



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING
GRADUATE PROGRAM IN RAILWAY ENGINEERING

**Application of Composite Material (Fiber Glass) on Addis
Ababa Light Railway Car body and It Structural Analysis
by FEM**

A Final Report submitted to the Graduate School of Addis Ababa University

Master of Science in Mechanical Engineering
(Under Railway Engineering)

By

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October, 2017
Addis Abba, Ethiopia

Application of Composite Material (Fiberglass) on Addis Ababa Light
Railway Car body and its Structural Analysis by FEM

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Master's Program Final Thesis Acceptance Approval Form

**Thesis Title: Application of Composite Material (Fiber Glass) on
Addis Ababa Light Railway Car body and Its Structural Analysis by
FEM**

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled “**application of composite material fiber glass on Addis Ababa light railway car body and its structural analysis by FEM**” is original work oh as not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

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ACKNOWLEDGEMENT

Firstly and above all my great, thank goes to the almighty God who helped me in all the way to arrive at this point. I would like to express my heartfelt appreciation and gratitude to my advisor Mr. Tollosa Deberie for his invaluable advices, technical supports to strengthen and enlightening vision that helped me out many times throughout every stage of the study. The friendly attitude combined with the practical knowledge he shared, had a major influence on me. This paper would not have come in its present form had it not been complemented by his proper follow up in re-shaping and organizing. I am also thanks to Ato Andinet for his kind help on different occasions. Also thanks Mr Wakuma from LRT rolling stock Manager for giving me some material data and all the required data. I would also like to express my special thanks to all of my colleagues and classmates.

Finally, I would like to thank this university Addis Ababa Institute of Technology for giving me the opportunity to study on this Degree of Masters of Science in Railway Engineering (rolling stock engineering). I appreciate their interest in my research and their Patience and love.

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ABSTRACT

This thesis presents the application of composite of composite for the AALRT car body structure. In the past few decades emission of gases by the vehicle has got attention due to its immense effect on the environment. The amount a gas emitted by the vehicle is directly related with the amount of fuel consumption. The higher the fuel consumption the higher the emission by the vehicle. One of the major factors that contribute for the high fuel consumption of the vehicle is its high dead weight. Beside to the high fuel consumption, large dead weight lengthens the manufacturing time of vehicle. This urges the automotive manufacture to look for a solution so as to minimize the weight of the vehicle without compromising of its static and fatigue strength, crashworthiness and stiffness. That is to have light weight vehicle system.

Railway carriage can be divided into three main assemblies the running gears, car body structure and equipment (propulsion, interior, car body etc.). Thus to have light weight railway vehicle system weight reduction for the either the sub assembly shall have to be done. However the most effective approach in terms of cost and complexity of the vehicle system is to reduce the weight car body structure by using composite materials which light weight material but have the desired capability.

The light weight, high crashworthiness, high fatigue and static strength, high stiffness and in corrosiveness behaviour of the composite makes them as suitable material for the car body structure as compared to the steel, the material which has been used for the railway car body structure. This thesis presents the application of composite material for the AALRT car body structure. For sake of comparison of composite with that of steel static analysis has been done based using SOLIDWORK software. The result shows that composite are capable of producing lower deformation and stress ranging 40-66.5% and 32% respectively for the similar loads applied on them, while minimizing the weight of car body structure by 67%.

KEY WORDS: Car body Structure, Light Weight System, Dead Weight, Composite Material

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SYMBOLS

A = Area

M_s = Mass of the persons for standing.

F₁ = Load at the condition 1

F₂ = load at the condition 2

F_z = vertical load

L = Length

M₁ = Total mass [In case of 6persons / m^2] for rated passenger capacity

M₂ = Total mass [In case of 8persons / m^2] for over crowded capacity

P₁ = Pressure due to load 1

P₂ = pressure due to load 2

W = Width

GFRP =glass fiber reinforced plastic

AALRT = Addis Ababa city light railway-transit

EN 12664 = European standard for the rail application-structural requirements of the railway body (in English, EN)

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CHAPTER ONE

INTRODUCTION

1.1 Background

Car body structure is one of the main consistent elements of the railway carriage system. It is the major component that highly determines the weight of the railway vehicle. Studies have shown [1] that it accounts for the 15 to 30% of the vehicle empty weight .usually it's made from steel. Generally materials for the car body structure needs to have high tensile and fatigue strength ,impact resistance ,crashworthiness and high stiffness .Despite that steel fulfill most of the above criteria's due to its higher density it result a heavy weight structure. This intern paly major role for higher fuel consumption and leng time of manufacturing of the vehicle.

Thus basic aim of developing new materials for rail vehicle application is to reduce the engine fuel consumption by reducing the dead weight of the vehicle [2]. Moreover, their aesthetical appearance should be upgraded by researching required materials for this application. A number of researches have demonstrated that composite materials are lightweight, fatigue resistant and easily molded to any shape; in other words, a seemingly attractive alternative to the metallic materials. If these composite promising characteristics with their high specific energy absorption ability and ease of forming are to be exploited more widely by the rail vehicle industry, then there is a need to identify the critical technical barriers that must be overcome [3, 4].

In order to conserve natural resources and economize energy, weight reduction has been the main focus of rail vehicle body designers and manufacturers in the present scenario, Weight reduction can be achieved primarily by conducting a research on better material, design optimization and better manufacturing processes, Due to the rising in demands of lightweight, more efficient vehicles and better mechanical performance of materials in rail vehicle applications, different material combinations such as composites, plastic and light weight metals are implemented on different structural parts of vehicles. Composite materials have high modulus to weight ratio and strength to weight ratio, excellent fatigue properties, and non-corroding behaviors.

Traditionally, the materials used in the construction of vehicle bodies have various grades of steel and aluminum. Mostly, plastics and some synthetic material dominate vehicle interior parts. The

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manufacturers meet the requirements of a particular crashworthiness standard and fuel efficiency by making the approximate design change in their vehicle structure and by introducing the necessary structural components that satisfy the overall design objectives [5].

With the composite materials the designer can vary structural parameters, such as geometry, and at the same time designers vary the material properties by changing the fiber orientation, and fiber content. These properties of the composite materials create a positive environment for vehicle industries, for they provide the required strength for less weight when compared to steel and aluminum. [4, 6]

Less weight and effective utilization of natural resources are the main focus of railway vehicle manufacturers in the present scenario. The above can be achieved by introducing better design concept, better material and effective manufacturing processes. Steel car body have many advantages such as good load carrying capacity, excellent impact and fatigue resistance and have high rigidity. In spite of its advantages, it stays behind in low strength to weight ratio. It is reported that weight reduction with adequate improvement of mechanical properties has made composites as a viable replacement material for conventional steel [7].

Over many years of rail vehicle evolution, the car body shells were developing as well as depicted in the (fig 1). Their construction was dictated by the manufacturing capabilities and materials available at the time. The figure 1(which is adopted from) [8] shows the timeline of the body shell evolution from the initial riveted steel construction to the present-day composite material construction.

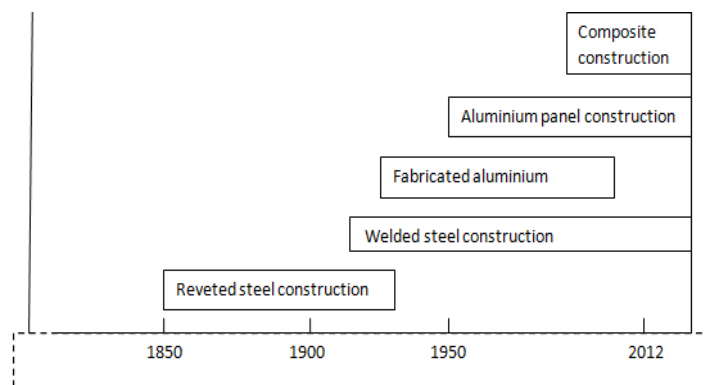


Figure 1: Timeline of evolution of rail vehicle body construction [8]

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1.2. Problem statement

The type of constructing material used for the rail way vehicle car body structure is the determinant factor for the weight of the vehicle. The material used for the carbody structure needs to be light weight, tough and rigid. In the existing railway car body structure of the Addis Ababa light rail-vehicle transit (AALRT) carbon steel is the primarily material used. While steel has good strength and rigidity but it will result in heavy body structure due to its high density. Heavy weight car body structure results higher fuel consumption which brings higher gas emission, complicated manufacturing process and long-time of assembly [9].

Thus reduction weight of vehicle is the prior thing to reduce the above problem .Reduction in the weight of the railway vehicle can achieved through reducing the weight of either of its components these are car body structure, running gears and equipment which comprise the propulsion system and interior part .however weight saving in the gears and equipment is difficult since this might affect the required property like the stability of the run, wear resistant and fatigue resistant. In addition to this it requires advanced technology. Whereas reduction in the weight of the car body structure by changing its material can be possible and effective approach to the deal with light weight system.

Taking this above fact in to the consideration in this thesis aims for assessing the application of the composite material for the AARLT vehicle car body structure. The comparative advantage of the composite in terms strength and deformation over the steel material is validated trough the static analysis done using SOLIDWORS software.

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1.3. Objective of the study

1.3.1. General objective

The general objective of this research paper is to study the application of the composite material for the AALRT car body structure. And assess the comparative advantage of the composite material over the existing carbon steel material.

1.3.2. Specific objective

- Determining the various loads that appear in the train body structure load
- Evaluate stress and deformation on the train body structure considering steel and the composite material.
- Investigating the advantage of the composite over the steel material.

1.4. Limitation of the study

The limitations of the research are:-

- The cost visibility of the composite is not done.
- The crashworthiness behavior and long term performance of the composites is not studied
- Only the stress and deformation for the applied loads on the structural body of the vehicle is studied
- The internal parts of the vehicle is not studied since the difficulty of weight reduction by this components
- Finite element analysis for both composite and steel is done taking only for the resulted stress and deformation by the static loads.

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1.5. Methodology

Literature review and data collection: paper works, researches, journal and international train manufacturing companies' web page were observed and a part of it was considered in this project, and other relevant literature was used. The standards of rail vehicle design and collection of the specifications of the body components for this study were taken from Ethiopian Railways Corporation but with European standard.

Modeling and Static Analysis: using **SOLIDWORK 2017**, the vehicle structure of the body was modeled using the dimension of the AA-LRT (Addis Ababa City light Railway) for the Ethiopia standard. The static analysis for the deformations and von misses stress is carried out using **SOLIDWORKS** software , as per recommendation of European Standard of EN12663 (it is a standard that present the structural requirement for the rail vehicle), [10] for the applied loads.

1.6. Organization of the paper

The paper is organized in five chapters

Chapter one: Presents the background, statement of problem, objective of the study delimitation and methodology of the research. **Chapter two:** Contains the discussions literature review on the structural analysis of the body rail vehicle and the material select for composite fiberglass. **Chapter three:** Describe materials used and their general properties. It also contains the brief description and types of material used in passenger car body and calculations of each load and pressure of the car bodies, which shows the modelling of vehicle car body and finite element modelling and simulation **SOLIDWORK 2017**. **Chapter four:** deals with the results of the final static analysis. **Chapter five:** discusses about the conclusion of the final design of the car body for vehicle car body, recommendation and future work.

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CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Rail cars are relatively heavy in comparison to other transportation modes. As an example, the weight per seat is around three times higher for rail vehicle than for buses. In addition to this, the price of rail cars per kilogram is high. Reasons are partly short series and individual design for each customer. Conservative load assumptions in railway standards are another contributor [11].

Today there is quite a lot of knowledge existing about properties and manufacturing possibilities of composite structures. Due to this reason and their enhanced performance, composite recently are emerge as the primary constituent for the car body structure replacing the existing steel structure. This has been seen in some automobile and truck car models like Chevrolet Silverado 2007, XPT, ETR 500, TGV. In addition composite structure has found some application in the rail vehicle .Buses with the composite car body is already existed [7].

Composites materials bring the lightweight vehicles system. However, this was achieved without sacrificing the current self-protection levels. The enhanced performance of composites over the more conventional isotropic materials are the lower density, very high strength to weight ratio, and tough to withstand impact load.

While the composite have shown enhanced performance over the steel. Previous studies confirm that composite structures deform in a manner different from the structural components made of conventional materials like steel and aluminium. The micro failure modes, such as matrix cracking, delamination, fiber breakage, etc., constitute the main failure modes of composite structures. These complex fracture mechanisms make it difficult to analytically and numerically model the collapse behaviour of fiber reinforced composites structures. This has limited the application of composites materials for mass production in the railway vehicle industry [12].

To sum up this chapter go through a comprehensive literature review in mind of the thesis idea .The review works presented in various sections. In the first section i.e. section 2.2 to light weight

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principles and challenges of the weight reduction in car body structure is assessed .in section 2.3studies for the various class of composite and their property has been done with an emphasis on the fiberglass composite. Section 2.4 goes through to this the various previous works on the modelling of composite car body structure. Then the chapter ends identifying the practical application of composite in the railway, trucks and rail vehicles.

