly ash Composite		☐		
					Fatigue Data at zero

Properties of Outline Row 4: Al6063/E-Glass Fiber/Fly ash Composite

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	2.65	g cm^-3	☐	☐
4	Isotropic Elasticity			☐	
5	Derive from	Youn...			
6	Young's Modulus	92159	MPa		☐
7	Poisson's Ratio	0.31			☐
8	Bulk Modulus	8.0841E+10	Pa		☐
9	Shear Modulus	3.5175E+10	Pa		☐
10	Compressive Ultimate Strength	836.81	MPa	☐	☐

Figure 3. 16 Workbench material properties of Al6063/E-Glass Fiber/Fly ash composite

The Next step is importing or attaching geometry. The mechanical geometry model of the panel of the steel and Al6063/E-Glass Fiber/Fly ash is done using SOLIDWORK 2017 which is supported by the ANSYS Workbench and saved as "IGS" form present as shown in figures 3.17 and 3.18 respectively.

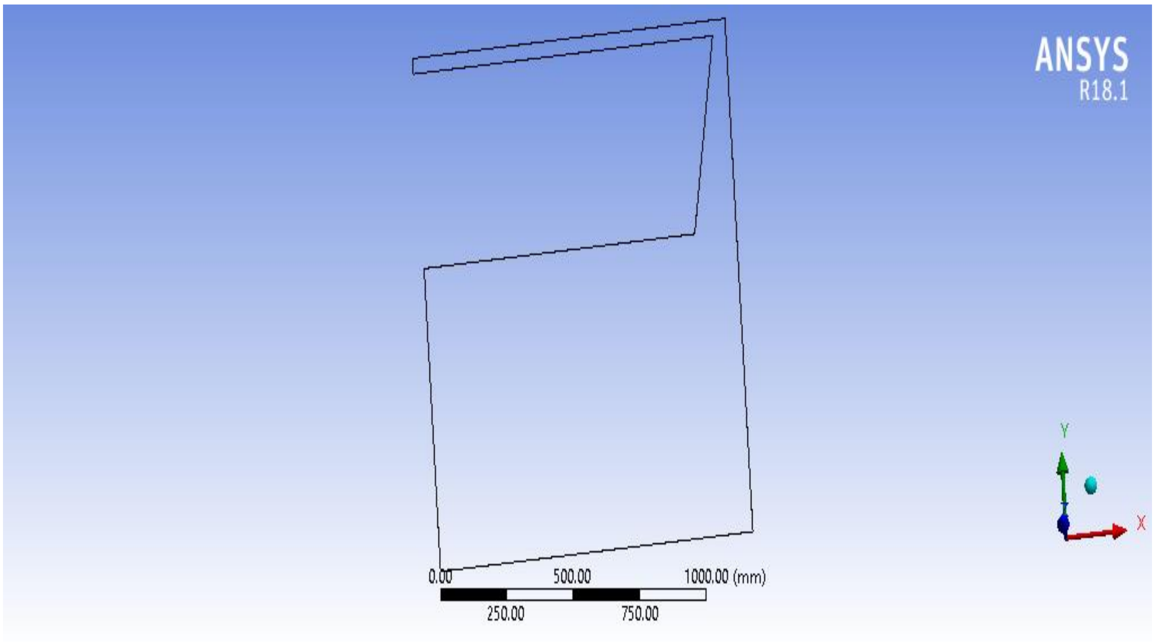


Figure 3. 17 Imported 3D model of steel outer door panel

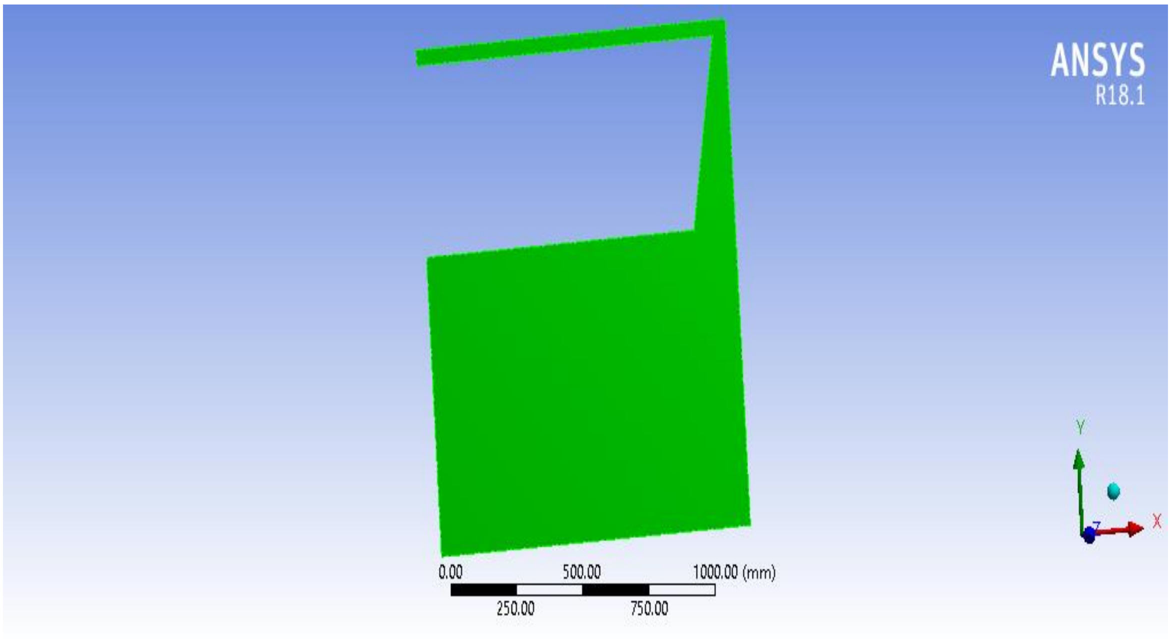


Figure 3. 18 Imported 3D model of Al6063/E-Glass Fiber/Fly ash composite outer door panel.

APPLY MESH CONTROLS/PREVIEW MESH

The basic conception in FEA is analyzing the component as an assembly of discrete pieces called elements which are interconnected to each other a finite number of points known as nodes. The link between these elements is called meshing. Meshing is a procedure of dividing the complex geometry model into small elements that become solvable in an otherwise too more advanced situation. It is performed only after the specification of the element type. Solid modeling of a structure manages a part of the finite element analysis and its main purpose is to form the mesh of the geometry, as conveniently and efficiently as possible [52]. In this study, the process of meshing is completed by using this automatic meshing generation method. The mesh size can be observed from the convergence test. Here the mesh size was refined from 5mm to 2mm range and selecting an element size of 2mm will be equitable, because no substantial difference will be attained by further reducing the mesh size as displayed in figure 3.19. The meshed model for both steel and Al6063/E-Glass Fiber/Fly ash outer door panel is shown in figures 3.20 and 3.21 with a node of 11483 and a number of elements 1540.

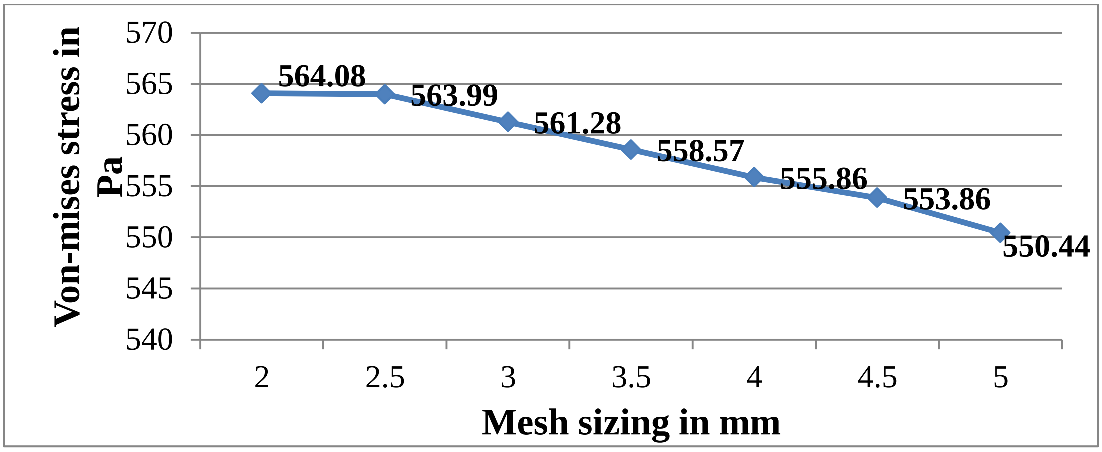
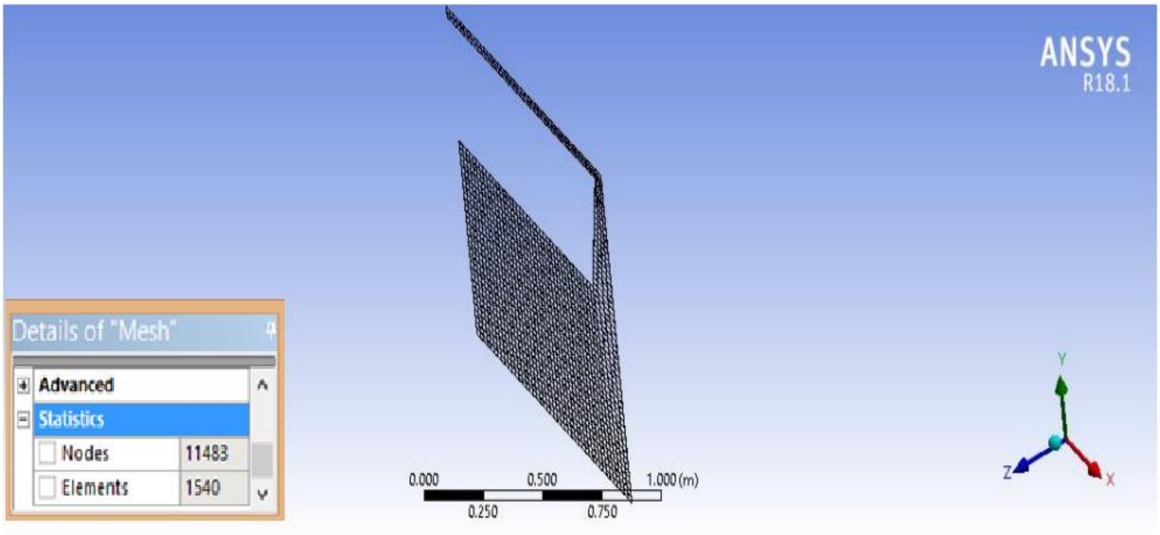


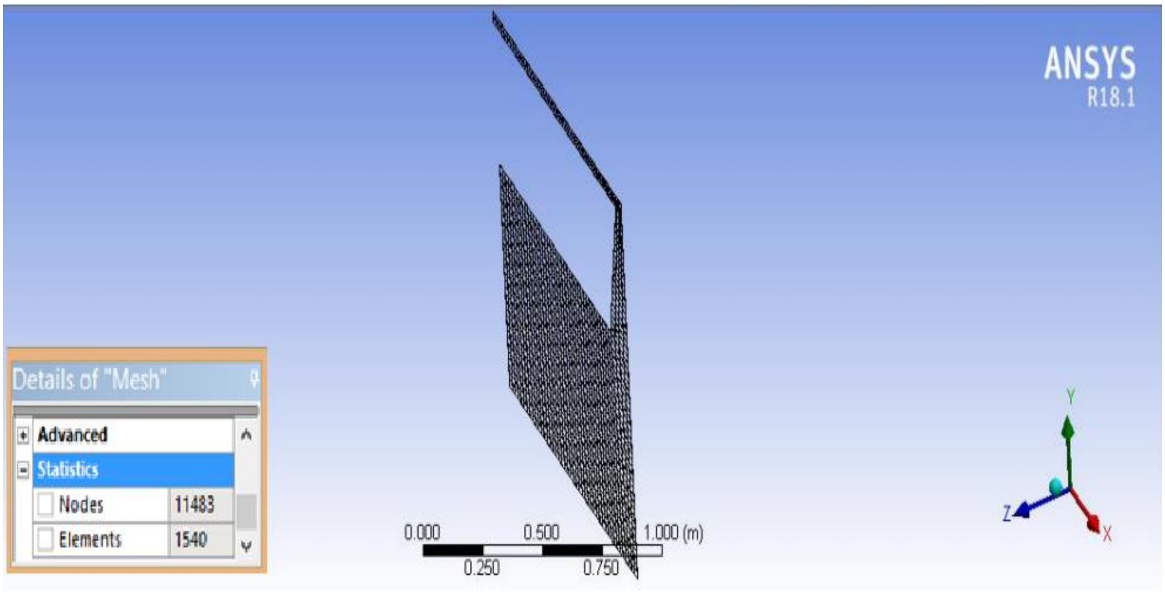
Figure 3. 19 Convergence result.