2.2 LIGHT WEIGHT RAILWAY VEHICLES

2.2.1. Light Weight Principles

Currently there are different car body concepts in use. These are car bodies in the differential style, integral style and rarely in the hybrid style (Figure 2.). The differential style is a metallic framework planked with blank sheets in principle. The integral style uses material extruded profiles, which are welded together in longitudinal direction and possibly local reinforced. The hybrid style is a mix of different materials, which uses the potential of every material.

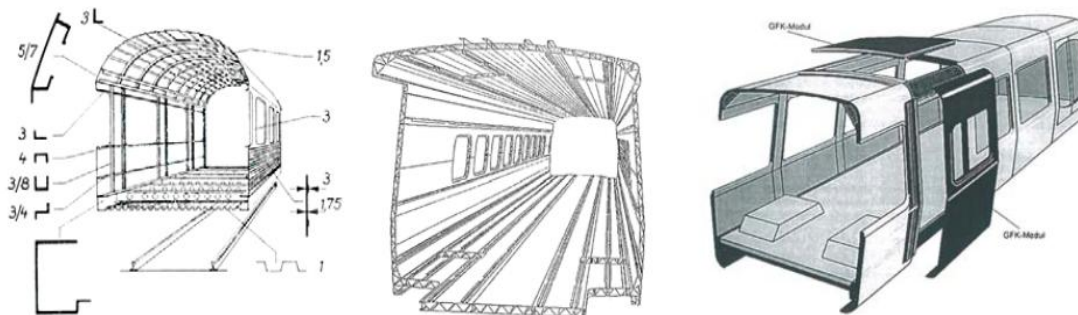


Figure 2: Car body concepts (from left to right): composite style [1]

It is to note that for actual current car body styles (integral style, differential style) a lot of expert knowledge exists. Therefore further weight reductions are limited regarding conventional constructions. A global use of light weight principles is indispensable.

The light weight principles can be divided in:

- Material light weight construction,
- Function and system light weight construction,
- Shape and form light weight constructions.
-

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The notice of these principles gives the possibilities of a significant weight reduction. The highest potential for extensive lightweight constructions promises shape and form lightweight constructions. In this case the load bearing car body structure is adapted regarding the main load paths. So unnecessary material can be saved and the load bearing structure adapted to the inertial forces in the car body.

2.2.2. Weight Saving in the Railway Carriage

A railway carriage can be divided into three main assemblies (Figure 3): the running gears, car body structure and equipment (propulsion, interior, car body etc.) [13].

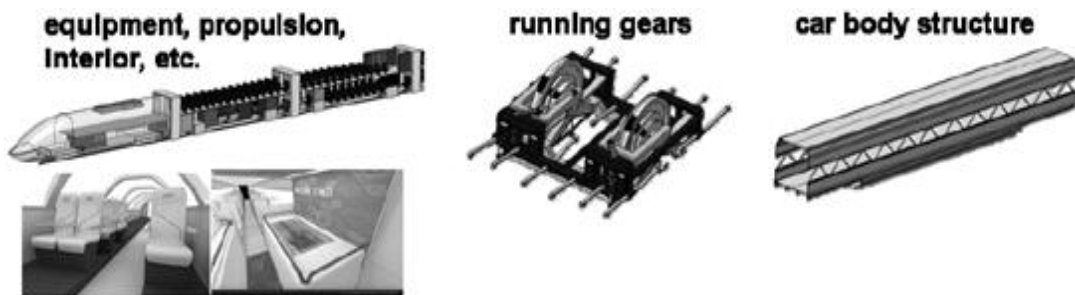


Figure 3: Main assemblies of a railway carriage [13]

The equipment and car body completion is a main cause of the carriage weight (Figure 4). It is composed of a large number of diverse subassemblies. These subassemblies are predominantly independent from each other, so they have to be regarded separately. Based on that, the global weight saving potential resulting of the several equipment is limited [13].

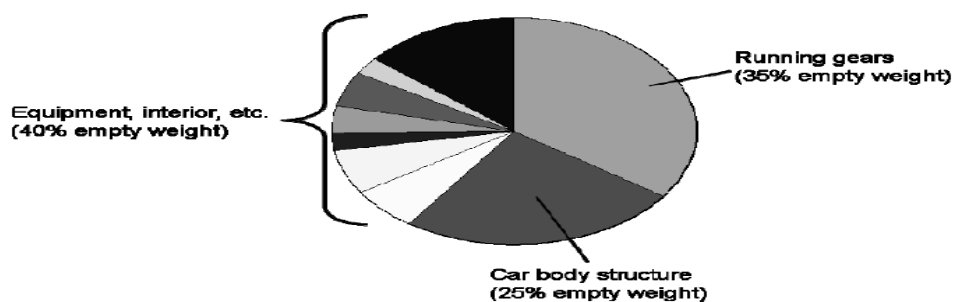


Figure 4: Exemplary percentage distribution of the main assemblies [13]

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The Running gears must fulfil diverse requirements, like, stability of the run, fatigue strength, low wear in the wheel/rail contact and moveable parts. So weight saving of running gears is difficult because of the manifold and security relevant requirements. Currently there are several on-going research activities, e.g. by the DLR [14] to improve run stability, wear and minimize weight of the running gears.

It is to note that beside the maximal velocity the car body weight, equipment weight and payload are significant influence parameters on the running gears. For this reason the weight optimisation of the car body structure is an important criterion for a light weight carriage.

2.2.3 Factors that influence the car body structure

The quantitative analysis for the vehicle dead weight by [1] showed that the mass of the rough car body normally accounts for 15% to 30% of the vehicle's empty weight. The car body structure is in an interaction with different parameters (Figure 2.6). This means the car body structure has a direct influence on the weight saving potential of these parameters.

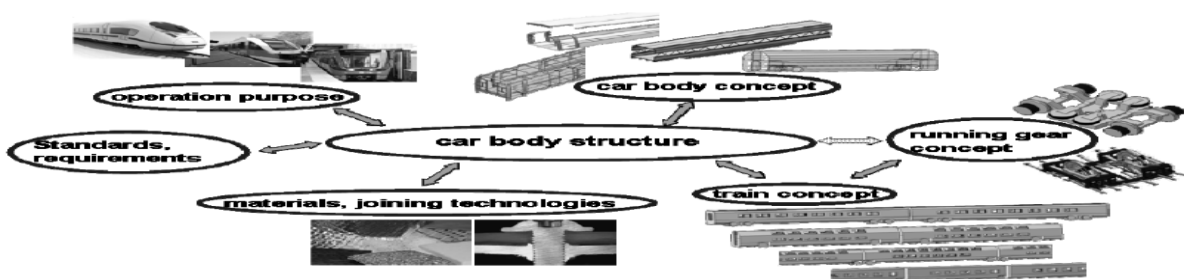


Figure 5: Influences on car body structure [1].

The car body structure is also influenced by the car body concepts which can constrain the conception of the structure design. For example conventional car body structures constrain the scope of design. On the other hand a novel car body concept gives the possibility to create an ideal structure for the respective requirements.

Another influence factor is the train concept which defines the geometry of the car body in principle, the position and distances between supports, etc.. Furthermore the train concept is in an interaction with the running gears. As noted above the running gear concepts define the maximal

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weight of the completed car body and so its length. Also the running gear concept has an influence on the design of the connection to the car body structure.

The joining technology goes together with the materials. The utilized materials have to correspond with the joining technology. The light weight approach of the multi material design (adapted material in adapted positions) brings a large number of challenges regarding the connection of materials with different characters. Materials and joining technologies have an extensive impact on the costs, design, concept and weight of the car body structure.

Since the design of carbody structure is influenced by the various parameters like the joining technology, train concept and carbody concept, the weight saving in the carbody structure shall take into account for this parameters.

DESIGN CONSIDERATION AND REQUIREMENTS FOR RAIL VEHICLE BODY

Definition: The car body of a rail vehicle refers to the load carrying structure, doors, windows, interior with seats etc, inner lining and so-called comfort systems for lighting, heat, ventilation and sanitation.

The technical equipment for propulsion, braking etc is by definition not included in the car body, even though this equipment usually is attached/hinged on this (commonly under the car body).

It seems that the concept of car body limited to load carrying structure of the vehicle ,however despite of its ability to bear the load of the vehicle system ,the car body structure needs to fulfill other requirements like including: safety requirements set up for crash scenarios, derailment, fire, projectiles impacts, pressure waves in tunnels, etc. The car body must also be within the specific construction profile of the operated line. It must be strong to withstand the fatigue, dynamic and impact load. A large amount of these requirements including the above are covered by the norm for EN 12663 [10].

70% Low-floor LRV for Addis Ababa, Ethiopia adopts frame bearing and adhesion exterior wall panel carbody, and the general design of carbody shall meet with requirement of basic function, as well as high quality and light weight. Meanwhile, the car body strength (incl. fatigue strength),

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rigidness shall bear dead load, vertical load and longitudinal load produced by traction and brake system. The carbody strength shall meet with EN12663 standard [10].



Figure 6: General car body [10].

- The vehicle structure should not collapse, or show any permanent damage during typical operational loads, from for example inertia forces between two adjacent car bodies.
- The weight of the vehicle structure needs to be small. The train exerts forces on the infrastructure due to their weight which results in wear of the tracks. High weight also increases the wear on wheels, axles, breaks, shocks, etc.
- The car body should be sufficiently stiff. From a safety perspective the car body should not move outside the track gauge during operations or show significant vertical displacement due to the passenger load.
- The car body has to isolate the passenger compartment from intense sound. For high speed trains the sound level on the outside of the train can be above 100 db. [15] Thus car body has to isolate the passenger compartment from these sound levels.
- The car body should be designed to limit the risk of fire ignition due to both electrical malfunctions. In addition, in case this fails and there is an ignition point, the fire spread should be slow and limited. The car body should be able to retain structural integrity, at least for enough time to safely evacuate passengers.
- The carbody structure should be resilient under harsh environmental conditions. Rail vehicles operate in many different climates and temperatures, from temperatures as low as -40°C during winter to above 40°C in the summer. Thus the stability under these conditions is crucial for the safety and comfort of the passengers.

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- The carbody need to have crashworthiness. Even though the extent is small is the trains are liable to the accident and crash. This requires higher crashworthiness and higher energy absorption capability for the assuring the safety of the passage and lengthen the life of the train body.

2.4. COMPOSITES MATERIALS

2.4.1. Introduction

The interest of a material with light weight and high performance is increasing in a dramatic way time to time. The improvement of the performance for a material is limited when there is only one composition. Therefore, there have to be a new material with high performance which constitutes two or more conventional materials. Composite materials are engineering materials (engineered materials) in which two or more distinct materials are combined together but remain uniquely identifiable in the mixture, having reinforce such as strong fibers surrounded by a weaker matrix material to obtain an enhanced property different from the individual components.

The Reinforcing fibers provide the physical and mechanical properties; specifically to improve the physical and mechanical properties of the matrix and thus add strength and stiffness for the composite whereas the matrix serves to hold, protect and distribute the fibers, and also to transmit and distribute the load to the fibers. A collaboration between these two basic materials produce material properties that are not provided for each material element of origins [16, 17 and 18]. Overall, the properties of the composite material are determined by the properties of the fiber, the properties of the resin, the ratio of fiber to resin in the composite (Fiber Volume Fraction) and the geometry and orientation of the fibers in the composite.

2.4.2. Polymer matrix Composites and their role as the structural element

Composites are materials that combine two or more materials that have quite different properties. When combined, composites offer properties which are more desirable than the properties of the individual materials. The different materials work together to give the composite unique properties, but they do not dissolve or blend into each other.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

Structural materials are divided into four basic categories: metals, plastics, composites, and ceramics, as shown in Figure 7. Metals include all kinds of steels (iron steel, HSS, stainless steel, etc.) and non-ferrous metals (aluminium, magnesium, etc.). Ceramic materials are inorganic, non-metallic, often crystalline oxide, nitride or carbide materials. Plastics are polymers composed of long covalent-bonded molecules [7].

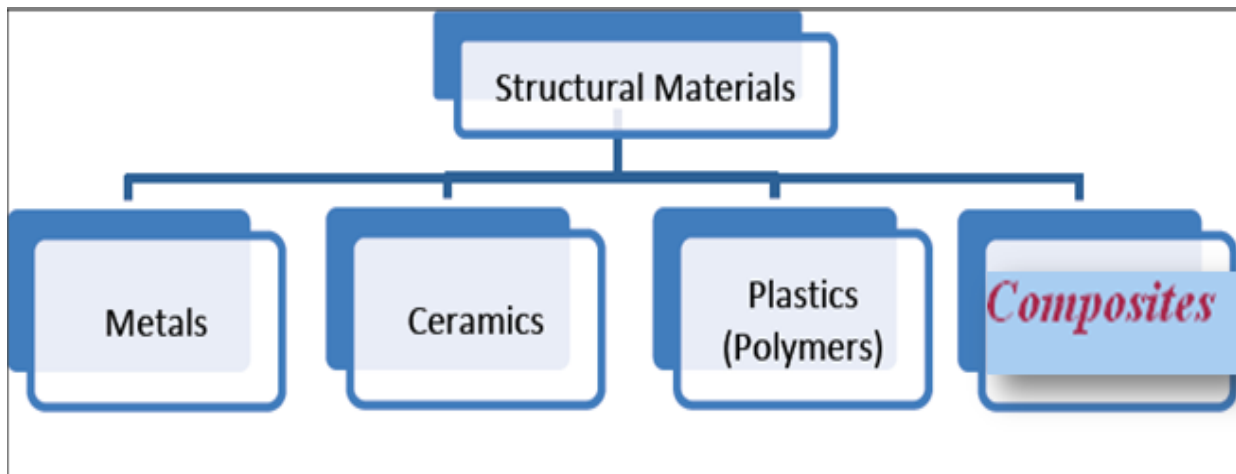


Figure 7: Classification of structural materials.

Metals and polymers are reinforced for increased strength and modulus; ceramics are reinforced to increase their toughness and damage tolerance. Polymers are unquestionably the most widely used matrix materials in modern composites. Although plastics have a poor strength-to-density ratio by themselves, polymer matrix composites have advanced as structural materials while offering many advantages over metal. Polymer matrix composites amount to 75 percent of the world composite market by value or by tonnage [7].

2.4.3. Classification of composite by the filler material

Composites can be categorized by filler types as shown in Figure 8. The matrix materials are reinforced by fillers in the form of single-crystal whiskers, platelets, long fibers, short fibers, small particles, or precipitates (or a combination of any of these).

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

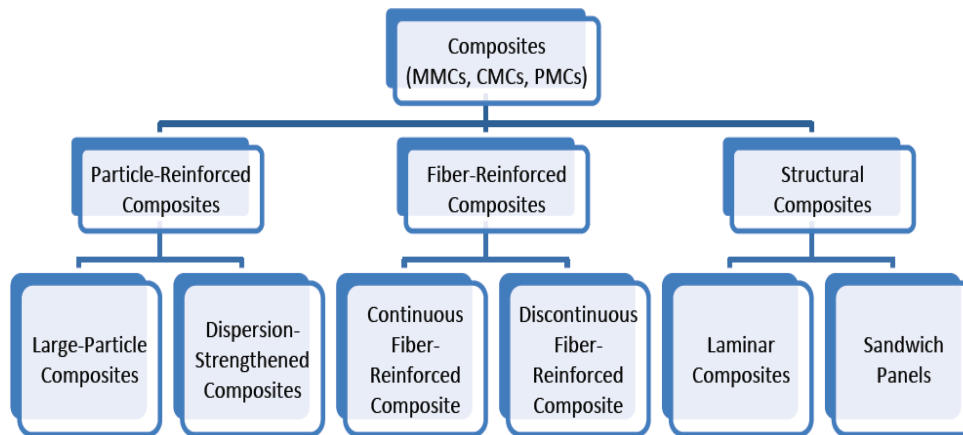


Figure 8: Classification of composites by filler types.

Furthermore, composites can be categorized by filler types as shown in Figure 2.5. The matrix materials are reinforced by fillers in the form of single-crystal whiskers, platelets, long fibers, short fibers, small particles, or precipitates (or a combination of any of these). Particle-reinforced composites are the cheapest and most widely used. They fall in two categories depending on the size of the particles: large-particle composites (cermet, tire, concrete, etc.) and dispersion strengthened composites (thoria-dispersed nickel, sintered aluminum powder, etc.). Fiber reinforced composites are divided into two categories depending on the fiber length. These fibers may be short or long, and they may be aligned in the directions where loading will be greatest, or randomly oriented to give it equal strength in all directions. The properties of structural composites depend on the properties of the constituents and the geometric arrangement of these materials. There are two types of structural composites, laminar composites and sandwich panels.

The fiber-reinforced polymer composites are the main interest in this review.

a. Particle-reinforced composite: The role of reinforcement in composite materials is primarily to add mechanical properties to the material such as strength and stiffness. Thus, particles are used to increase the modulus of the matrix, to decrease the permeability of the matrix, or to decrease the ductility of the matrix. Particle reinforced composites support higher tensile, compressive and shear stresses. Particles used for reinforcing include: ceramics and glasses, metal particles, and amorphous materials. [18]

b. Fiber-reinforced composites: Fiber reinforced composites provide improved strength, fatigue resistance and strength to weight ratio over the constituent materials. Reinforcing fibers are responsible to increase the modulus of the matrix material in the composite. The strong covalent bonds along the fibers length give them a very high modulus in this direction because to break or extend the

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fiber the bonds must also be broken or moved. [17, 18] The arrangement or orientation of the fibers relative to one another, the fiber concentration, and the distribution all have a significant influence on the strength and other properties of fiber reinforced composites. [18]

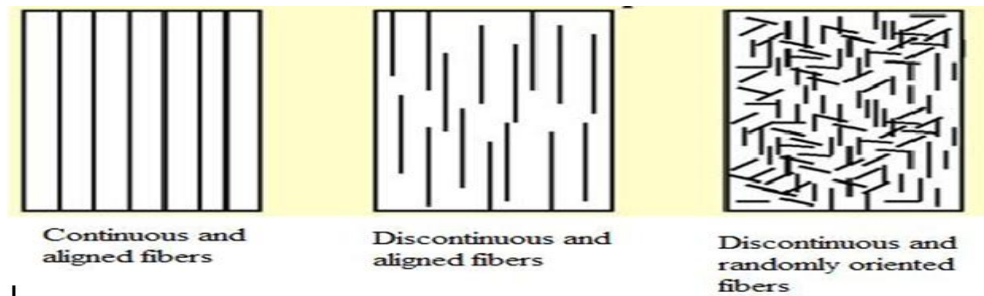


Figure 9: Fiber reinforced composites [18]

c. Structural composites

Laminates are sheet constructions which are made by stacking layers (also called plies or lamina) in a specified sequence. The one preamp regnated with partly cured resin which are consolidated in an autoclave. A laminate may have more than 4 layers and the fiber orientation changes from layer to layer in a regular manner through the thickness of the laminate. The figure shown below describes how the laminate is formed from the ply or lamina [17, 19].

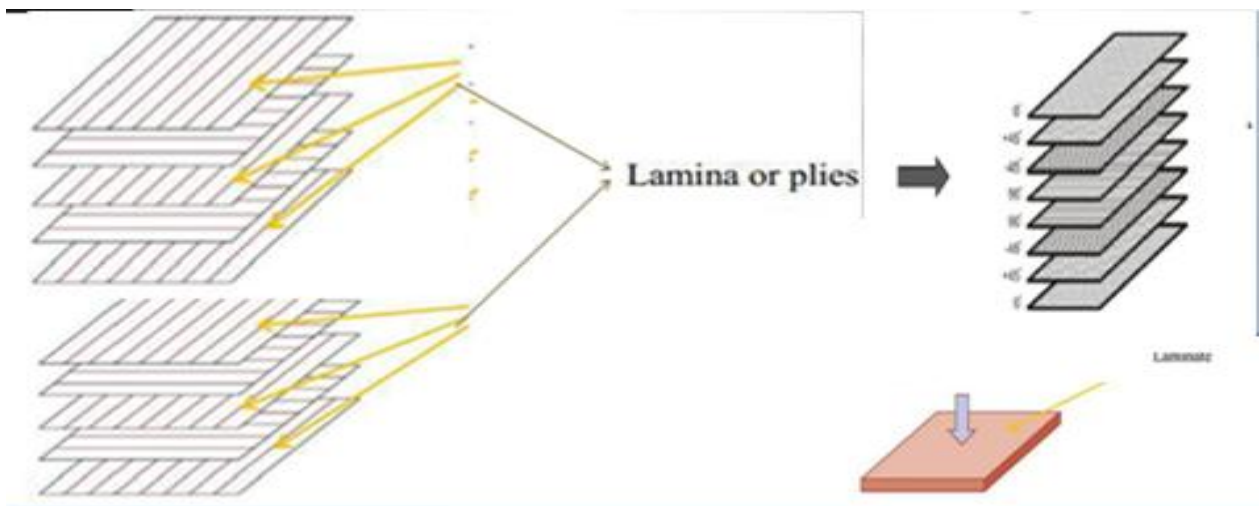


Figure 10: Composite laminate [19]

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❖ Sandwich panels

These composite polymer matrixes have low density, honeycomb core as a reinforced bonded with the face sheet matrix by adhesive layers. Sandwich panels have the benefits of light weight, large bending stiffness and energy absorption. [17, 18]

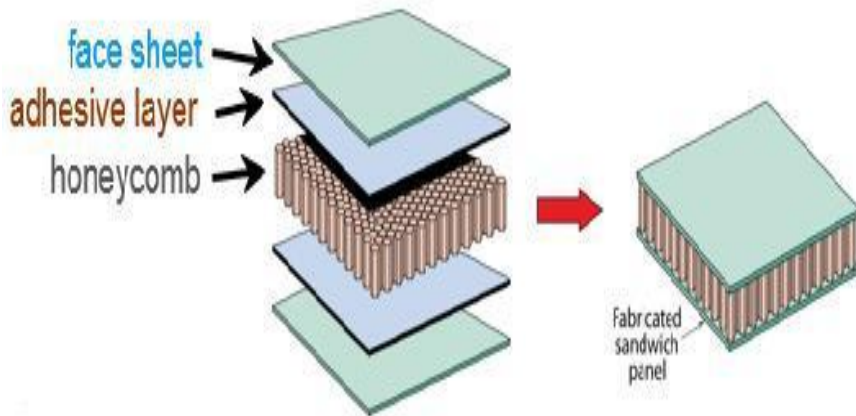


Figure 11: composite sandwich panel

Matrix materials

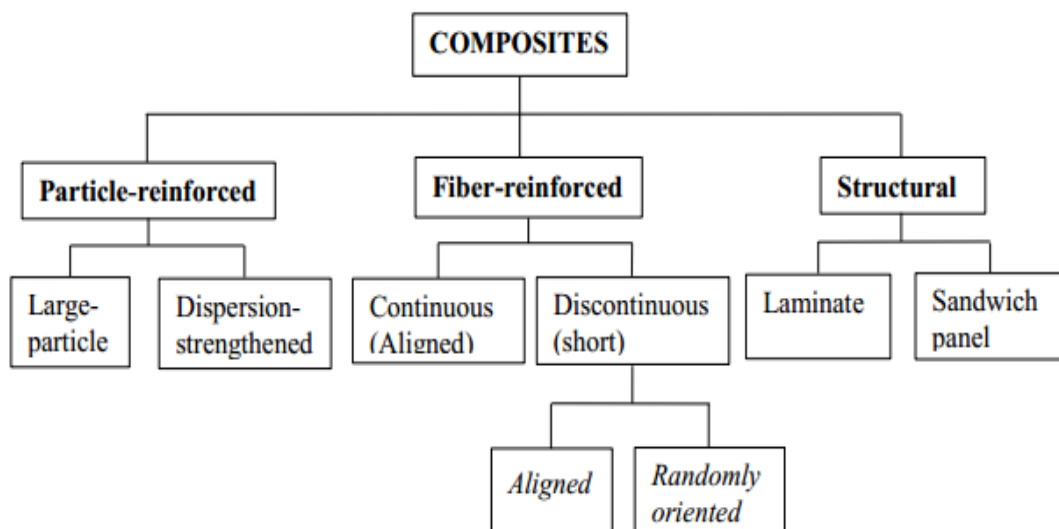


Figure 12: composite materials classification based on matrix type [19, 20]

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

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

Thermoset polymers are polymers that are cured into a solid form and cannot be returned to their original uncured form. Composites made with thermoset matrices are strong and have very good fatigue strength. They are extremely brittle and have low impact-toughness making. They are commonly used for high-heat applications because the thermoplastics. Thermoset composites are generally cheaper and easier to produce because the liquid resin is very easy to work with. Thermoset composites are difficult to recycle because the thermoset cannot be remolded or reshaped; only the reinforcing fiber used can be reclaimed. [21]

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

Thermoplastic composites are less dense than thermosets making them a viable alternative for weight critical applications. The thermoplastic composites manufacturing process is more energy intensive due to the high temperatures and pressures needed to melt the plastic and impregnate fibers with the matrix. The energy required makes thermoplastic composites more costly than thermoset. These two similar materials have such different properties that both will continue to be used in different applications for very different reasons and the products of the future will likely be a combination of both [21]

2.4.4. Fibers

Fibers are the principal load-carrying members in Fibre reinforced composites (FRC). Fibrous reinforcement is so effective because many materials such as glass and graphite are much stronger and stiffer in fiber form than they are in bulk form. For very small diameters, the fiber strength approaches the theoretical cohesive strength between adjacent layers of atoms; whereas for large diameters, the fiber strength drops to nearly the strength of bulk glass. Fibers can be categorized in four groups depending upon the matrix material see figure 13 groups as shown in Figure 2.10.

As compared to the other class glass fiber are widely used since (1) the molten glass can be easily drawn into high-strength fibers (2) it is readily available/easy to fabricate (3) relatively strong

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

fibers produce very high strength in composite form (4) it is not affected by the chemical agents contained in plastics.