Nodes 11483

Elements 1540

Figure 3. 20 Meshed model of steel Outer door panel.



Nodes 11483

Elements 1540

Figure 3. 21 Meshed model of Al6063/E-Glass Fiber/Fly ash Outer door panel.

LOADING AND BOUNDARY CONDITIONS

This step contains specifying the appropriate boundary conditions and the proper loading mechanisms in ANSYS. Since the foremost objective of finite element analysis is to observe how a structure or component responds to certain loading conditions. To achieve the correct stress analysis for any application, the support and the load should be defined. This will guarantee that the solution integrates to support the domain. The door panel is mounted on the floor and roof of the automobile and it slides between the two parts in the "X" direction and in the negative and positive ''Z'' direction it is considered as fixed support.

In this research, the load that is to be applied for the analysis purpose is the inertial load due to the acceleration field intensity through closing the door. The maximum acceleration value through closing the door is 350m/s^2 [41]. For this analysis, this value is used for both steel outer door panel and composite outer door panel along a_x direction as shown in figure 3.22 and 3.23.

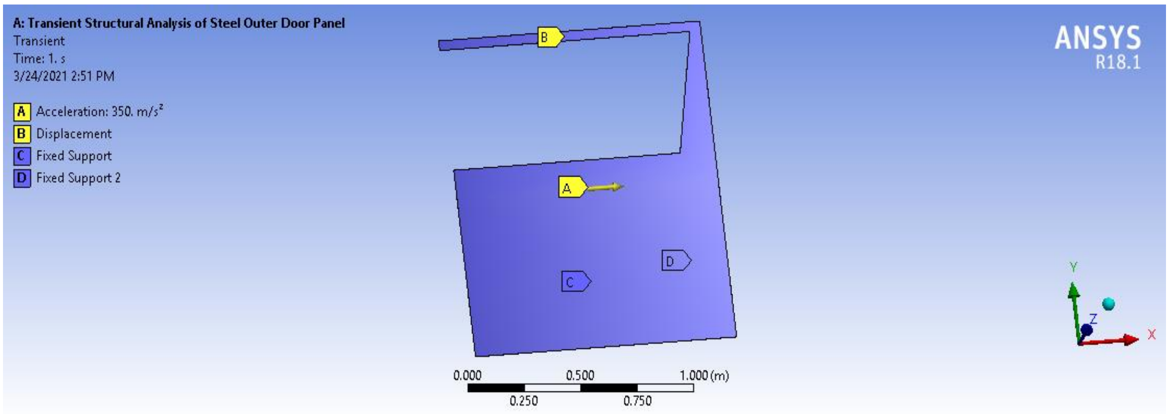


Figure 3. 22 Boundary condition and applied load of Steel outer door panel

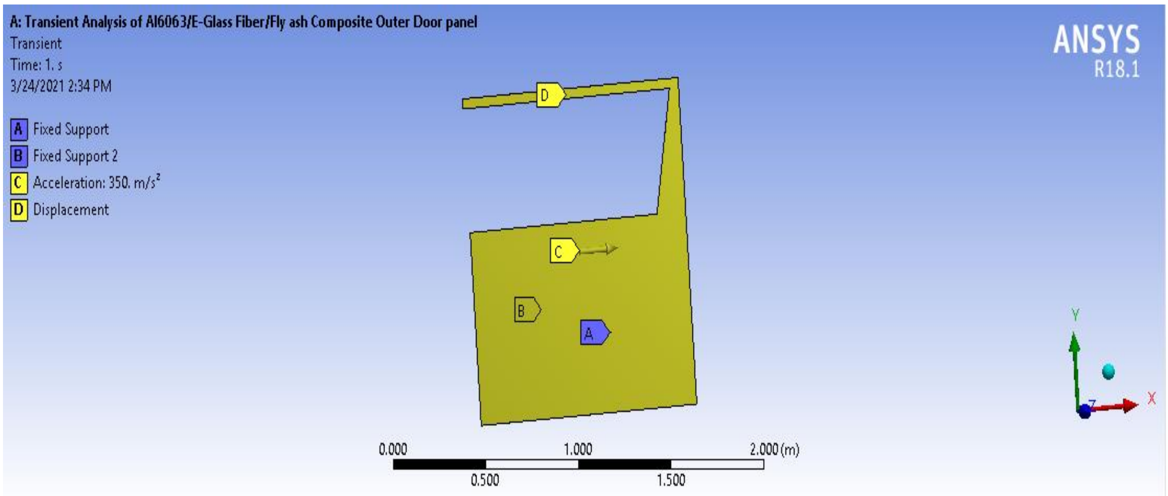


Figure 3. 23 Boundary condition and applied load of the Al6063/E-Glass Fiber/Fly ash composite outer door panel.

GENERATE SOLUTION

Based on the above input parameters of the research the solution is generated. By using this software, the equivalent (Von Mises) stress and the total deformation are the basic variables to be solved.

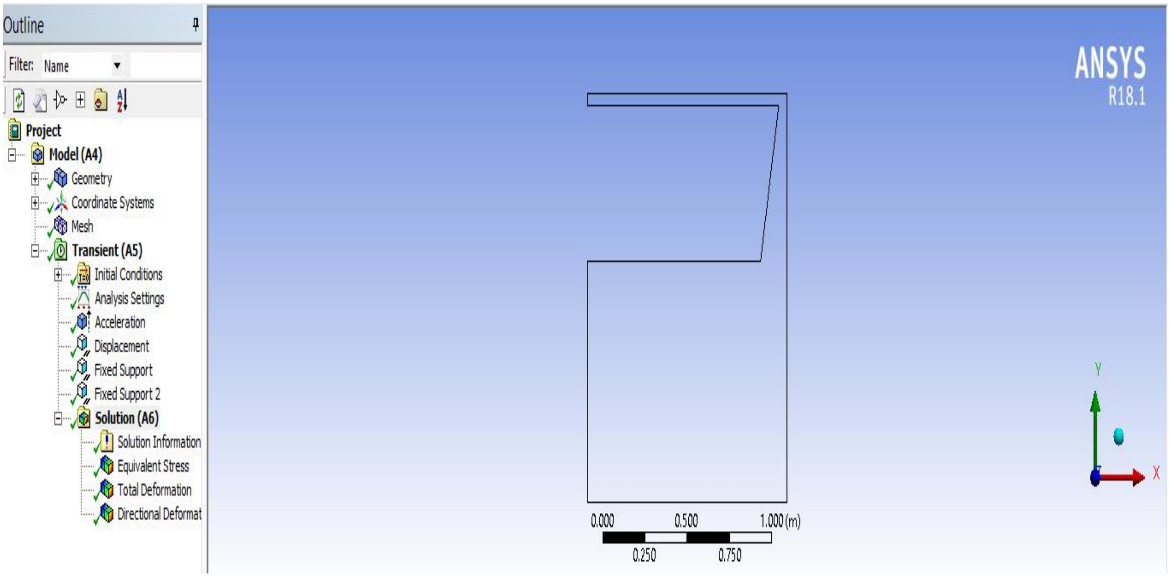


Figure 3. 24 Generating solution of steel outer door panel

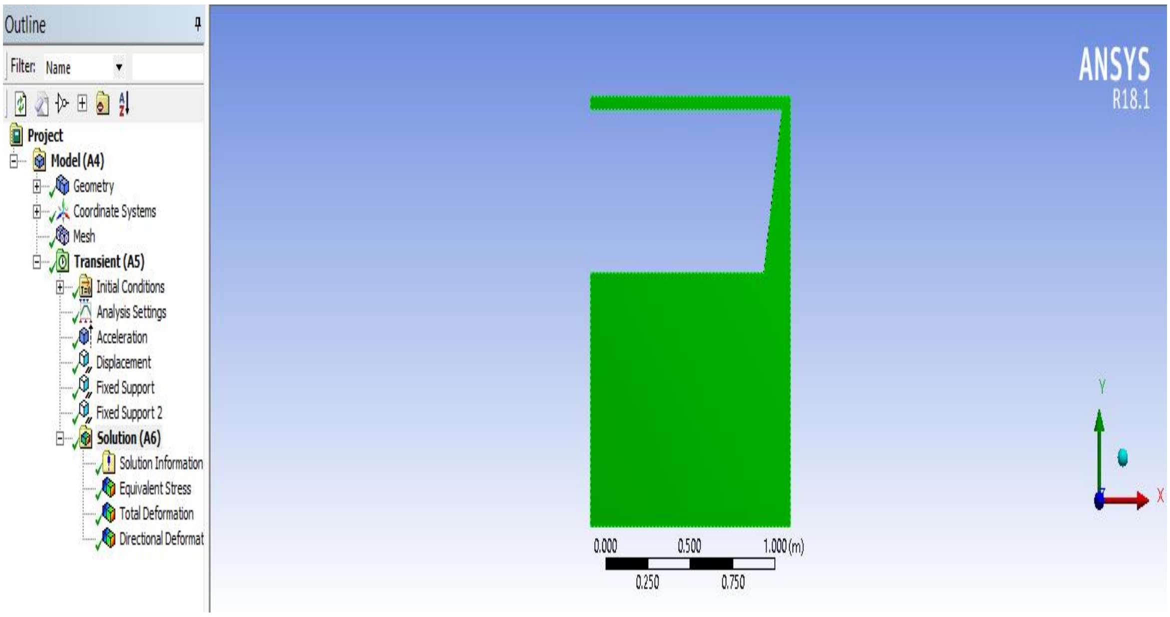


Figure 3. 25 Generating solution of Al6063/E-Glass Fiber/Fly ash outer door panel.

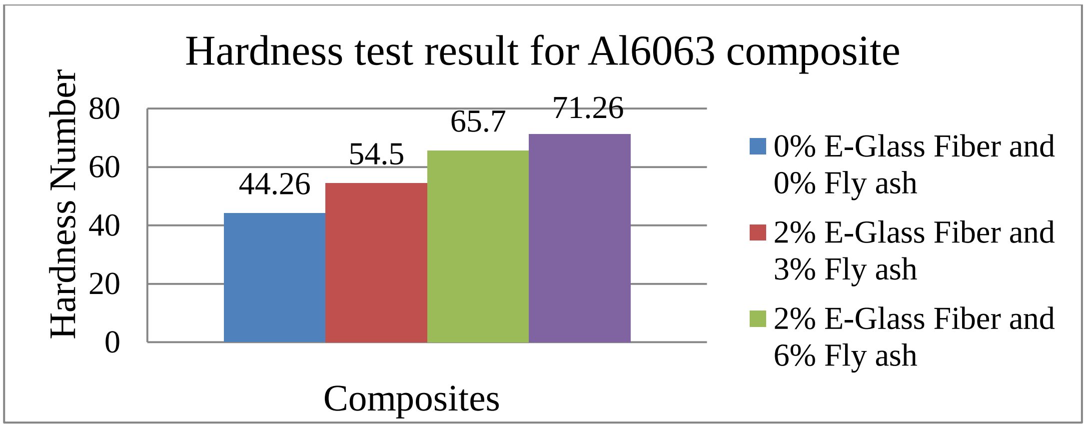
CHAPTER FOUR
RESULTS AND DISCUSSIONS

This chapter describes the results of the analysis performed by using experimental analysis and simulation analysis. The experimental analysis is to define the material property of Al6063/E-Glass Fiber/ Fly ash composite as per ASTM standard and the finite element model comprises the transient structural dynamic analysis to determine the von-mises stress and total deformation of the outer door panel for both materials of both steel outer door panel and Al6063/E-Glass Fiber/ Fly ash composite outer door panel although the geometry and load application are the same for both outer door panels.