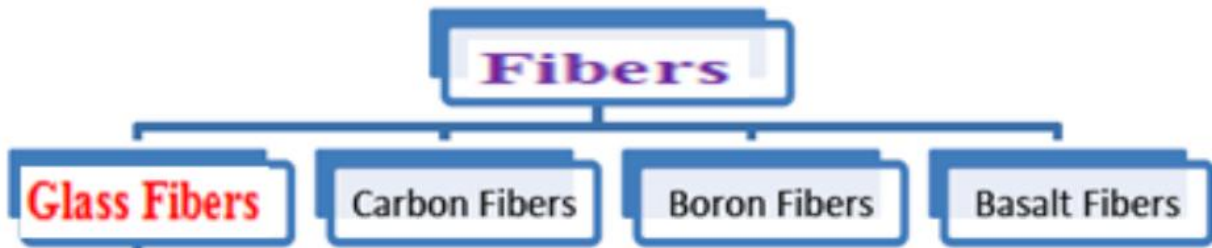


Figure 13: Classification of fibres.

2.4.4.1. Glass fiber

The aim of fibre reinforced plastics is to combine the stiffness and strength of fibrous material. This material has corrosion resistance, low density and mould ability. The majority of reinforced plastics produced today are glass reinforced epoxy or polyester resins, both of which are thermosetting. Glass fibers have also been used with phenolic, silicones, polystyrene and polyvinyl chloride. Glass fibers are the obvious choice as reinforcing agents, principally because of the relative ease with which high strengths can be obtained fiber a few microns in diameters. It is possible to produce composites with a range of strength according to glass content and nature of the reinforcement [22].

I) Properties

Some of the basic properties of glass fiber are [23]:

- Specific Strength (tensile strength per volume)
- Low density
- Impact resistance
- Electrical properties
- Incombustibility
- Low thermal conductivity
- High resistant to the chemical agents
- Dimensional stability at high temperature

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II) Different Types of Glass Fibers

Glass is the most common fiber used in polymer matrix composites. The most commonly used glass fibers are E-glass, S-glass, R-glass, C-glass and D-glass fibers. The E in the E-glass stands for electrical as it was designed for electrical applications. In S-glass S stands for higher content of silica. It retains its strength at high temperature and has higher fatigue strength. It is used mainly in aerospace applications. But In C-glass C stand for corrosion, it is designed to give improved surface finish. It is available usually in the form of a surface tissue for the reinforcement of corrosive barriers in chemical plant. In D-glass D stands for dielectric used for applications requiring lower strength [24].

Table1: Mechanical property of glass fiber [39]

Glass fiber	Density [gm/cm ³]	Tensile strength [Mpa]	Modulus Gpa	Percent elongation
E -class	2.54	1950/2050	72	4.7
S-class	2.53	4600	89	5.2
R-class	2.52	4400	86	5.1
D-class	2.56	2500	55	4.5
C-class	2.56	3300	69	4.8

Even though S and R class glass has higher strength with lower density as compared with the E-class they are not suitable for our design since

- ✓ Significantly higher cost as compared to E-glass
- ✓ Self-abrasiveness if not treated appropriately leading to reduced strength
- ✓ Relatively low fatigue resistance

Even though E glass is used for the electrical application its good tensile and fatigue strength, good complying character with the various forms resin and its reasonable low cost found appropriate for this thesis [24].

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

III) Advantages of Glass Fibers

Glass fiber is most widely used as reinforcement of all composites due to the following advantages:

- Molten glass easily drawn into high-strength fibers
- It is readily available/easy to fabricate
- Relatively strong fibers produce very high strength in composite form
- It is chemically contained in plastics.

These materials are limited to low temperature applications where strength is important without the need for high rigidity. The typical uses for this material are boat hulls, flooring materials and vehicle bodies. The main type of glass used is E-glass. However, nowadays it is used for many other purposes such as decorations and structural applications [22].

2.4.3.2 Epoxy Resin

The choice of a resin system for the use of most composite structural component depends on a number of its characteristics, such as: adhesive properties, mechanical properties, and degradation from water ingress. The most commonly used thermoset resins are epoxy, vinyl ester, polyester and phenolic.

Among the thermoset resin, Epoxy resins are the most commonly used for the coating electronic material adhesive and matrix for the fiber reinforced composite because of their outstanding mechanical property like high adhesion strength ,good heat resistance etc [26].

. They are low molecular weight organic liquids which contain epoxide groups. etc... Although epoxy is expensive than other polymer matrices, it is the most popular PMC matrix. Epoxy resin are also used in the aerospace as the material for the space vehicles, helicopter blades, spoilers, elevator etc [27].

The main reasons for epoxy being the most used polymer matrix materials are [22].

- excellent adhesion to wide variety of fibers
- high tensile strength and fatigue resistance
- resistance to the water degradation

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

- Good performance at elevated temperatures
- Low viscosity and low flow rates, which allow good wetting of fibers and misalignment of fibers during processing.
- Low shrink rates, which reduce the tendency of gaining large shear stresses of the bond between epoxy and its reinforcement.

2.5. FIBER REINFORCED THERMOPLASTIC COMPOSITES AND THEIR APPLICATION AREAS

Composites combine high strength fibers and lightweight matrices, creating materials with high specific properties. Applications for these materials are varied and wide ranging, from short fiber reinforced injection molded thermoplastics for high volume manufacturing, to high performance aligned long fiber composites for more demanding applications. Reinforced injection molded thermoplastics for high volume manufacturing, through to high performance aligned long fiber composites for more demanding applications. There are a broad range of commercially available resin systems, fibers and preimpregnated composite materials. Each offers a different level of mechanical performance, surface finish, recyclability, formability and cost.

Thermoplastic matrix based composites have become popular for large volume production of components and structures, as they offer a number of advantages over thermosetting composites. They are tough, and can be formed or molded quickly through the application of heat. They can be recycled easily and produce very little waste during manufacturing. These factors combine to make them appeal strongly from medium to high volume automotive manufacturers.

2.5.1. Application of Thermoplastic Composites to Railway structures

Legislation is constantly demanding improvements to every aspect of new passenger vehicles. This legislation can be simplified into two key requirements. Firstly, cars must be more environmentally friendly in terms of both fuel efficiency and recyclability and secondly, they must be safer, offering more protection to both passengers and pedestrians in the event of an accident. Composites materials can offer solutions to both these problems.

Safety and in particular crashworthiness can be significantly improved by the use of composites.

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Metallic crash structures absorb energy during an impact primarily through plastic deformation. Composites have the potential to absorb considerably larger amounts of energy due to damage modes, including matrix deformation, delamination, local cracking and crushing. The specific energy absorption of composites has been well documented and shown to offer substantial performance improvements [29].

Probably the most recent, high profile, use of composites in the railway industry has been the Aston Martin Vanquish. This vehicle launched in 2001 uses carbon fiber reinforced composites in the crash energy management structures, A-pillars and transmission tunnel. These parts not only provide increased stiffness and enhanced levels of crashworthiness, but offer significant weight saving over similarly performing steel structures [28].

As well as production parts, research and development work is on-going, to develop new composite components for the railway industry. Some published applications include structural instrument panels and cross car beams developed by Delphi, Beyer and General Motors, a glass fiber reinforced B-post developed in conjunction with Volvo and an energy absorbing knee bolster designed and tested by GE Plastics. Much of the current industrial research work remains unpublished though, due to its commercially sensitive nature [25].

2.5.2. Crashworthy Applications of Composite Materials

Metallic crash structures absorb energy during an impact primarily through plastic deformation. Composites have the potential to absorb considerably larger amounts of energy due to damage modes, including matrix deformation, delamination, local cracking and crushing. The specific energy absorption of composites has been well documented and shown to offer substantial performance improvements [27].

As compared with to the metals, Aligned fiber composite materials, in general, offer a combination of high specific stiffness, strength and energy absorption when compared to metals. This is observed, not only in materials, but even when considering bulk thermoplastic matrix materials such as polypropylene reinforced with glass fibers, Composites therefore have the potential to replace metallic crash energy management structures in transport applications, where low mass and high strength and energy absorption are key economic drivers [16].

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

2.5.3. Application of Composite Materials in the Automotive

Traditional barriers to composite materials entering high volume passenger vehicle design, such as processing time, cost and recyclability are being overcome by thermoplastic matrix composites.

Glass reinforced polypropylene GMT is used extensively in the Mercedes A Class, where the rear hatch is manufactured as a module, produced and delivered by an external supplier. This module saves 3kg over a conventional pressed steel structure, which equates to approximately 25% of the component mass). The BMW Mini also uses thermoplastic composites in a semi-structural application in this vehicle a complete front-end carrier component is manufactured using StaMax, an injection moulded glass-reinforced polypropylene material. This structure requires 40 fewer parts when compared to a steel front-end carrier and offers a cost and weight advantage. This material is also used in front-end applications on the Porsche Cayenne and the Volkswagen Touareg and in the door module of the Ford Fiesta [21], [51].

Long glass fiber reinforced polypropylene Twintex has been used for a bumper beam structure in the Peugeot 806/Evasion van, where the beam has been shown to perform effectively in both low and high speed collisions remaining in one piece after testing and overcoming the problems of catastrophic collapse and failure associated with thermosetting matrix composites.

Twintex has also been used, by Nissan, for the rear load floor of the Primera Break. This component, aligned fiber reinforced composite facings are molded as a sandwich structure with polypropylene honeycomb and polypropylene trim fabric. This use of 100% polypropylene and glass fiber allows relatively easy recycling of the complete part [23].

Two significant barriers to the use of composites in automotive structural design still remain. The first of these is the End of Life Vehicle Directive, which specifies requirements for recyclability. The second is the relatively high component cost of composite parts when compared to metals. Aligned fiber reinforced thermoplastic composites therefore seem a promising option for high volume automotive applications, if they can be proven to meet both structural and crashworthiness requirements [24].

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2.6. PREVIOUS WORKS

2.6.1. Sandwich structures in rail vehicles

In ground transportation sandwich structures can be found in cars, busses and trains. Since the 80s front cabs of locomotives have been built with sandwich technology because of its high strength and good impact and energy absorption properties. Some examples of this are the XPT locomotives in Australia, the ETR 500 locomotives in Italy, the French TGV and the Swiss locomotive 2000.

The high specific bending stiffness of sandwich structures can with advantage is used in vehicles, provided that the structural behavior during a crash situation is well understood and possible to predict [34].

2.6.2 Korean Tilting Train Express, TTX

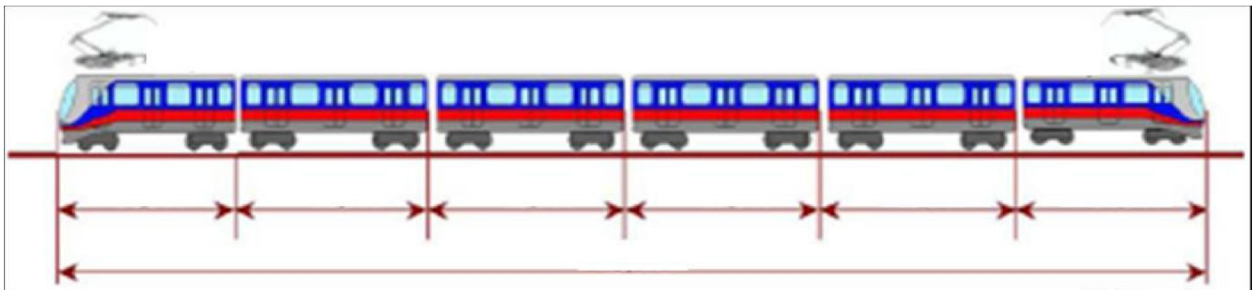


Figure 14: Vehicle configuration of TTX [36]

The sandwich structure elements consist of carbon fabric/epoxy prepreg for the faces and an aluminum honeycomb core. The entire car body is manufactured as one single structure.

This was accomplished by means of large scale auto-clave. A large mold was built in which the outer face was firstly laid out. The outer face was then cured in the auto-clave. Secondly the inner frame and honeycomb core was placed on top of the outer skin. The core and skin was bonded by use of an adhesive film. After this step followed lay-up of the inner face. Lastly the entire structure was, after appropriate vacuum bagging, cured in the auto-clave. By constructing the entire car body as one structure weak links between panels is eliminated. The only remaining weak link is between the upper body and under frame [36].

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The sandwich structure reduced the upper car body weight by 78% compared to a stainless steel car body. The total weight reduction, including under frame, was 28%.

2.6.3 Research on vehicle structure and sandwich materials

A number of researches were done on vehicle structural analysis and researches on sandwich materials strength test using simulation software and material labs. Some of the researches related to tram car and sandwich material are found below.