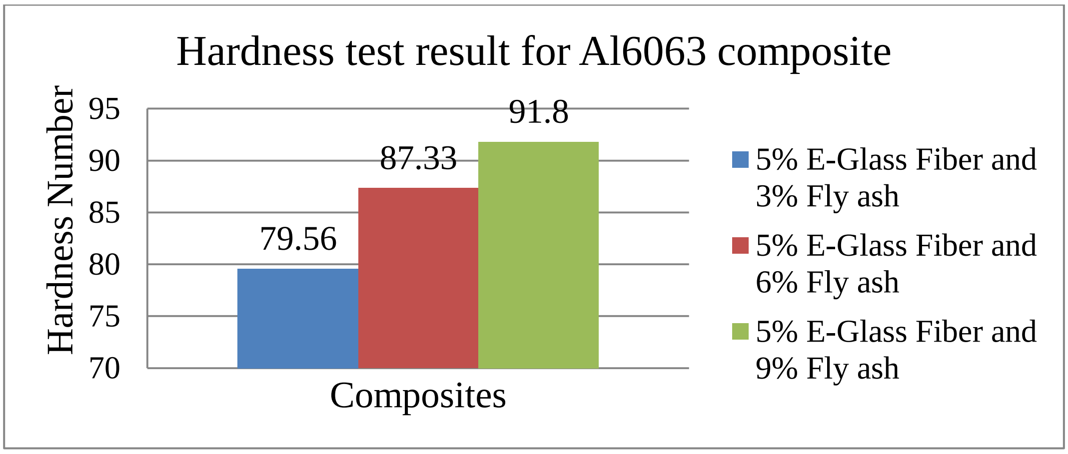
4.1 EXPERIMENTAL RESULTS

4.1.1 HARDNESS TEST

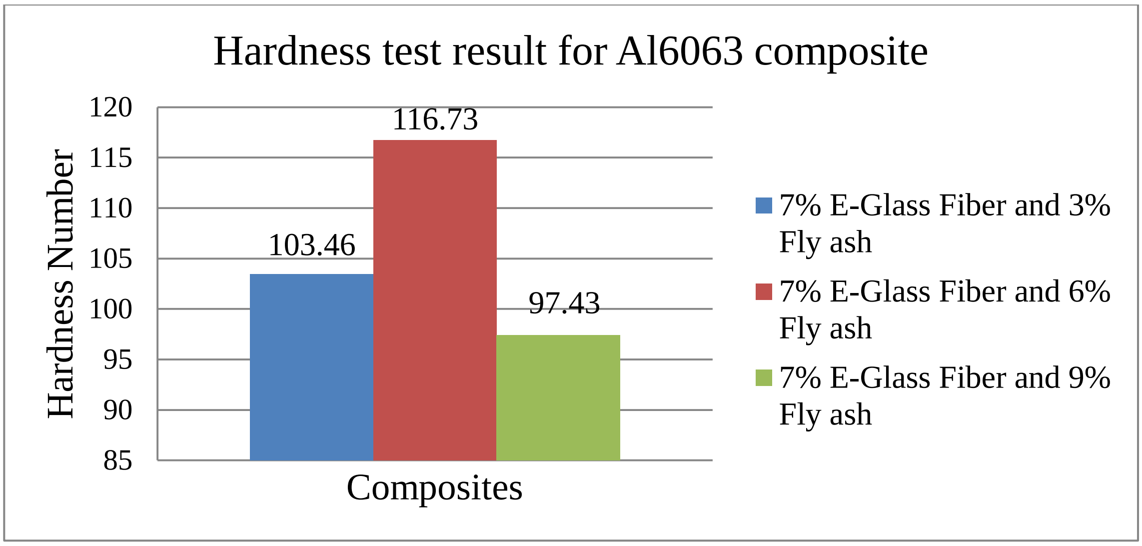
For the Hardness test, three specimens were prepared, their average value is taken and presented in the figure (a,b,c,d).



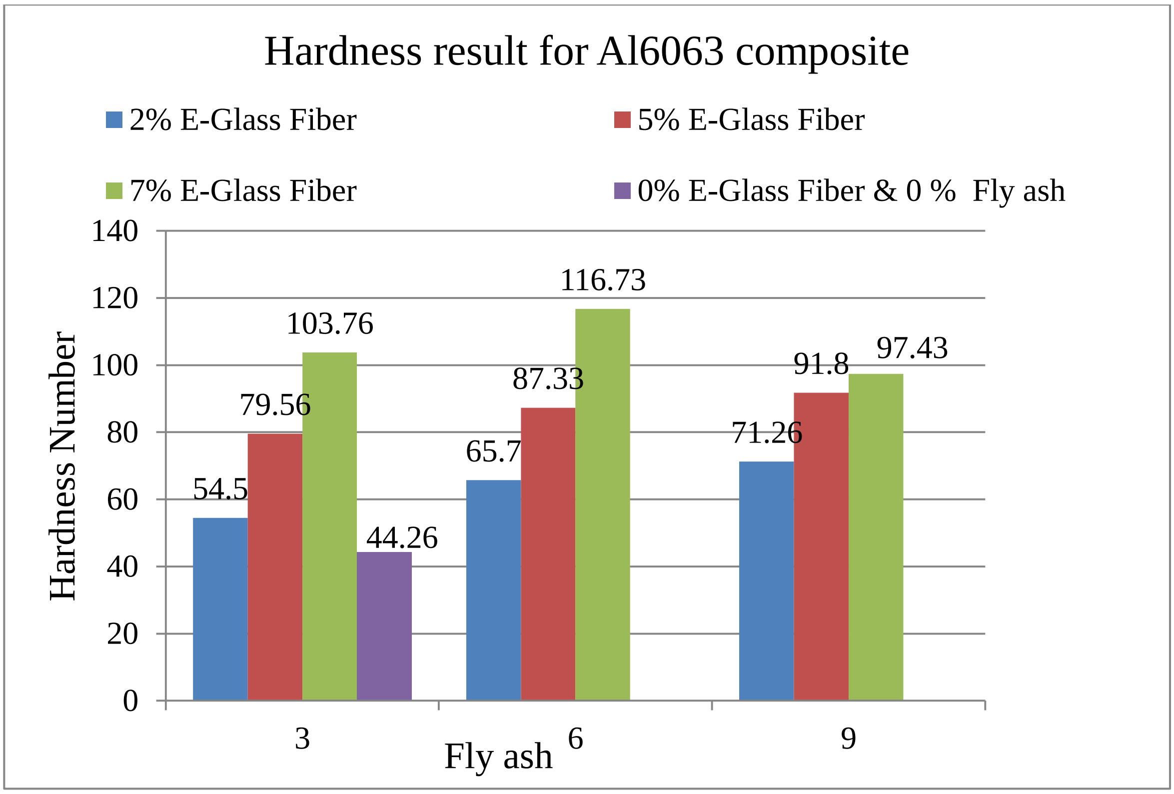
(a)



(b)



(c)

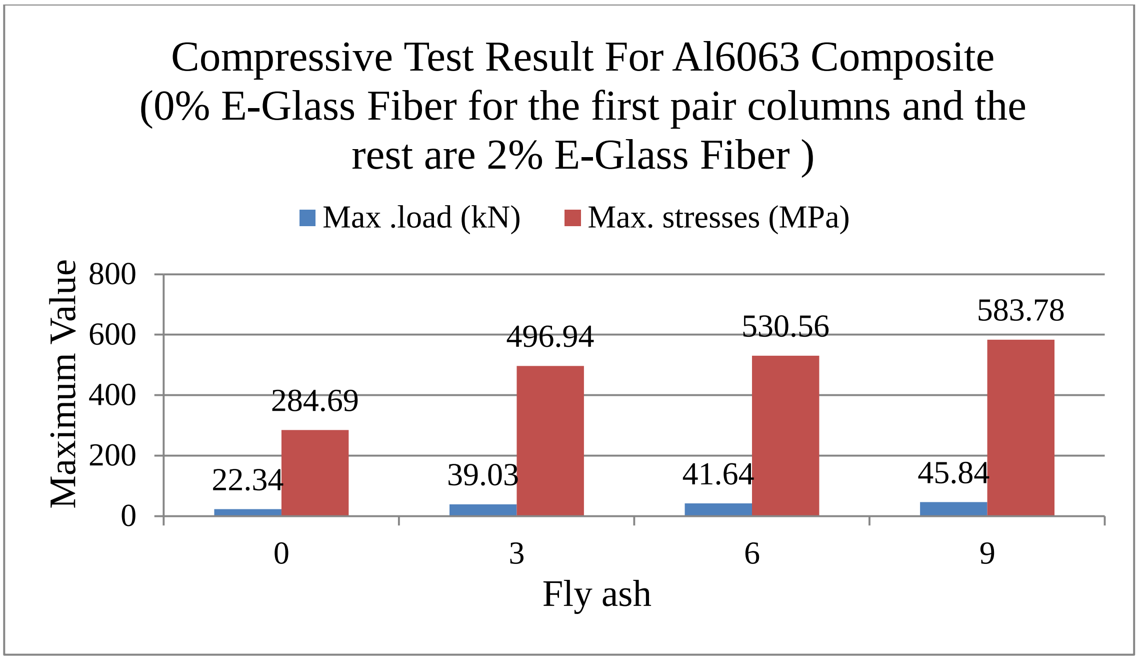


(d)

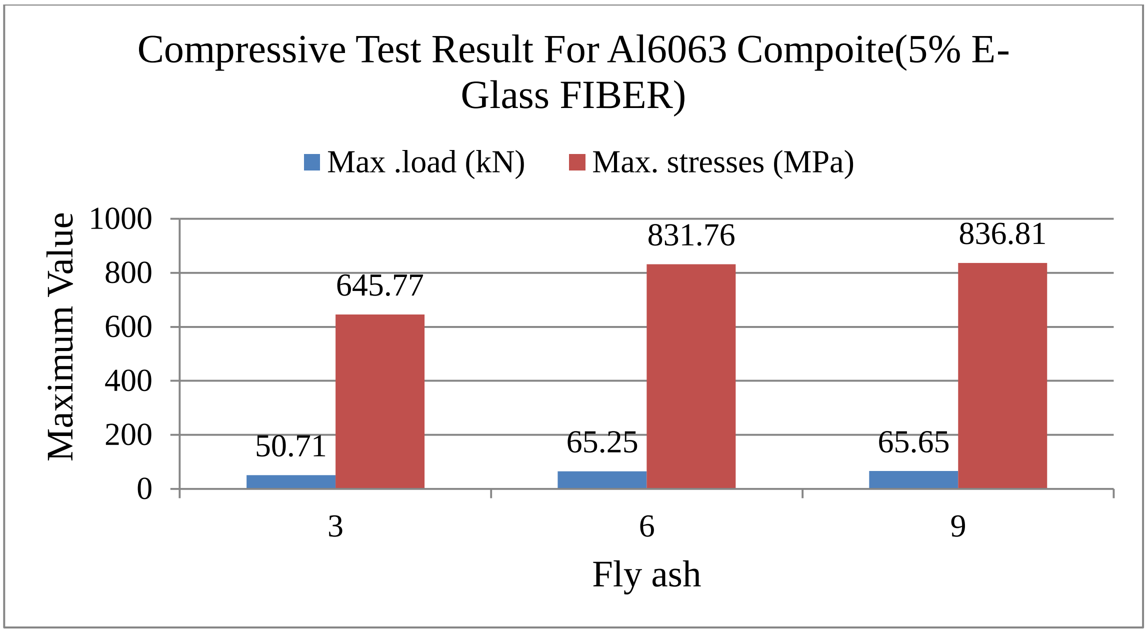
Figure 4. 1 (a,b,c,d) Hardness test result for Al6063 with different volume fraction E-Glass fiber & Fly ash.