[35] Performed a multi-level approach on weight optimization for a “typical” rail vehicle body shell [36]. Initially the sandwich panel configuration was a 28mm thick polyurethane core with two 8mm thick face sheets of glass fiber reinforced epoxy composite plies giving a total of 16 plies and a lay-up of $[0^\circ/\pm 45^\circ/90^\circ]_S2$. Each ply was 1mm thick. This gave a total panel thickness of 44mm. The panels were supported by a frame of steel stiffeners. The car body was furthermore subjected to a longitudinal compressive force of 1500kN during the optimization.

Investigates how various requirements, such as stiffness, strength, buckling, thickness and area density, influence the choice of load carrying sandwich panels for high-speed rail vehicles. Requirements on the load carrying structure are defined where after various sandwich alternatives are studied to match these requirements. Panels that first pass a general requirement evaluation are further studied by Finite Element Analysis (FEA) [37].

Performed Design and Testing of Sandwich Structures with Different Core Materials the purpose of the study was to design a light-weight sandwich panel for trailers. Strength calculations and selection of different materials were carried out in order to find a new solution for this specific application. 3D FEA was applied to virtually test the selected sandwich structure in real working conditions. Based on FEA results the Pareto optimality concept has been applied and optimal solutions determined [38].

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2.6.4 FE model of Chevrolet Silverado,

In order to investigate the weight reduction opportunities in a current vehicle, a lightweight vehicle was developed numerically (i.e., a finite element model was developed). An FE model of a 2007 Chevrolet Silverado, which is a body-on-frame pickup truck, was selected as the candidate vehicle for weight reduction. Composites were considered as the primary substitute materials in the study [39].

Furthermore, the steel ladder frame, which is the primary structural member of the Silverado, was selected and weight-reduced with a composite material in order to evaluate the crashworthiness of a structural composite member in the vehicle structure. A carbon fiber thermoset matrix braided composite was considered as the substitute material for the ladder frame.

The developed lightweight vehicles were simulated to investigate the weight reduction effect on vehicle crashworthiness, to evaluate the crash performance of the composite structural component (Ladder frame), and to look into the opportunities of using composites for weight reduction in a current vehicle [39].

In this thesis, costs were not considered. In particular, a cost increase is one of the critical barriers to using composites material in vehicle car body. However, in order to investigate opportunities for weight-reduced vehicles using composite and identifying the potential safety benefits of composites applications in future lighter, this study mainly focused on identifying currently available composite materials and their applicability to current vehicle components, and did not consider cost variations. Also, the manufacturability for vehicle components using composites is another critical issue.

Instead, the existing vehicle design, which has optimal structures for steel material and steel manufacturing technologies, was used to develop the lightweight vehicle having composite as material substitutes in this study. So, the design changes of original vehicle structures and components were limited to replacing components, and therefore are considered to be a minimal approach that could be taken for reducing the weight in the weight reduction process [39]. A more optimal approach would have been a comprehensive, clean-sheet design from the ground up to achieve a maximized weight reduction for the Silverado. However, such an approach was beyond the scope and available funding for this thesis

CHAPTER THREE

MATERIALS, ANALYTICAL METHODS AND CONDITIONS OF LIGHT WEIGHT RAIL VEHICLE BODY

3.1 Introduction

The focus of this research design is the application of the composite material for the carbody structure of the AALRT .And investigate the comparative advantage of the composite over that of steel .but here this study does not deal with the internal parts of the vehicle (as it has been stated in the scope) since weight saving by this difficult in terms technological and performance aspect. However changing the material of the car body structure by the light weight composite material is practicable without undermine its requirements.

In this portion of the thesis the various applied loads on the train body structure is investigated as per recommendation of EN12663standard. The geometry modeling and FEM analysis for the rail way car body structure is with steel and composite material is done using SOLIDWORK software.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.2. Numerical Analysis of Rail vehicle body

The modeling for the rail vehicle is based on the Technical Specification for passenger Rail vehicle as per the AALRT .Table 2 presents this technical specification that comprises the dimension for the various section of the rail vehicle.

Table2: Technical Specification for passenger Rail vehicle [40].

Basic technical parameter	Parameter value
Track gauge	1435 mm
Minimum radius of vertical curve	1000 m
Minimum radius of horizontal curve	25 m
Weight of trams	43t
Axle load	11t
Maximum gradient	50
Rated voltage	DC 750V
Train length	12880mm
Maximum width	2180 mm
Height	2625 mm
Floor level to rail level at low-floor area	380 mm
Floor level to rail level at high-floor area	655 mm
Center-to-center distance between both bogies	10400 mm
Axle distance of the motor unit	1900 mm
Axle distance of the trailer unit	1800 mm
Clear height in passenger compartment at low-floor area	2255 mm
Clear height in passenger compartment at high-floor area	1980 mm

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3.3. Load condition

According to AALRT the no of passenger at the peak hour is 6 persons/m² and according to EN 10025 standard average passenger's weight is 60 kg. The occupied area of standing person is 6 persons/m² for rated passenger capacity, or 8 persons/m² for over crowded capacity.

➤ For rated passenger capacity total mass of the passenger, M_1 is given by

$$M_1 = \text{mass of persons on seat} + \text{mass of person standing for 6 person/m}^2$$

For

- One passenger weight = 60kg
- Number of seat per chair = 65 seat (chair)

$$\text{Mass Persons on seat} = 65 \times 60$$

$$= \underline{\underline{3900\text{kg}}}$$

➤ Number of standing person,

The number of standing person in the train depends up on the on the available free area for standing .given that the total internal area for the passenger (A_{pas}) and the area for the sitting (A_{sit}), the available free space for the standing person can be calculated by

$$A_{ave} = A_{pas} - A_{sit}$$

$$A_{sit} = 65 (L \cdot W) = 0.42 \text{ m} \cdot 0.47 \text{ m} = \underline{\underline{0.1974 \text{ m}^2}}$$

$$A_{pas} = L \cdot W = 9.79 \text{ m} \times 2.18 \text{ m} = 9.79 \text{ m} \times 2.18 \text{ m} = \underline{\underline{21.3 \text{ m}^2}}$$

➤ $A_{ave} = A_{pas} - A_{sit} = 21.3 \text{ m}^2 - 0.1974 \text{ m}^2 = 21.10 \text{ m}^2$

For rating capacity, 6 persons/m²

$$M_1 = \frac{6 \text{ persons}}{1 \text{ m}^2} \times 21.2 \text{ m}^2$$

$$= 127 \text{ persons} \longrightarrow \text{the person for standing}$$

The average mass of the person for standing is calculated by:

$$M_s = 127 \times 60 \text{ kg} = \underline{\underline{7620 \text{ kg}}}$$

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

- **In case of 6persons /m² the total mass is calculated as follows**

$$\begin{aligned}M_1 &= \text{mass Persons on seat} + \text{mass of standing persons} \\ &= 3900\text{kg} + 7620 \text{ kg} \\ &= \underline{\underline{11520 \text{ kg}}}\end{aligned}$$

- **In case of 8persons /m² the total mass is calculated as follows**

The number of standing person:

$$= \frac{8\text{persons} \times 127\text{persons}}{6\text{persons}} = 170 \text{ persons for standing}$$

The mass of the person for standing is

$$\begin{aligned}M_s &= 170 \times 60\text{kg} \\ &= \underline{\underline{10200\text{kg}}}\end{aligned}$$

$$\begin{aligned}M_2 &= \text{mass of person on seat} + \text{mass of standing persons for } 8\text{person/m}^2 \\ &= 3900 \text{ kg} + 10200 \text{ kg} = \underline{\underline{14100\text{kg}}}\end{aligned}$$

Therefore the total Load, F is calculated by two conditions.

$$\begin{aligned}F_1 &= m_1 \times g \\ &= 11520\text{kg} \times 9.81\text{m/s}^2 \\ &= \underline{\underline{113011.2 \text{ N}}}\end{aligned}$$

$$\begin{aligned}F_2 &= m_2 \times g \\ &= 14100\text{kg} \times 9.81\text{m/s}^2 \\ &= \underline{\underline{138321 \text{ N}}}\end{aligned}$$

From these we can calculate the total pressure applied on the vehicle body structure assuming that the distributed uniformly for the entire area.

$$P_1 = \frac{F_1}{A} = \frac{113011.2\text{N}}{21.10\text{m}^2} = \underline{\underline{5330.1 \text{ Pa}}}$$

$$P_2 = \frac{F_2}{A} = \frac{138321\text{N}}{21.10\text{m}^2} = \underline{\underline{6524.6 \text{ Pa}}}$$

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.4. FE ANALYSIS METHOD OF STEEL AA-LRT CAR

3.4. 1. Modelling

As stated earlier, to build the model of the AA-LRT drawn in a SOLIDWORKS 2017. The detail dimension for the train body structure is given in the page (67). But the overhaul dimension is present here below

Overall dimension:

- Length= 12880 mm
- Width=2180 mm
- Height between under frame to car top=2625 mm

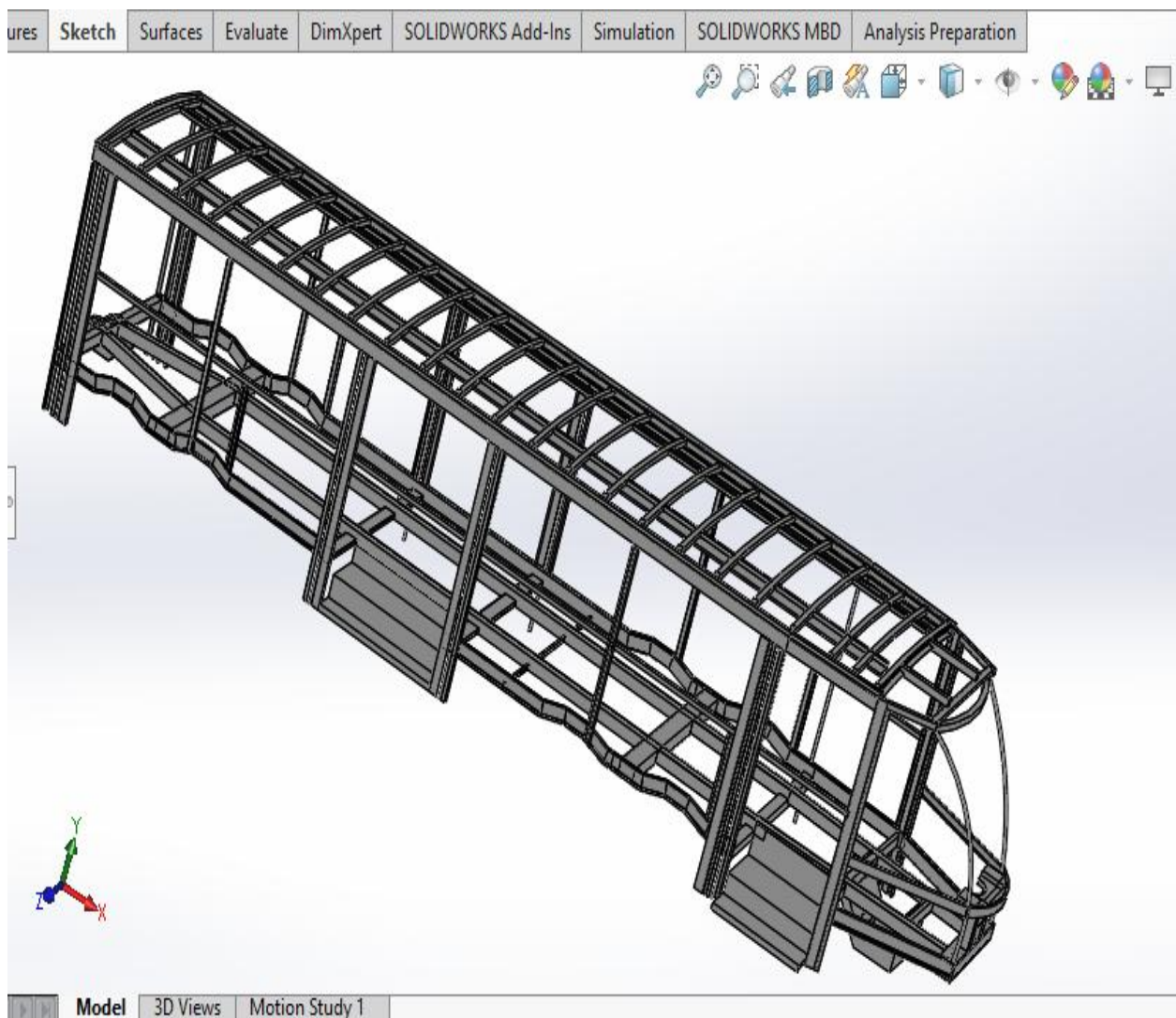


Figure 15: Modelling using solid work

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

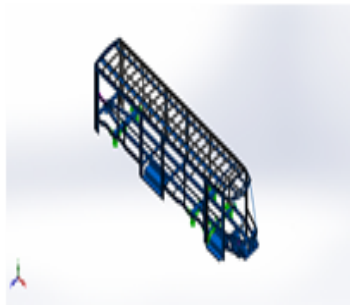
3.4.2. Define material property

Properties of material under study Material is structural carbon Steel according to EN 10025:2004 standard.

Table 3: Material property of carbon steel frame.