4.1.2 COMPRESSION TEST

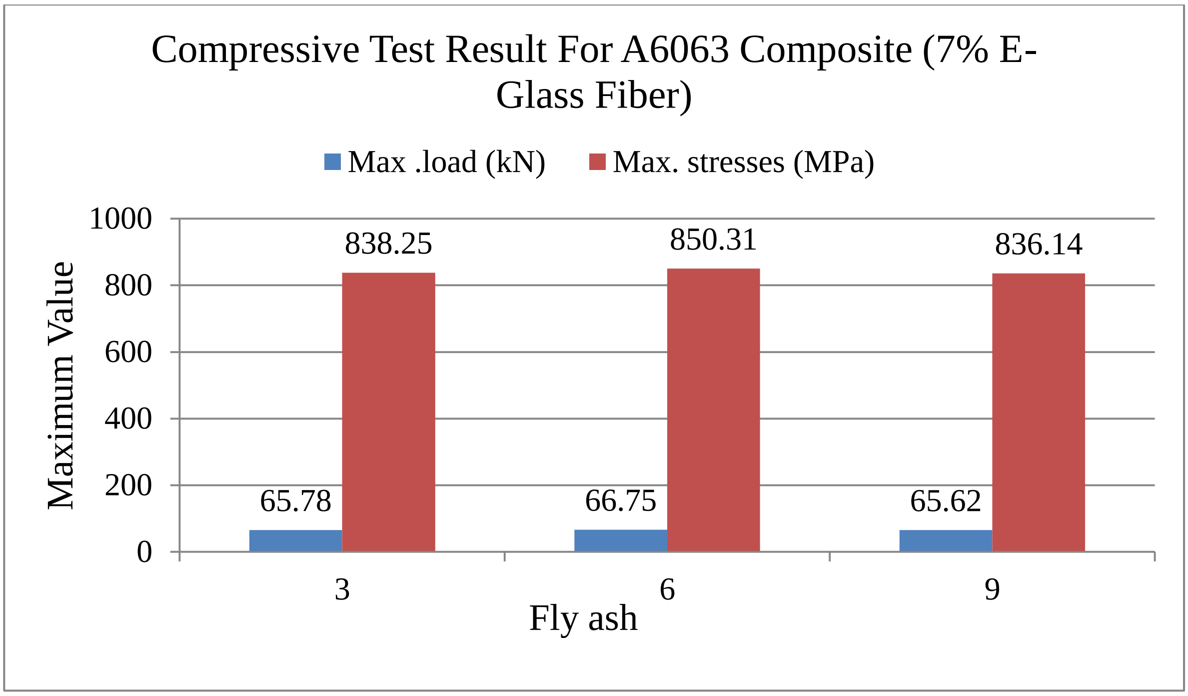
For the compression test, three specimens were prepared, their average value is taken and presented in the figure (a,b,c,d).



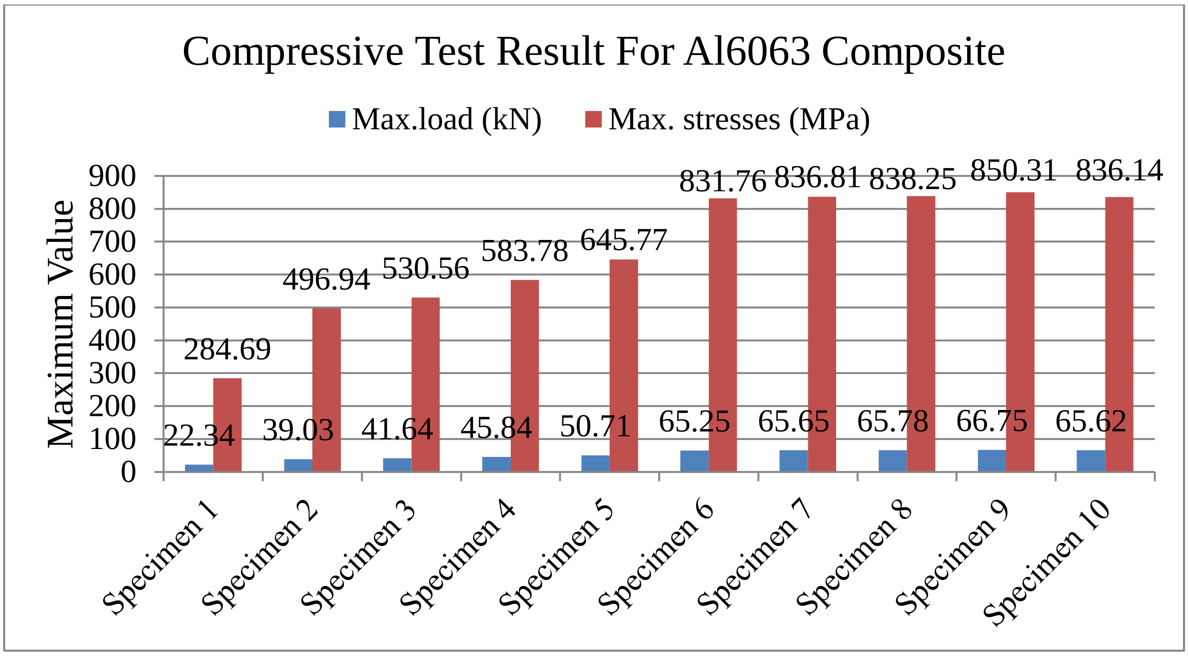
(a)



(b)



(c)



(d)

Figure 4. 2 (a,b,c,d) Compression strength test result for Al6063 with different volume fraction E-Glass fiber & Fly ash.

4.1.3 FLEXURAL TEST

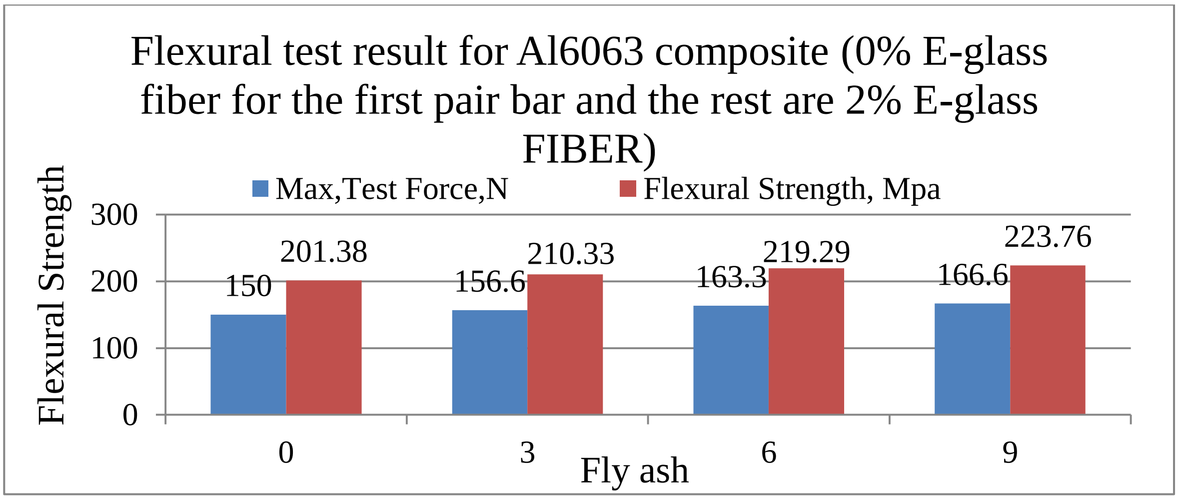
For the flexural test, three specimens were prepared and their average value is taken and presented in the figure (a,b,c,d). The flexural strength is calculated by using the following equation [2].

$$\sigma_{bf} = \frac{3LP}{2(bd^2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.1.$$

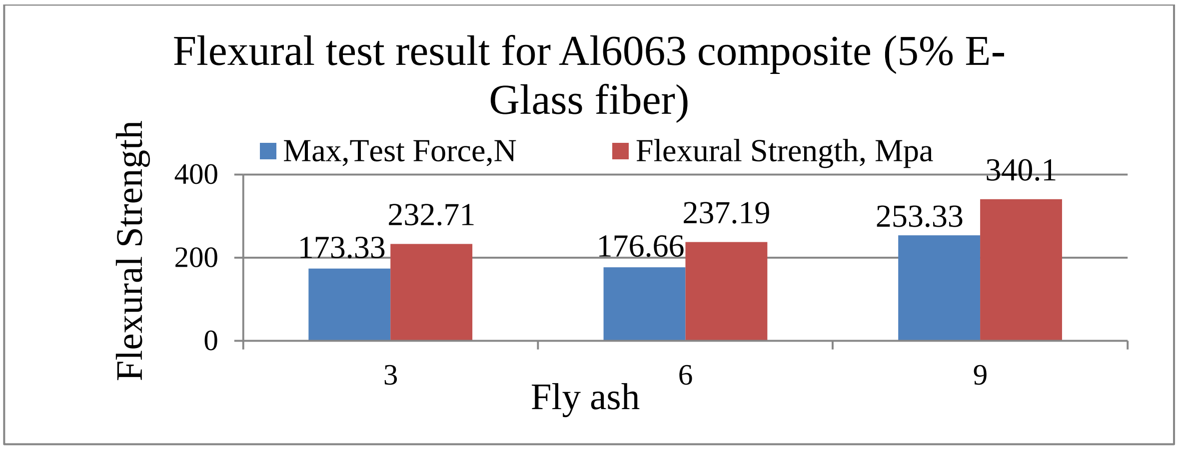
Where, σ_{bf} is stress in the outer surface at the midpoint (MPa),

P is the load at a given point (N), L is supported span (mm),

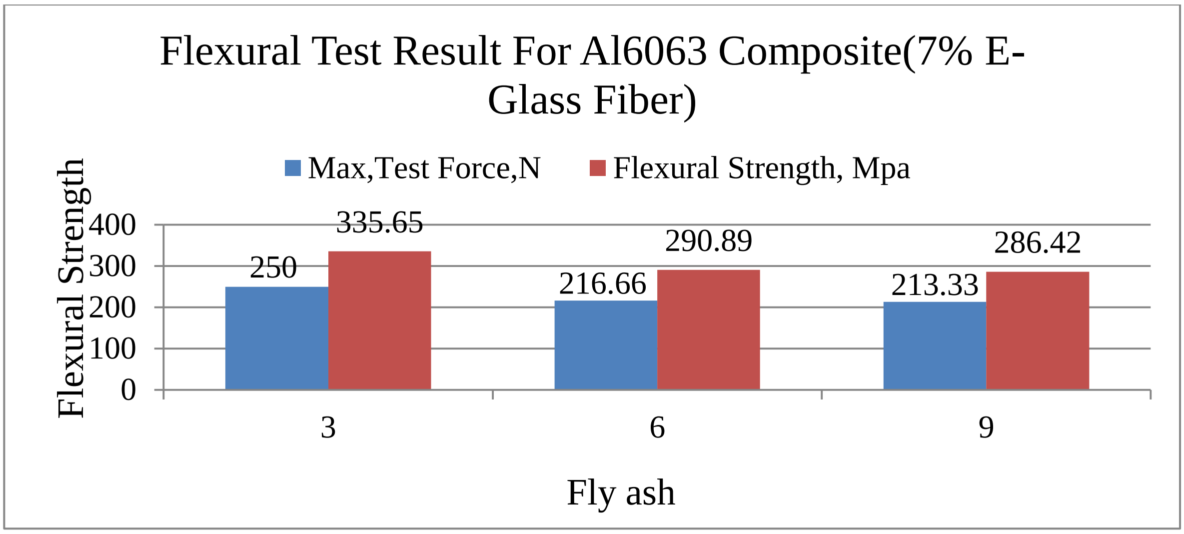
b is the width of the test beam (mm), and d is the thickness or depth of the tested specimen.