Mechanical Property	Value
Min yield stress limit [Mpa]	355
Tensile strength [Mpa]	510/630
Impact strength [KV-J]	20
Modules of elasticity [Gpa]	210
Poisons ratio	0.3
Density [kg/m ³]	7850

Table4: Material properties used in simulations on the solid word.

Model Reference	Properties	Components
	Name: carbon steel Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 3.55e+008 N/m ² Tensile strength: 6.30e+008 N/m ² Elastic modulus: 2.1e+011 N/m ² Poisson's ratio: 0.3 Mass density: 7850 kg/m ³ Shear modulus: 7.9e+010 N/m ² Thermal expansion coefficient: 1.1e-005 /Kelvin	Car body structure Train
Curve Data: N/A		

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.4.3. Mesh generation

The model consisted of 187499 elements and 377287 nodes and the mesh with fine sizing was selected. The detail mesh parameter including element size, mesh quality and tolerance are stated in the table shown below.

Study name	Static Carbon Steel
Mesh type	Solid Mesh
Mesher Used	Standard mesh
Element size	351.907 mm
Tolerance	23.9453 mm
Mesh quality	High
Total nodes	377287
Total elements	187499

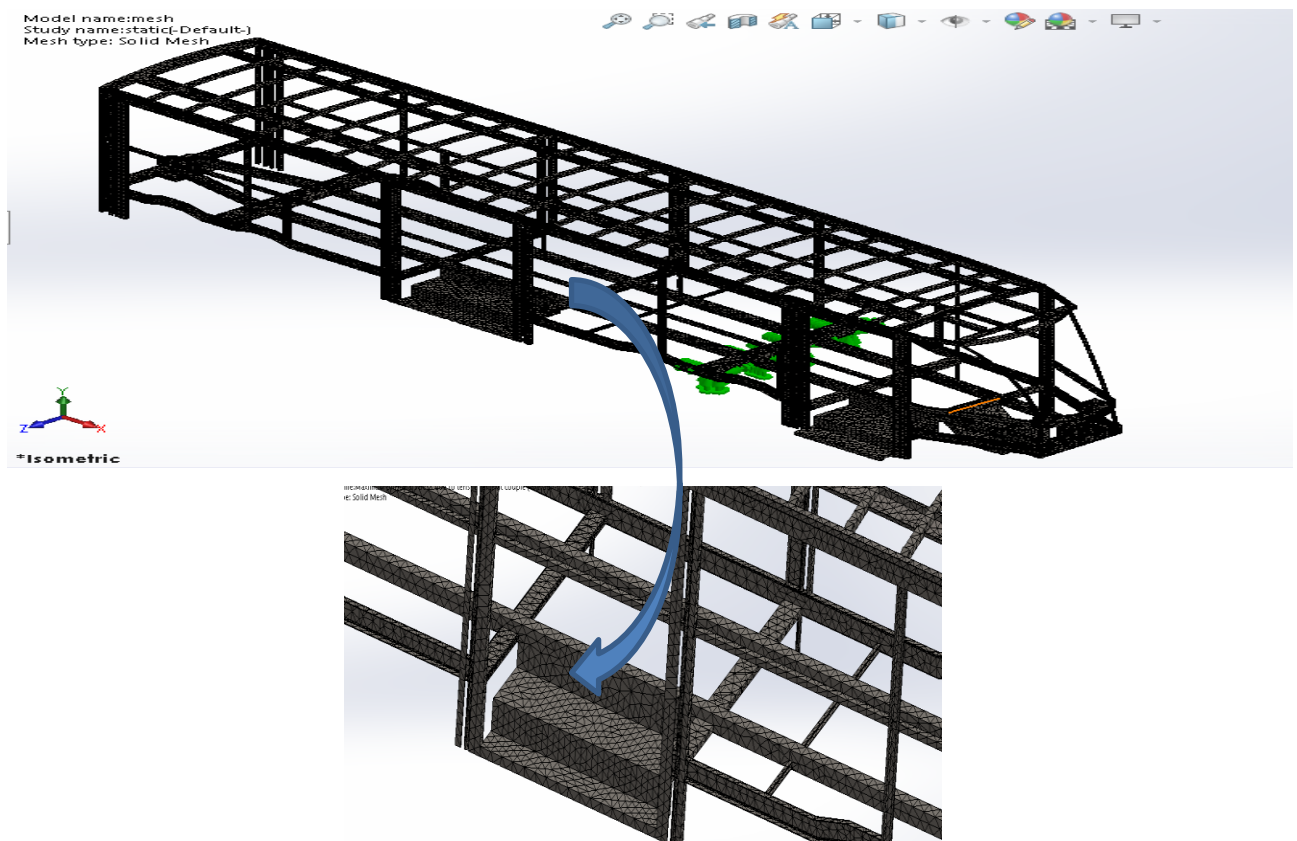


Figure 16: Meshing of steel vehicle body

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.5.4 Loads in the Train body structure

According to standard tram car categorized under P-V and I analyzed Addis Ababa LRT under these categories based on EN 12663 the load in the tram car comprises; tensile, compressive, turning and operating load. The table shown below summarizes and quantify the loads

Table5: load condition stated under EN 12663 for P-V type locomotive [10].

Load	Description	Value
tensile load at coupling area	150KN tensile load in both Direction	A value of 75 KN at each buffer
Compressive force at buffers	200KN compression force in both direction	A value of 100KN at each buffer
Turning right	0.15*gross vehicle weight in Y direction= 0.15*(11520+43000)	A value : 8178
Turningleft	0.15* gross vehicle weight in Y direction = 0.15*(11520+43000)	A value : 8178
Maximum operating load	1.3*gross vehicle weight in Z- Direction = 1.3*(11520+43000)	A value : 70876

I know that gross vehicle = $g (m_1 + m_2)$

From the European standard to calculate the forces on the equipment attachments during operation of the vehicle, the masses of the components shall be multiplied by the specified Accelerations in x, y and z direction.

X-Longitudinal direction

Y- Lateral direction

Z -vertical direction

Vertical load (F_z) is the load uniformly distributed over the floor of the car body $F_z = 1.3 * g (m_1 + m_4)$

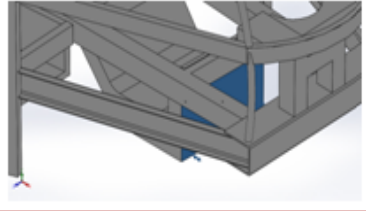
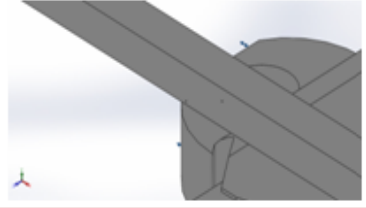
M1 is the design mass of the vehicle in working order according to EN15663 without bogie mass.

M4 is the mass of exceptional pay load. In Addis Ababa City, m4 takes the number of passenger at the peak hour is 6 person per meter square, according to EN 12663. And a standard average passenger weight is 60 kg.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.5.4.1 Tensile force

The tensile force which are applied at the front and back of the structure is presented as shown below:

Load name	Load Image	Load Details
Force-4		Entities: 1 face(s) Type: Apply normal force Value: -75000 N
Force-5		Entities: 1 face(s) Type: Apply normal force Value: -75000 N

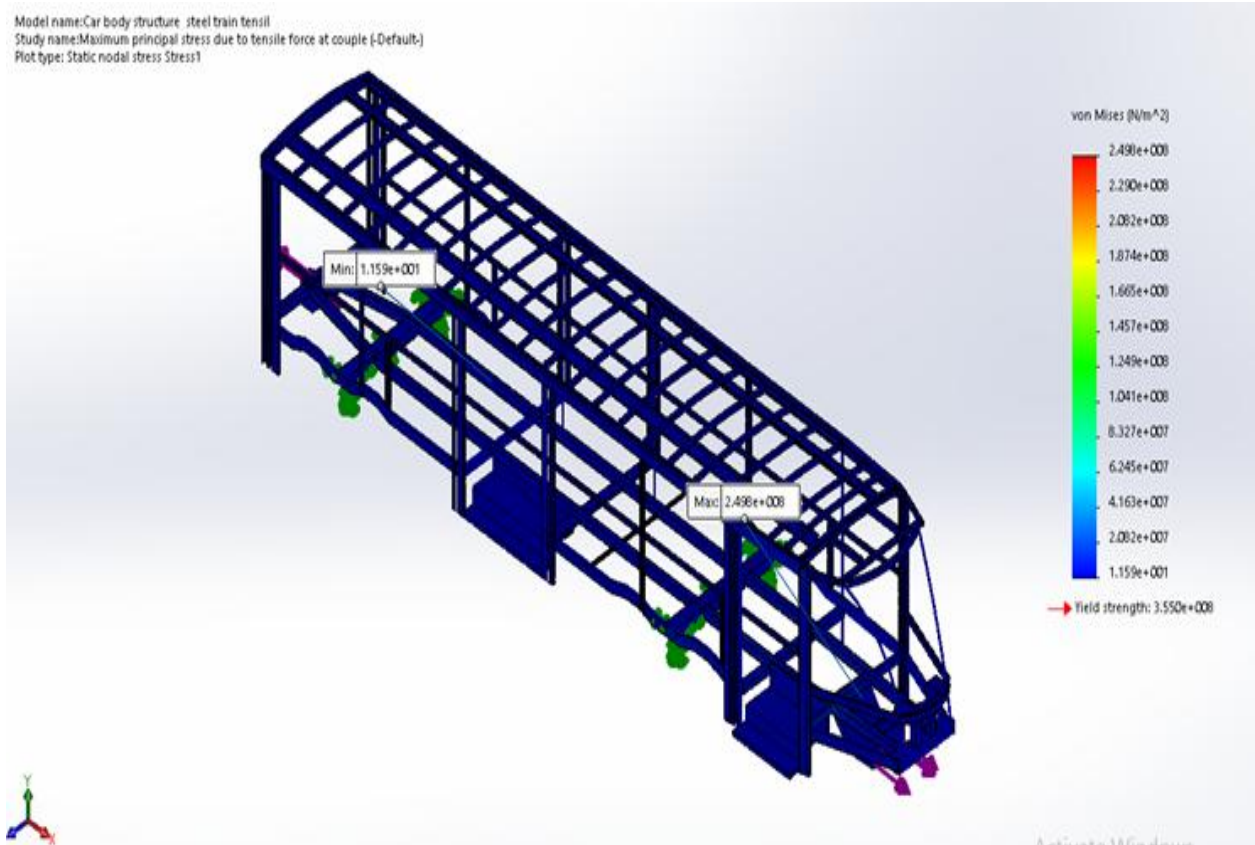


Figure 17: Tensile force at buffer

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

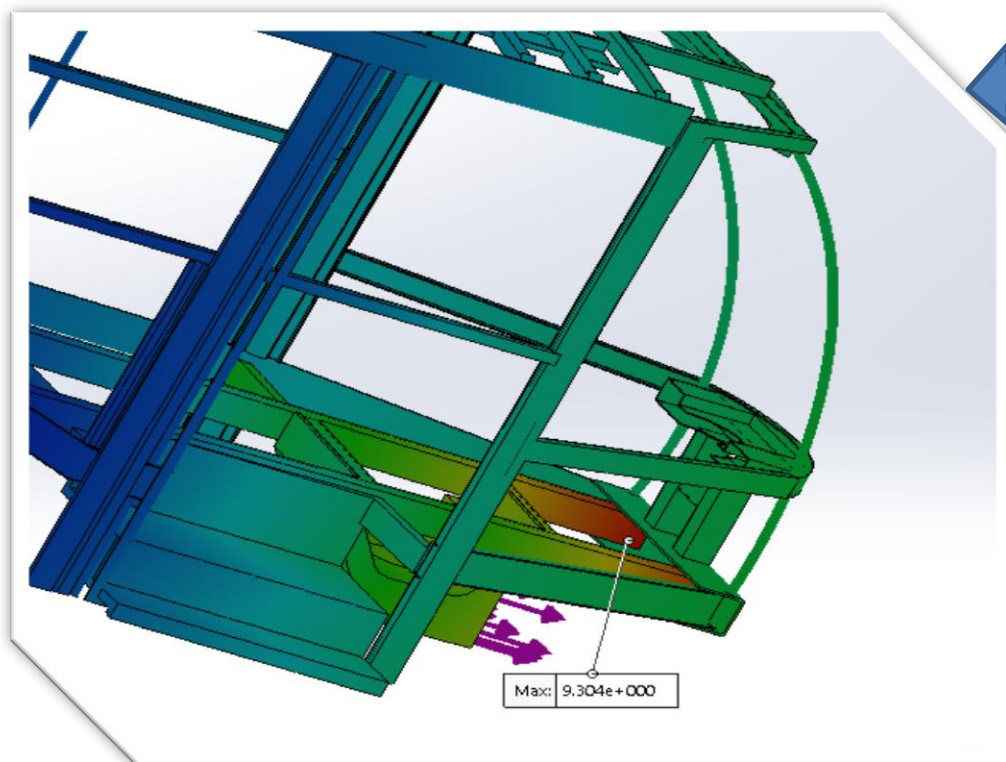
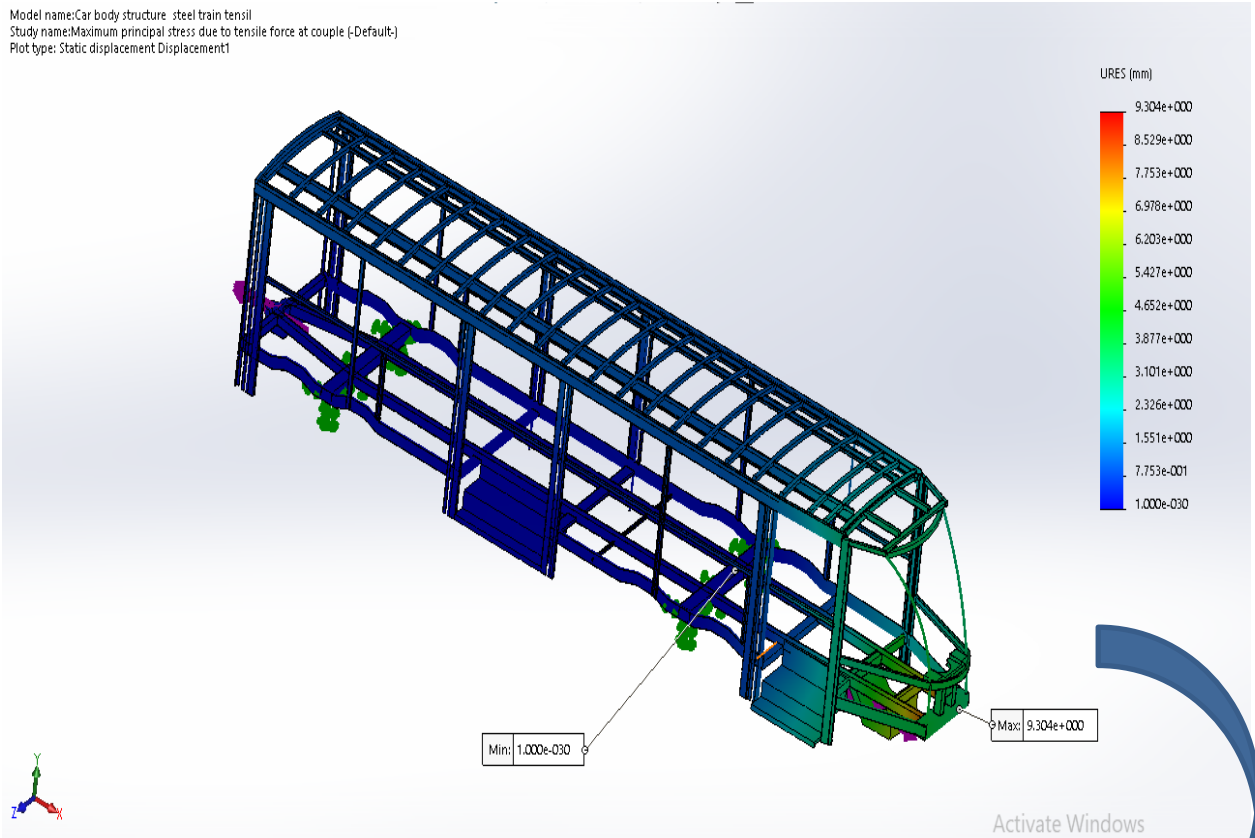
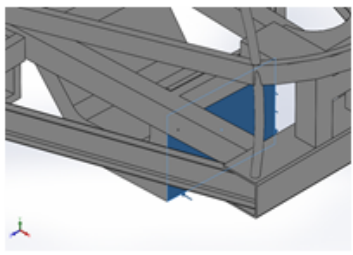
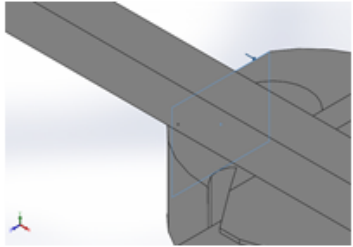


Figure 18: deformation due to tensile force

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.5.4.2 Compressive force

The Compressive force which are applied at the front and back of the structure is presented as shown below

Load name	Load Image	Load Details
Force-1		Entities: 1 face(s) Type: Apply normal force Value: 100000 N
Force-2		Entities: 1 face(s) Type: Apply normal force Value: 100000 N

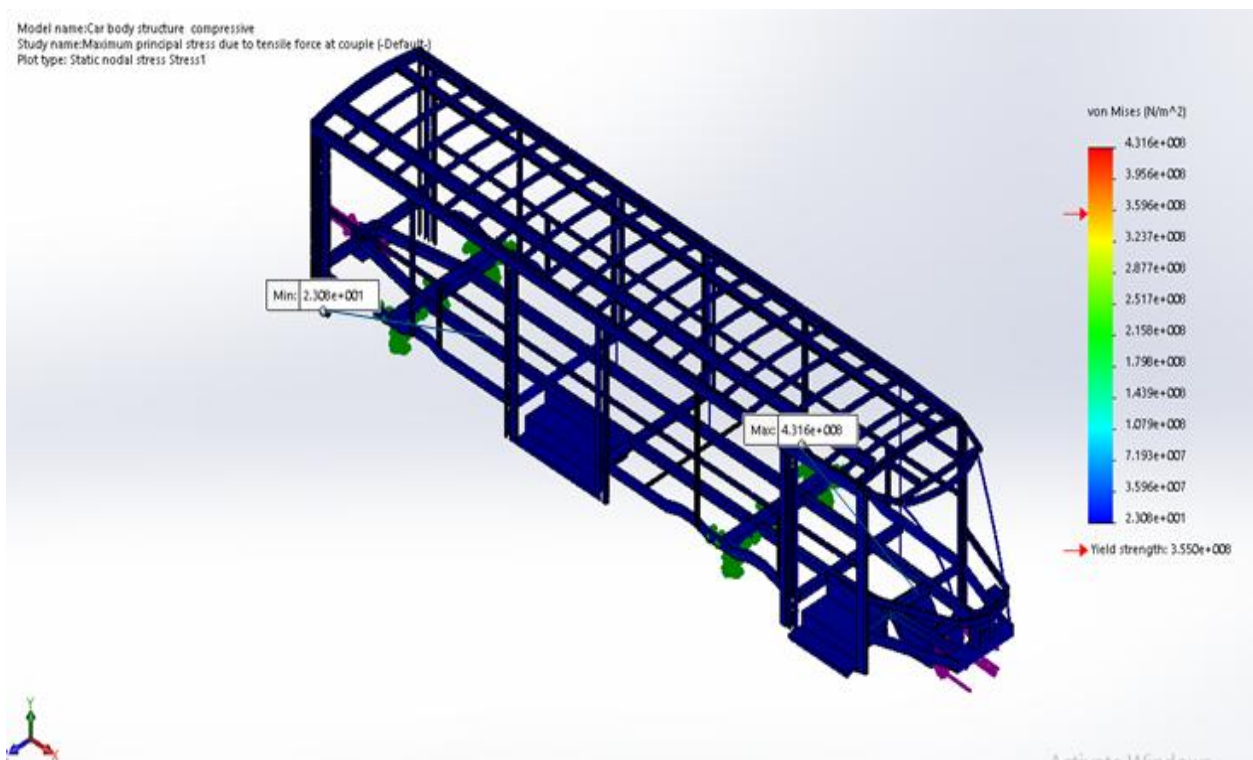


Figure 19: Compression force at buffer

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

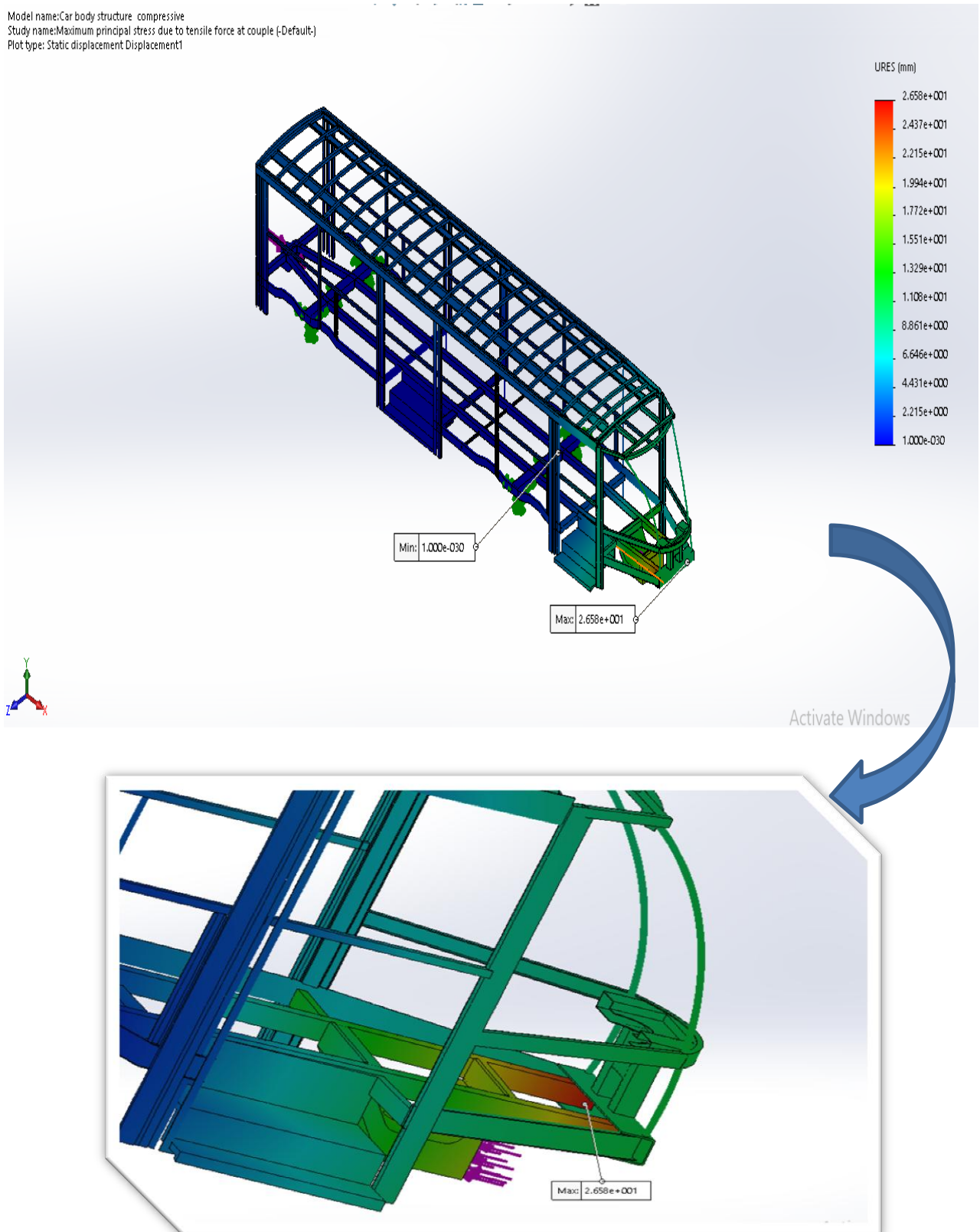
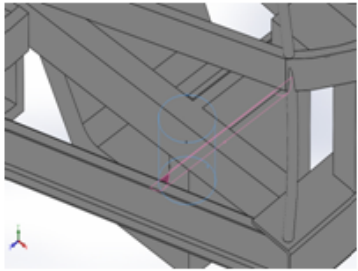
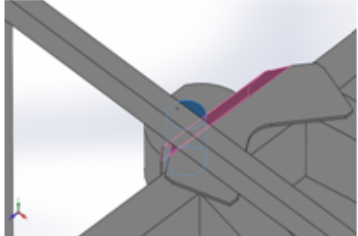


Figure 20: deformation due to Compression force.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.5.4.3 Turn right

To turn the structure to the right equal and opposite force are applied at the front and back of the structure long lateral direction.