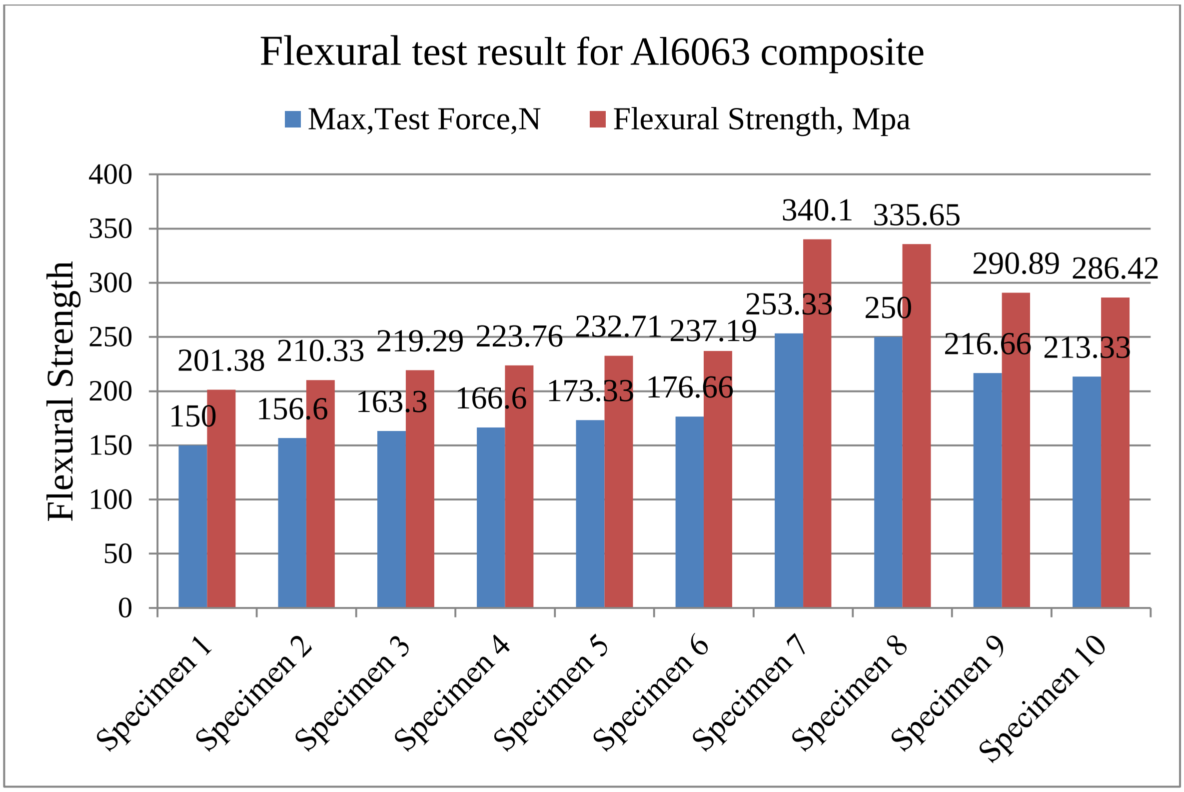
(a)



(b)



(c)



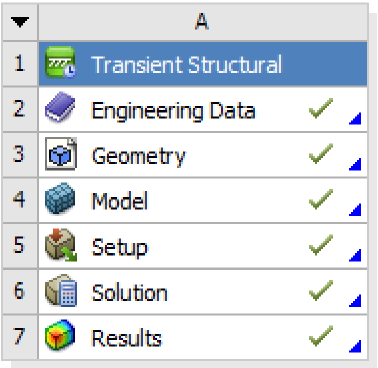
(d)

Figure 4. 3 (a,b,c,d) Flexural strength test result for Al6063 with different volume fraction E-Glass fiber & Fly ash

4.2 TRANSIENT ANALYSIS RESULT

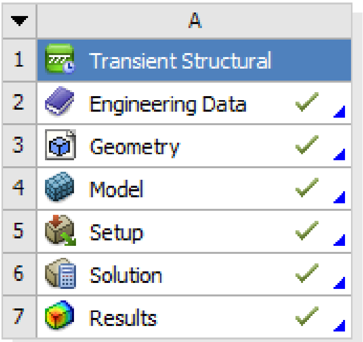
A. EQUIVALENT (VON- MISES) STRESS (Pa)

The transient structural dynamic analysis of the outer door panel is accomplished using FEM by using ANSYS 18.1 workbench that consists of a transient structural (ANSYS). This is for the determination of attaining the maximum and minimum equivalent stress and displacement on the structural model. The transient structural analysis defines the characteristics of the stress and deformation of the structure caused by the applied transient loading systems and boundary conditions. Fig 4.4 shows the listed transient structural analysis process and it could be accomplished one by one to complete the analysis and get applicable solutions to the problem.



	A	
1	Transient Structural	
2	Engineering Data	✓
3	Geometry	✓
4	Model	✓
5	Setup	✓
6	Solution	✓
7	Results	✓

Transient Structural Analysis of Steel Outer Door Panel



	A	
1	Transient Structural	
2	Engineering Data	✓
3	Geometry	✓
4	Model	✓
5	Setup	✓
6	Solution	✓
7	Results	✓

Transient Analysis of Al6063/E-Glass Fiber/Fly ashOuter Door panel

Figure 4. 4 ANSYS Workbench transient structural analysis process.

The equivalent (Von Misses) stress values of both the steel outer door panel and Al6063/E-Glass Fiber/ Fly ash composite outer door panel of FEA respectively looks like in figure 4.5 and 4.6.

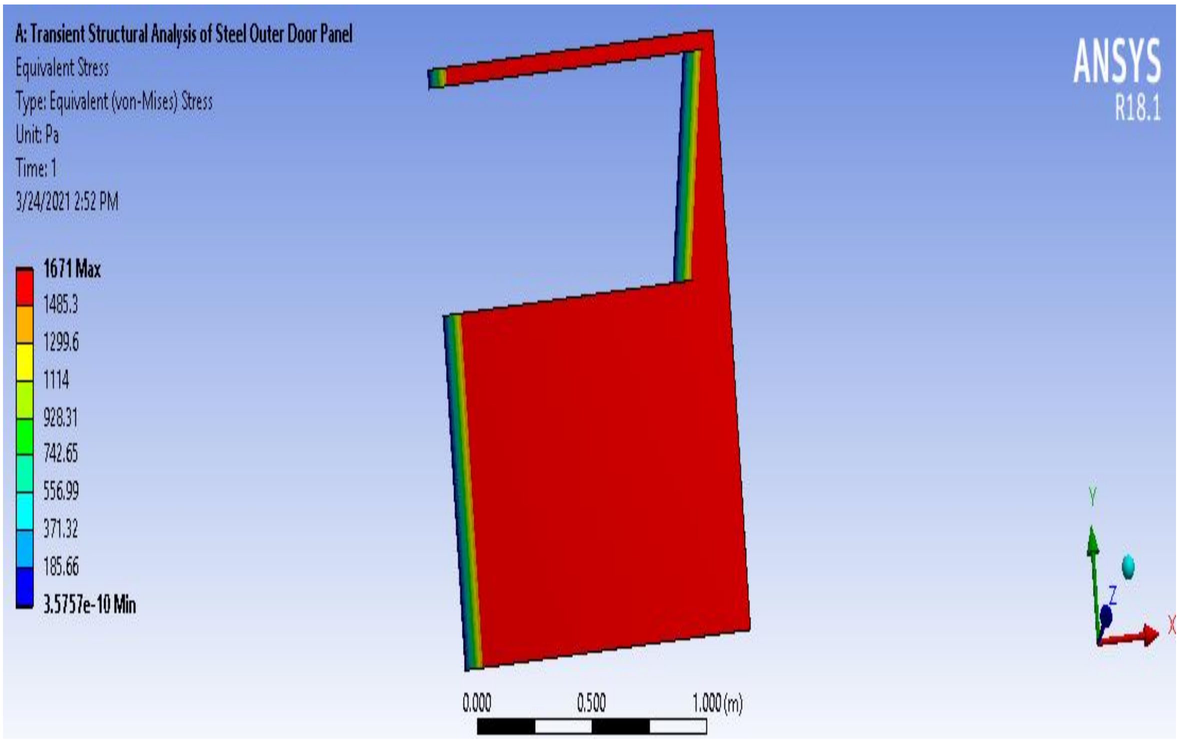


Figure 4. 5 Equivalent (Von Mises) stress of steel outer door panel.

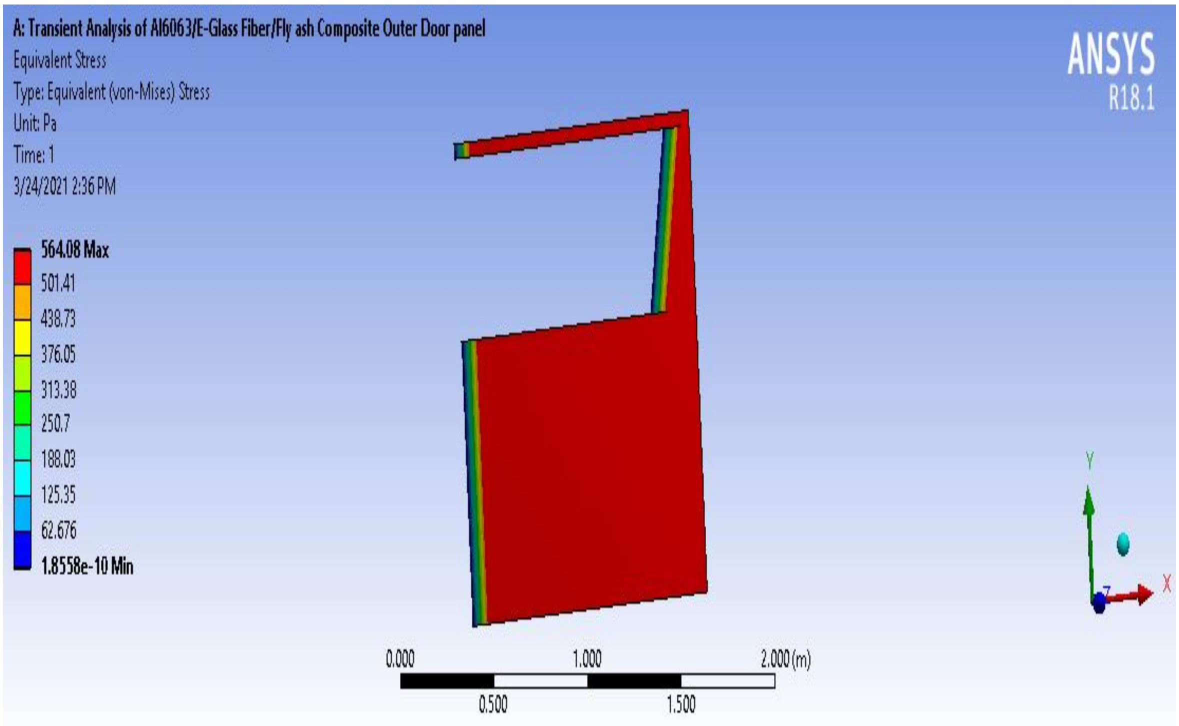


Figure 4. 6 Equivalent (Von-Mises) stress of Al6063/E-Glass Fiber/ Fly ash composite outer door panel.

B. DEFORMATION

The deformation values of both the steel outer door panel and Al6063/E-Glass Fiber/ Fly ash composite outer door panel of FEA respectively looks like in figure 4.7 and 4.8.

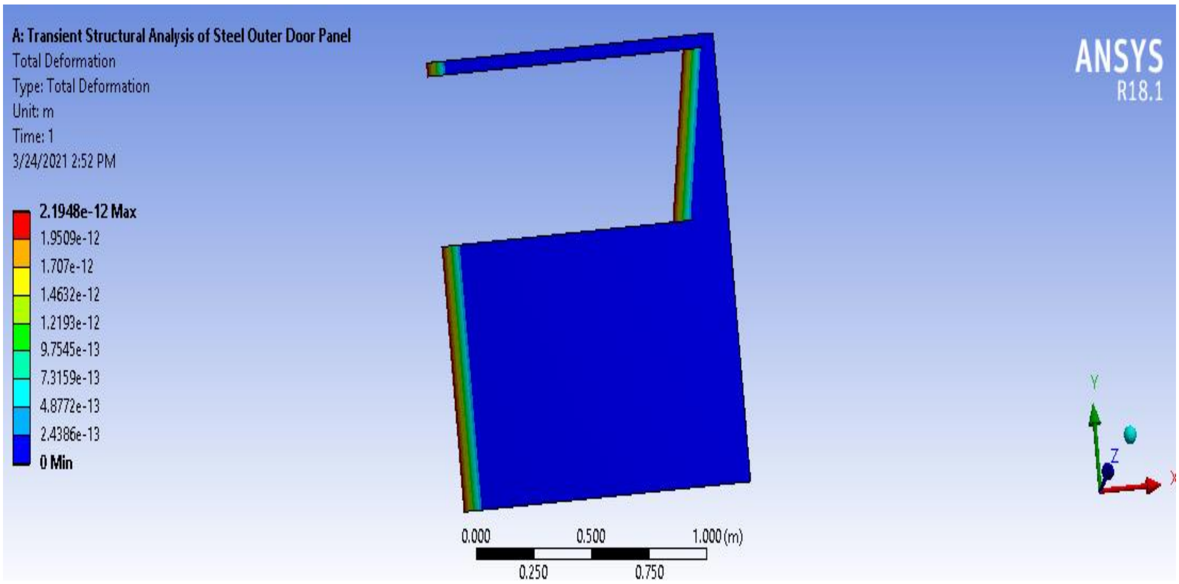


Figure 4. 7 Deformation of steel outer door panel.

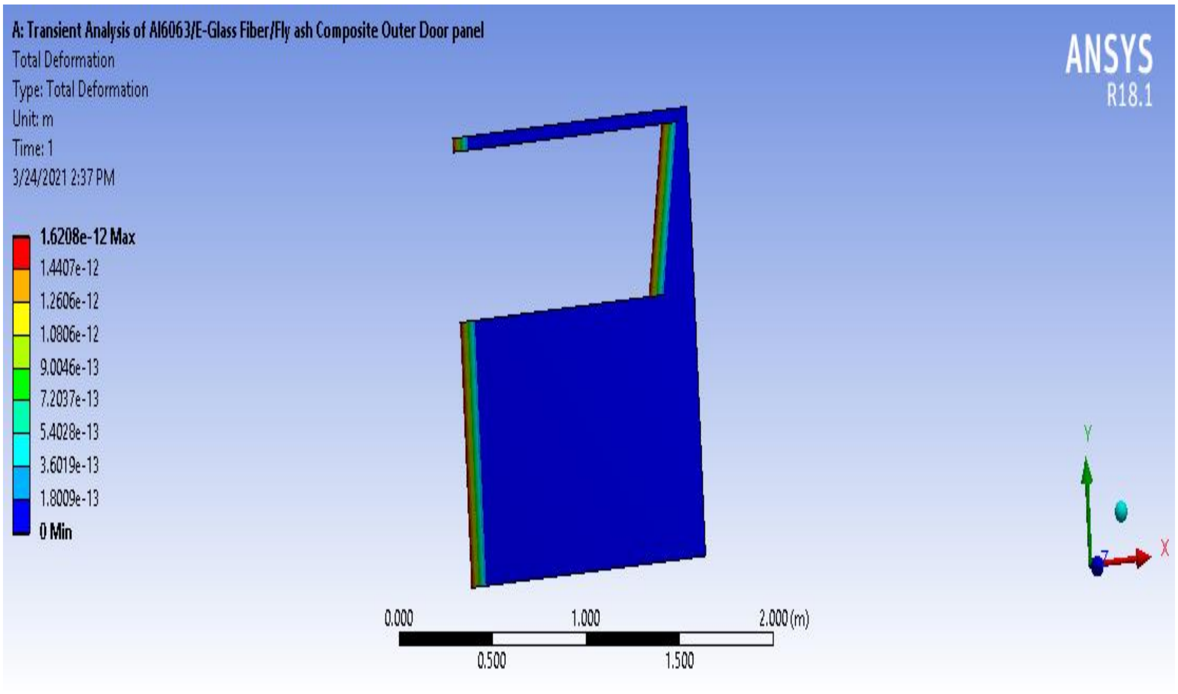


Figure 4. 8 Deformation of Al6063/E-Glass Fiber/ Fly ash composite outer door panel.

4.3 DISCUSSION

4.3.1. EXPERIMENTAL RESULT DISCUSSION

4.3.1.1 DISCUSSION OF HARDNESS TEST

As shown from fig 4.1 the results of the hardness of the composite are higher than the unreinforced matrix metal and it is also observed that there is a significant increasing trend of hardness with an increase in volume fraction of E-glass fiber and fly ash. Here because these reinforcing particles enhance the resistance of the deformation when it is subjected to a load. At 7% E-Glass fiber and 6% fly ash there is the maximum hardness (116.73 HRB) which is higher than the unreinforced aluminum by 54.7%. However at 7% E-Glass fiber and 9% fly ash hardness drops by 16.53% but still higher than the unreinforced metal matrix 54.5%. In this composition there is a high amount of reinforcements than the other compositions due to that it reduces the interfacial bonding between the matrix and constituents.

It is also revealed that the hardness of the composite material increases with the volume fraction of fly ash and E-glass fiber. The addition of reinforcing particles makes the ductile aluminum alloy more brittle and also the dispersion of reinforcing particles improves the hardness, as particles are harder than aluminum alloy, and reduce their inherent property of hardness to soft matrix [23, 33, 34].

4.3.1.2 DISCUSSION OF COMPRESSION TEST

From fig 4.2 compressive strength of the composite is higher than the monolithic metal matrix and also there is an increment of compressive strength during increasing the volume fraction of E-Glass fiber and fly ash. The incorporation of these reinforcing components resists deforming stresses and thus improving the compressive strength of the aluminum metal matrix composite. The maximum compressive strength was found in the composition of 7% E-Glass fiber and 6% fly ash which is a maximum load of 66.75 kN and maximum stress 850.31Mpa which is higher than the unreinforced aluminum by 66.51%. In composition 7% E-Glass fiber and 9% fly ash compressive strength decreases by 1.6% from specimen nine. It can be concluded that as the amount of reinforcing particles increase there is a possibility of forming a cluster that deteriorates the properties which leads to reducing the ability of the matrix to transfer load.

Similar results were shown that that the compressive strength increased with an increase in the weight percentage of reinforcing particles. This is due to the hardening of the base alloy by fly ash particulates [31, 32].

4.3.1.3 DISCUSSION OF FLEXURAL STRENGTH

Figure 4.3 illustrates the average values of flexural strength and output force for all bending test specimens. From the average values of flexural specimens, the maximum flexural strength value is 340.1MPa and the maximum output force is 253.33N it increases from the monolithic aluminum by 40.7%. But beyond specimen seven it decreases by 1.3%, 14.46%, and 15.75% from the maximum bending strength for specimen eight, specimen 9, and specimen 10 respectively. So, from here we can conclude that as the volume fraction increases the composite losses its property of restricting the plastic flow of the specimens. Similar results were demonstrated that the flexural strength of the composite increases with the increasing weight % of the particles [30].

4.4 TRANSIENT ANALYSIS RESULT DISCUSSIONS

This transient structural dynamic analysis of the outer door panel of a vehicle using Al6063/E-Glass Fiber/ Fly ash composite was done for self-weight inertial load intensity of the shock produced while closing the door. Comparing the results achieved by FEA of the Al6063/E-Glass Fiber/ Fly ash composite outer door panel with steel outer door panels is important to see the improved achievement. During comparing these two materials one thing to note is, except for the material properties the materials are the same in everything such as the same acceleration field, in the same model, and the same method of FEM analysis.

Stress: Stress can be defined as when external loads are applied to an object it is reacted by an internal resistance force set up within the object or it is defined as the average force per unit area [47].

4.4.1 EQUIVALENT (VON-MISES) STRESS

Equivalent (Von Mises) stress, is stress that arises from distortion energy failure theory, and it is extensively used by designers to check whether their design structure will withstand a given load condition. Using the ANSYS Workbench 18.1 software along with the given boundary conditions and applied loads as shown in figures 4.5 and 4.6 this result has been found; the maximum von - Mises stress is 1671Pa for steel outer door panel and 564.08 Pa Al6063/E-Glass Fiber/Fly ash composite outer door panel. The minimum von – mises stress is $3.5757e^{-10}$ Pa for steel outer door panel and $1.8558e^{-10}$ Pa for Al6063/E-Glass Fiber/Fly ash composite outer door panel. The results of this transient structural analysis show that the equivalent (Von-Misses) stress of the Al6063/E-Glass Fiber/Fly ash composite outer door panel is the smallest one as compared to that of the current conventional structural steel outer door panel under the same acceleration and boundary conditions. This indicates that the Al6063/E-Glass Fiber/Fly ash composite outer door panel is less stressed or can withstand the applied acceleration than the steel outer door panel.

4.4.2 DEFORMATION

From this transient structural analysis ANSYS 18.1 workbench software, shown in fig 4.7 and 4.8 the maximum deformation observed is $1.6208e^{-12}$ m for Al6063/E-Glass Fiber/Fly ash composite outer door panel and $2.19948e^{-12}$ m conventional structural steel outer door panel.

4.5 NUMERICAL ANALYSIS DISCUSSION

This section of the paper states the result attained from the ANSYS software carried out by making everything the same for both outer door panels, except material properties; i.e. at the same loading (acceleration)type and magnitude, the same boundary condition, and the same method of finite element analysis.

Table 4. 1 Transient analysis result summary

Transient Analysis		**Case 1**	**Case 2**	**Performance comparison**
Von - mises stress (Pa)	Max	1671 Pa	564.08 Pa	1671 – 564.08 = 1106.92 Pa % reduction of Max Stress= $\frac{1106.92}{1671} * 100$ = **66.24%**
	Min	$3.5757e^{-10}$Pa	$1.8558e^{-10}$ Pa	
Deformation (mm)	Max	$2.1948e^{-12}$m	$1.6208e^{-12}$ m	2.1948 -1.6208 m=$0.574e^{-12}$ m % reduction of Max Def.= $\frac{0.574\ e^{-12}\ \mathrm{m}}{2.1948e^{-12}\ \mathrm{m}} * 100$ = **26.3%**
	Min	0	0	

Note: Case 1- Current steel outer door panel.

Case 2- The newly designed AMMC composite outer door panel.

As shown from Table 4.1, the transient analysis result using ANSYS 18.1 Workbench software illustrates the value of the stress is vary for each case. The maximum stress position is also varying from case one to case two. In the current steel outer door panel (case1) as shown in figure 4.5 and figure 4.6, the maximum von - mises stress and deformation are 1671 Pa and 2.1948e^{-12} m respectively. In the newly designed Al6063/E-Glass Fiber/Fly ash composite outer door panel (case 2) as shown in figures 4.7 and 4.8, the maximum von mises stress and deformation is 564.08 Pa and 1.6208e^{-12} m respectively.

Depending on transient analysis results, the equivalent (Von-Misses) stress of the Al6063/E-Glass Fiber/Fly ash composite outer door panel is the smaller one as compared to that of the current steel outer door panel. It can be concluded from this AMMC outer door panel can resist the applied load than the steel outer door panel. The maximum displacement of the Al6063/E-Glass Fiber/Fly ash composite outer door panel has a lower deformation value compare with that of the steel outer door panel, under the same FEM. This indicates that the Al6063/E-Glass Fiber/Fly ash composite outer door panel is less stressed, lightweight, and has a better performance. Generally the comparison of transient structural analysis of outer door panel of a vehicle using both steel and Al6063/E-Glass Fiber/Fly ash composite material was performed. From FEA result comparing of steel outer door panel and newly designed Al6063/E-Glass Fiber/Fly ash composite outer door panel, the newly designed Al6063/E-Glass Fiber/Fly ash composite outer door panel has a good performance than that of current steel outer door panel.

4.5.1WEIGHT CALCULATION

I. FOR STEEL OUTER DOOR PANEL:

The weight of the outer door panel can be calculated from the mass, density, and volume relation as shown below:

$$(\rho) = \frac{\text{mass (m)}}{\text{volume(V)}} \qquad \text{...4.1}$$

Weight (W) = m * g, where m= ρ * V

$$W=\rho*g*V \qquad \text{...4.2}$$

Using acceleration due to gravity (g) = 10 m/s^2 and density of structural steel = 7.85 g/cm^3

Then weight of steel outer door panel will be:

$W= \rho*g* V$

$W = 7.85\ g/cm^3 * 10\ m/s^2 * 745.71\ cm^3$

W= 58.538N

II. FOR AL6063/E-GLASS FIBER/FLY ASH

The composite that is used for the outer door panel is casting seven and from this, the density of this data density is 2.6419 g/cm^3 ≈ 2.65 g/cm^3. The dimension of the Al6063/E-Glass Fiber/Fly ash outer door panel is almost the same as that of the current steel outer door panel. This is because to compare the two outer door panels and to decide which one is better feature material.

$W_C = \rho_c * g * V_c$

$W_C = 2.65\ g/cm^3*10\ m/s^2*745.71\ cm^3$

W_C = 19.761 N

Calculating the weight saved of the outer door panel.

Weight saved = 58.538N-19.761 N

= 38.77 N

% Weight saved = $\frac{38.77}{58.538} * 100$

= 66.24%

Therefore composite of Al6063/E-Glass Fiber/Fly ash is very light than that of the current conventional steel outer door panel.

POISSON'S RATIO (v)

The Poisson's ratio for the selected composite of outer door panel seven is calculated below:

As shown in the appendix part of this paper, from the experimental test of stress V_S strain compression test Young's Modulus (E) 92.159 Gpa, Max. stresses 836.81 MPa.

$$v = \frac{\text{lateral strain}}{\text{longitudinal strain}} = \frac{\frac{\delta d}{d}}{\frac{\delta L}{L}} = \frac{\frac{\delta d}{d}}{\varepsilon} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

δd / d calculated by direct measurement and found that 0.028 by substituting these two results in the above equation :

$$v = \frac{\frac{\delta d}{d}}{\varepsilon} = \frac{0.028}{0.908} = 0.31$$

Table 4. 2 Mass of Steel and composite material

Description	**Mass (Kg)**	**Percentage reduction of mass (%)**
Current steel outer door panel	5.853	66.24
Al6063/E-Glass Fiber/Fly ash composite outer door panel	1.976	

The weight of the current outer door panel is reduced by 66.24% as shown in Table 4.2 if the current conventional steel outer door panel was replaced by an Al6063/E-Glass Fiber/Fly ash composite outer door panel. This indicates that as discussed in the introduction section of this paper the smaller mass of the Al6063/E-Glass Fiber/Fly ash composite outer door panel helps to make the vehicle lightweight, consequently, this improves efficiency, running speed, and fuel consumption of the vehicle due to reduction of mass.

4.5.2 COMPARISON OF WEIGHTS

The bar- chart shown in figure 4.10 shows the comparison in outer door panel weight (N) for both steel and Al6063/E-Glass Fiber/Fly ash composite materials. In this chart blue bar is the weight of the steel outer door panel whereas the red bar shows the weight of the composite outer door panel. From this comparison of bar chart, it is easily observed that the weight reduction in the outer door panel. This indicates that the Al6063/E-Glass Fiber/Fly ash composite outer door panel is lightweight than that of the current conventional steel outer door panel of the Toyota Hiace car.

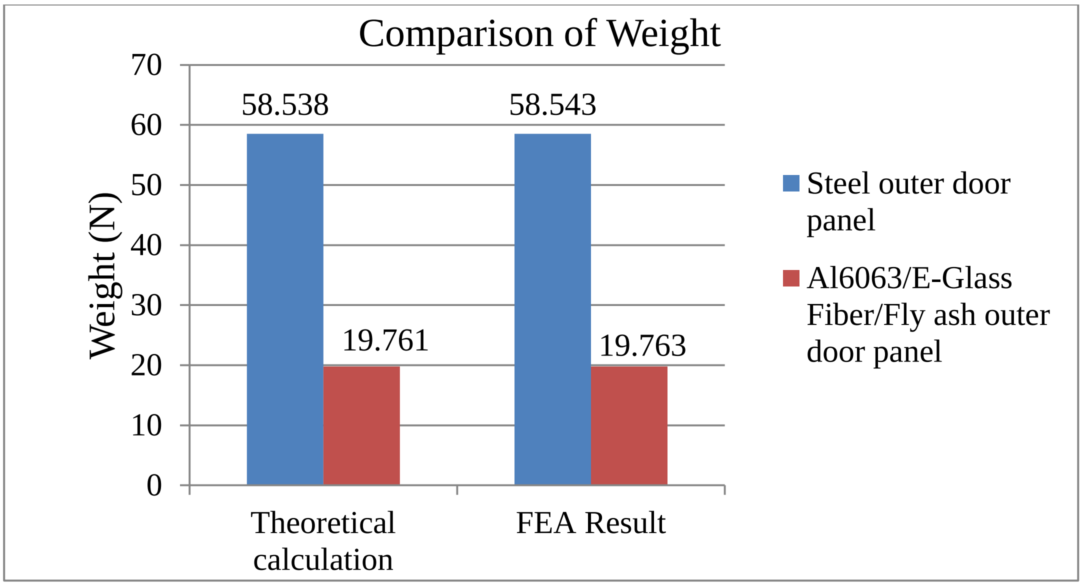


Figure 4. 9 Comparison of weights of steel outer door panel and Al6063/E-Glass Fiber/Fly ash composite outer door panel.

CHAPTER FIVE
CONCLUSION, RECOMMENDATION, and FUTURE WORK

5.1 CONCLUSION

The main objective of this thesis is to fabricate Al6063/E-glass fiber/Fly ash composite specimens of different compositions, characterize their mechanical properties. Then, based on the result obtained; the composite with better mechanical properties will be selected as an alternative material for the current steel outer door panel of the Toyota Hiace vehicle.

The composite of Al6063/E-Glass fiber/ fly ash was manufactured with different composition ratios and its mechanical performance such as the hardness, compression, and flexural properties were determined using experimentally and obtained the following conclusions:

- The maximum hardness was attained from specimen 9 with a composition of 7% E-Glass fiber and 6% fly ash with a value of 116.73 HRB. It is higher than the unreinforced aluminum by 54.7%.
- The maximum compressive strength was found in specimen 9 with a composition of 7% E-Glass fiber and 6% fly ash with a maximum load of 66.75 kN and maximum stress 850.31Mpa. It is higher than the unreinforced aluminum by 66.51%.
- The maximum flexural strength value is 340.1MPa from specimen 7 with a composition of 5% E-Glass fiber and 9% fly ash. It increases from the monolithic aluminum by 40.7%. But beyond specimen 7 flexural strength decreases.
- Depending on the experimental test results, the composition ratio of 87%/7%/6% Al6063/E-glass fiber/fly ash respectively has maximum hardness and compressive strength with a value of 116.73 HRB and 850.31Mpa but lower flexural strength of about 290.81MPa. So to achieve a balanced mechanical property suitable for the outer door panel specimen 7 has been selected which has higher mechanical property for all tests. The suggested specimen has values of 91.8 HRB, 836.81 MPa, and 340.1 MPa hardness, compression, and flexural strength respectively.

- The transient structural dynamic analysis of the 3D modeling of both steel and the composite outer door panel is done and analyzed and also a comparative study has been made concerning stresses and deflection between steel and composite outer door panel.
- From the transient structural dynamic analysis, the von-mises stress and maximum deformation in the steel outer door panel are 1671Pa and $2.1948e^{-12}$m respectively. And also in the Al6063/E-Glass Fiber/Fly ash composite outer door panel the von-mises stress and maximum deformations are 564.08 Pa and $1.6208e^{-12}$ m respectively. This direct that composite material has a higher resistance to the applied load of acceleration $350m/s^2$ while closing the door.
- It is observed that the weight reduction of the outer door panel is attained up 66.24% in the case of the composite than steel due to this, the weight of the vehicle decreases in addition to that the performance also increases.
- Finally from these results, it is understood that the Al6063/E-Glass Fiber/Fly ash composite outer door panel is lighter and less stressed than the current steel outer door panel with similarly applied acceleration. Generally, this indicates that if the steel door panel of the Toyota Hiace vehicle is replaced with an Al6063/E-Glass Fiber/Fly ash composite outer door panel it will be the best one.

5.2. RECOMMENDATIONS

The fuel efficiency of the vehicle directly relies on the total deadweight of the vehicle. Therefore selecting composite materials is the best choice to get a lightweight, fuel-efficient, and high-speed vehicle since the dead weight of the vehicle is reduced by composite materials. The reason behind composite materials being effective is that they are a high strength-to-weight ratio and high specific stiffness, good capability of energy absorption. The FEA result illustrates that the Al6063/E-Glass Fiber/Fly ash composite outer door panel has much better performance than the current conventional steel outer door panel. Additionally, as shown from the simulation result the weight of the current conventional steel outer door panel and the stress induced by the applied load is reduced by about 66.24% by the composite. Therefore, applying the results of this research work will advance the life of the door and the fuel economy of the vehicle. Finally, it is recommended that the Al6063/E-Glass Fiber/Fly ash composite outer door panel is suitable for vehicle outer door panel applications.

5.3 FUTURE WORK

From different features, adapting composite materials have numerous benefits. Based on this perspective, concerning Al6063/E-Glass Fiber/Fly ash composite material numerous products can be made and developed in the future in which this study couldn’t address.

- Design and static analysis of Al6063/E-Glass Fiber/Fly ash composite outer door panel.
- Analyze by considering other causes of failure of the outer door panel, such as a side-impact crash.
- The manufacturing of Al6063/E-Glass Fiber/Fly ash composite outer door panel.
- At present, the analysis is done by changing the current material and achieved a reduction of weight, stress, and deformation of the component. However, there is still the possibility of gaining better results than this research. Therefore, to perform this we can make other hybrid composite materials or designing the outer door panel by changing the composition ratio of the reinforcing particles.

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APPENDIX

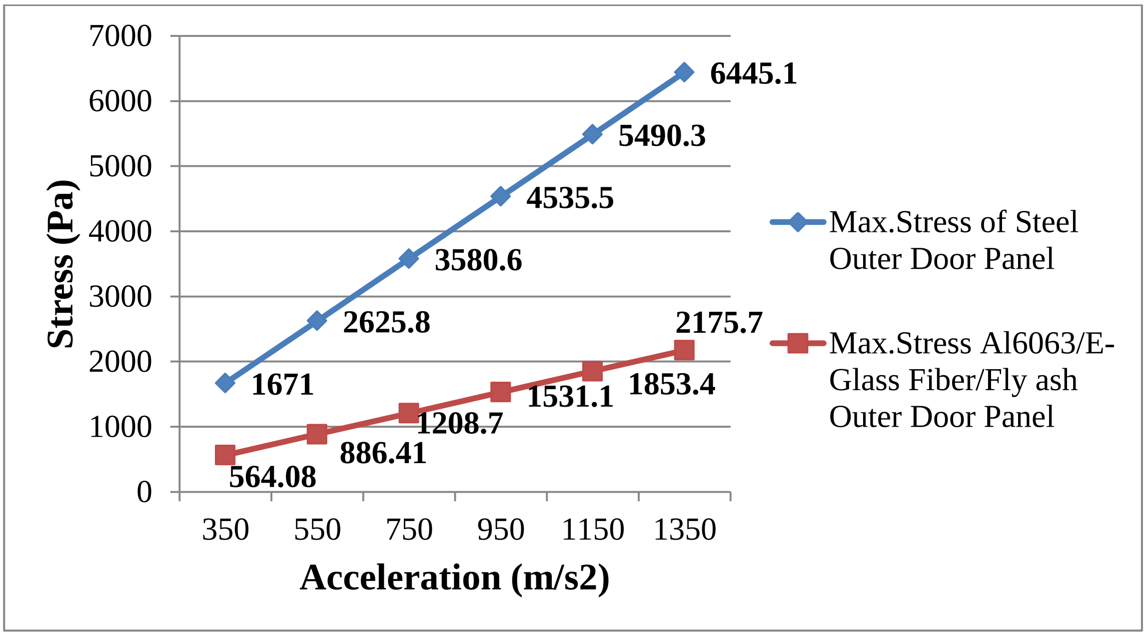

Figure A. 1 Comparison acceleration Verses Von-misses stress of steel and Al6063/E-Glass Fiber/Fly ash composite outer door panel.

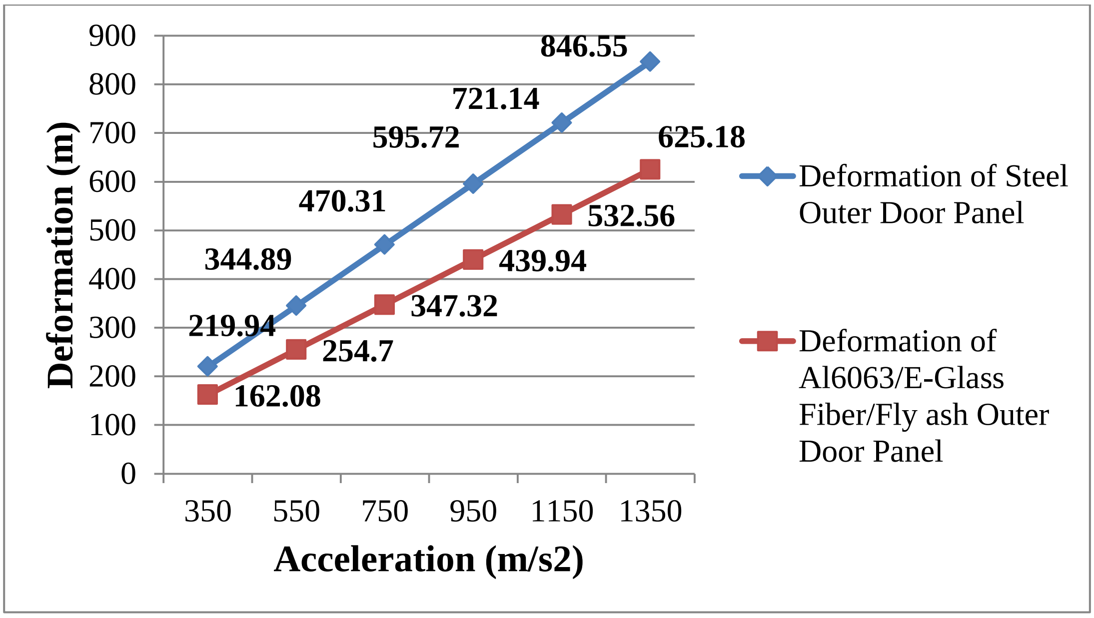

Figure A. 2 Comparison Acceleration Versus Deformation of steel and Al6063/E-Glass Fiber/Fly ash composite outer door panel.

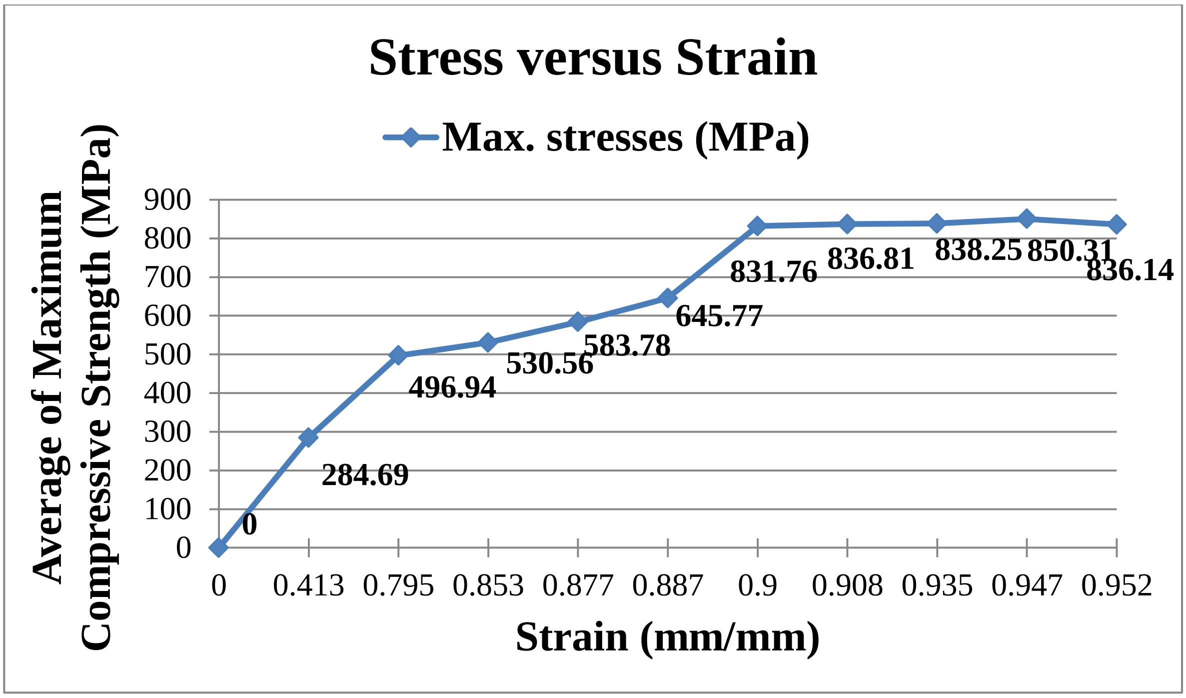

Figure A. 3 Stress V_S Strain for Compressive Test from Specimen 1-10.

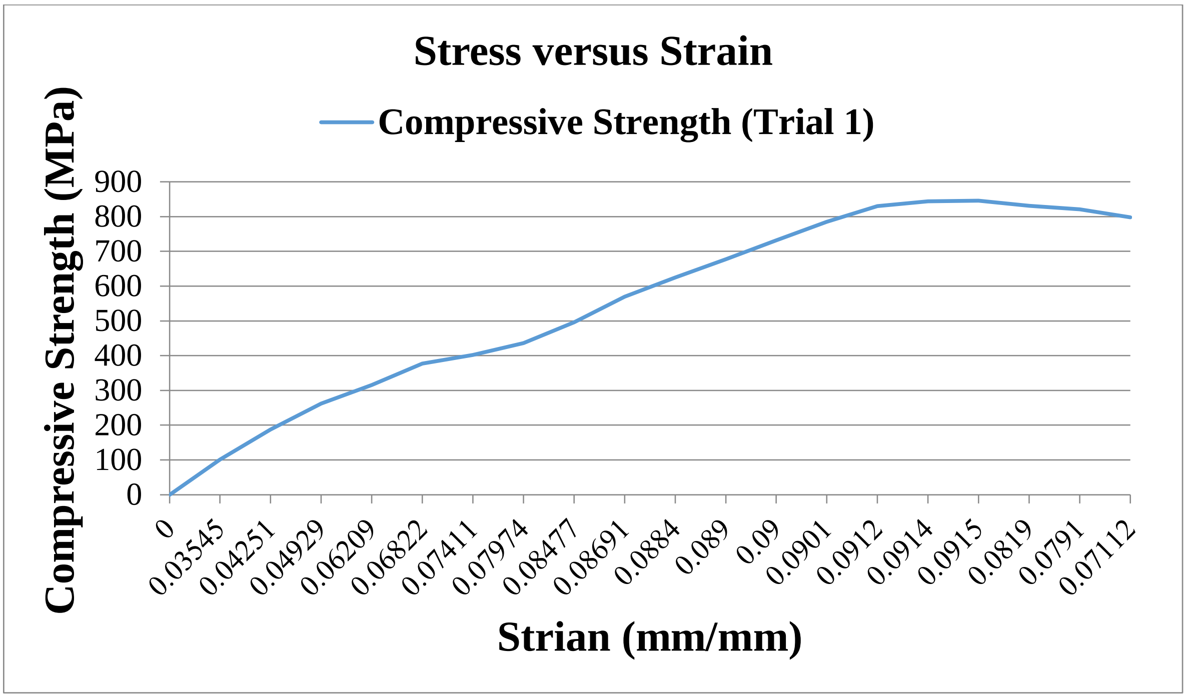

Figure A. 4 Stress V_S Strain for Compressive Test.

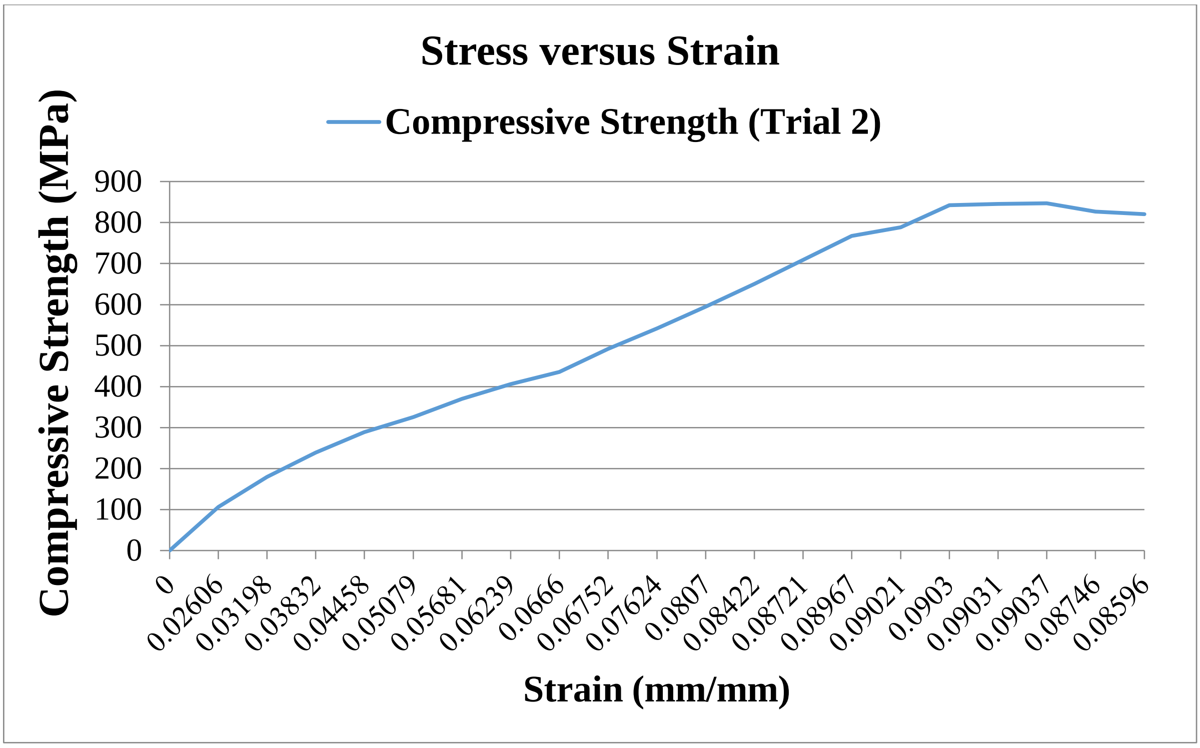

Figure A. 5Stress V_S Strain for Compressive Test.

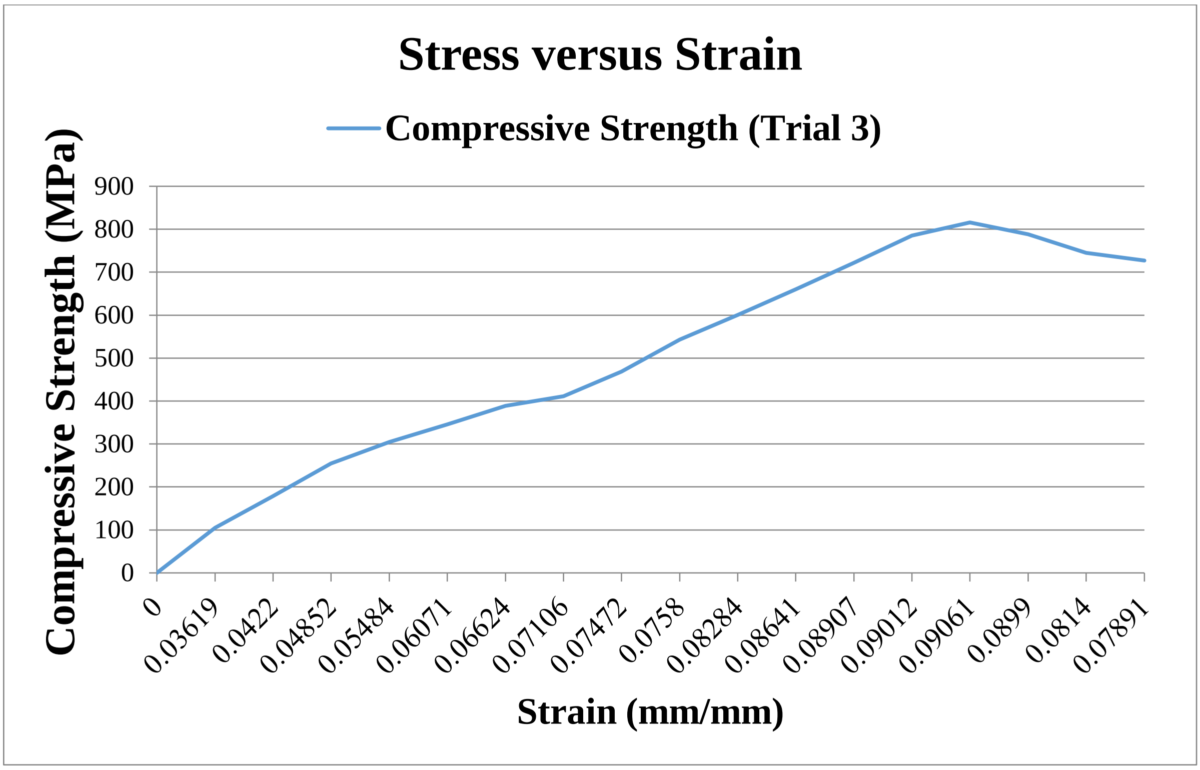

Figure A. 6 Stress V_S Strain for Compressive Test.