Load name	Load Image	Load Details
Force-1		Entities: 1 face(s) Reference: Face< 1 > Type: Apply force Values: -8178 N
Force-2		Entities: 1 face(s) Reference: Face< 1 > Type: Apply force Values: 8178 N

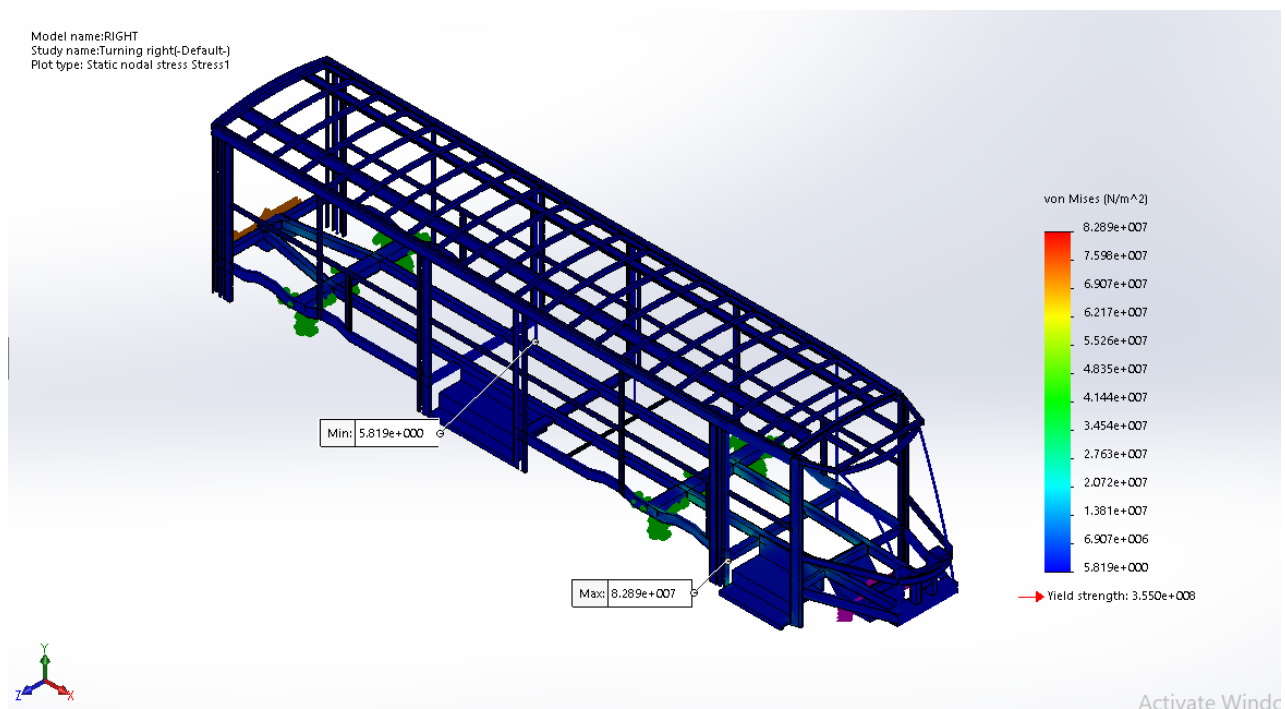


Figure 21: Maximum principal stress due to right turn.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

Model name:RIGHT
Study name:Turning right(-Default-)
Plot type: Static displacement Displacement1

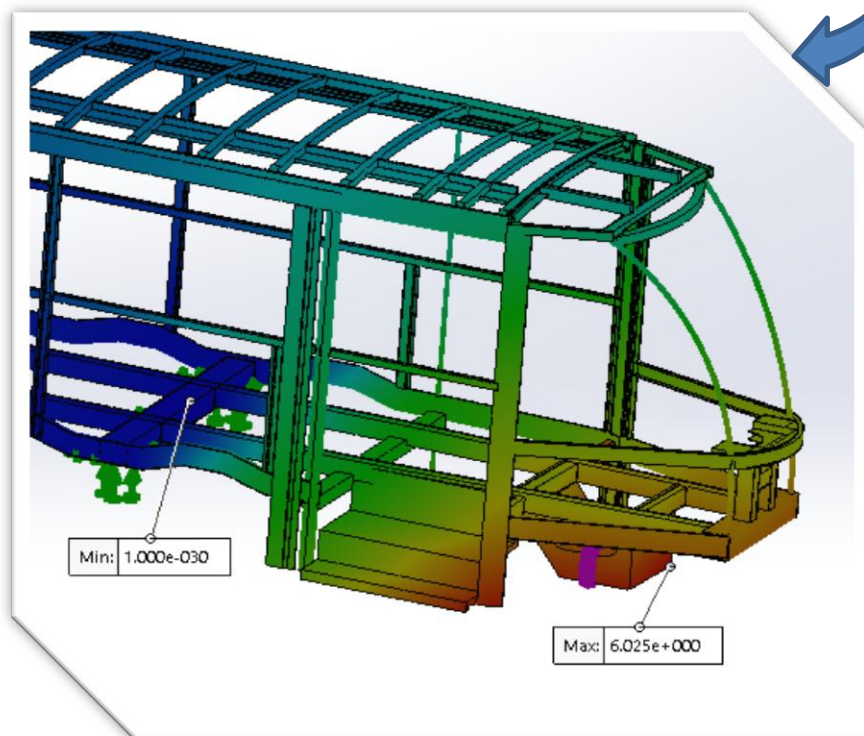
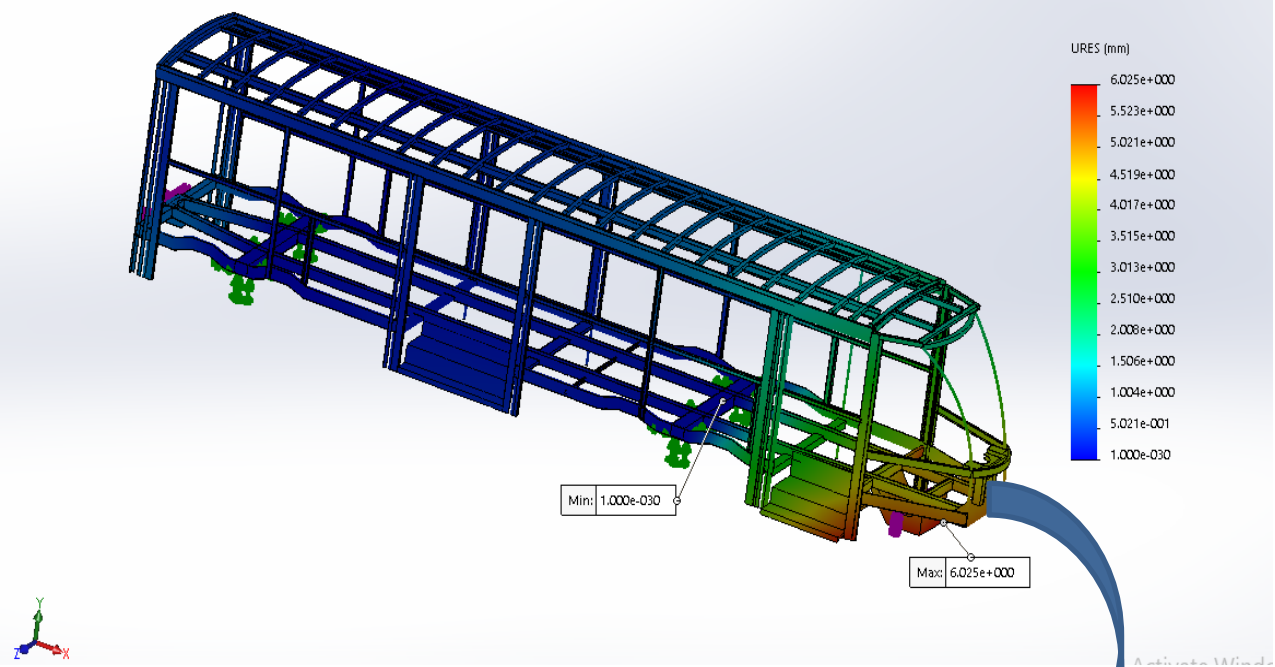
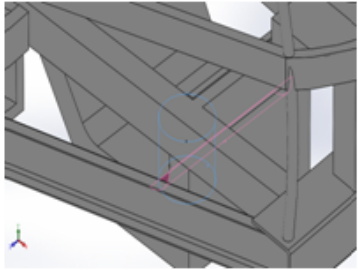
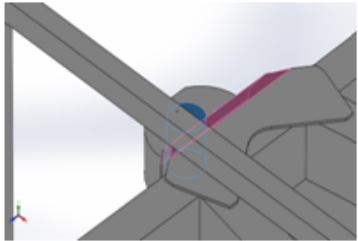


Figure 22: deformation due to right turn

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.5.4.4 Turn left

To turn the structure to the left equal and opposite force are applied at the front and back of the structure long lateral direction.

Load name	Load Image	Load Details
Force-1		Entities: 1 face(s) Reference: Face< 1 > Type: Apply force Values: 8178 N
Force-2		Entities: 1 face(s) Reference: Face< 1 > Type: Apply force Values: -8178 N

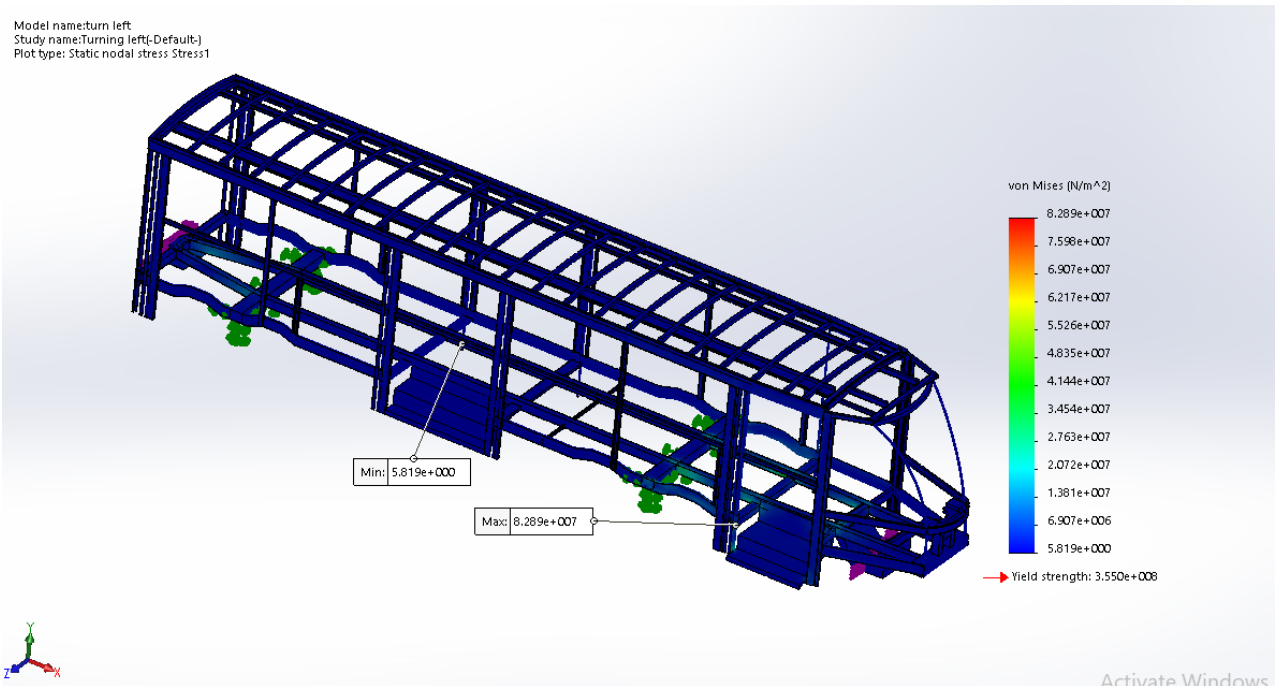


Figure 23: Maximum principal stress due to left turn.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

Model name: turn left
Study name: Turning left(-Default-)
Plot type: Static displacement Displacement1

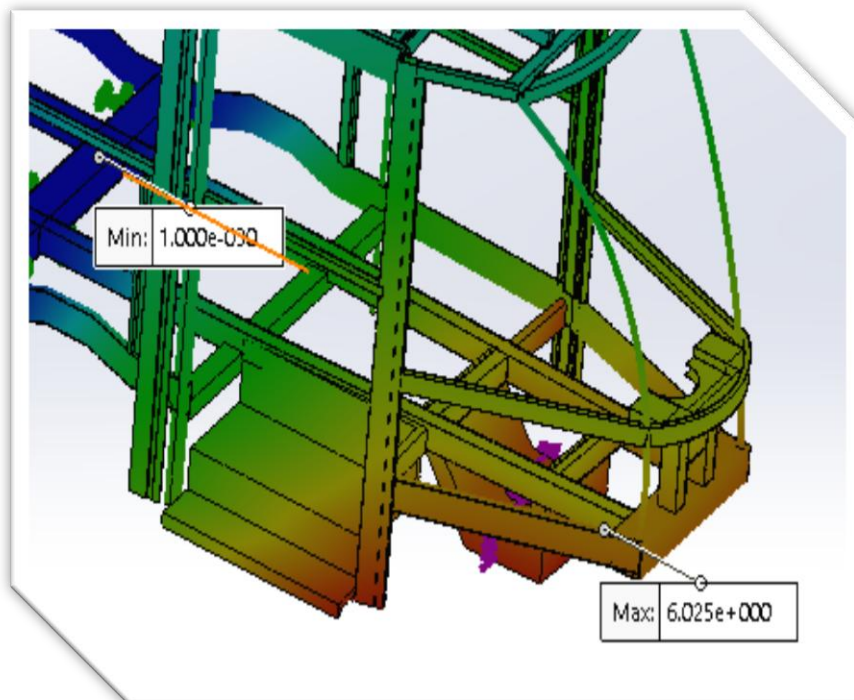
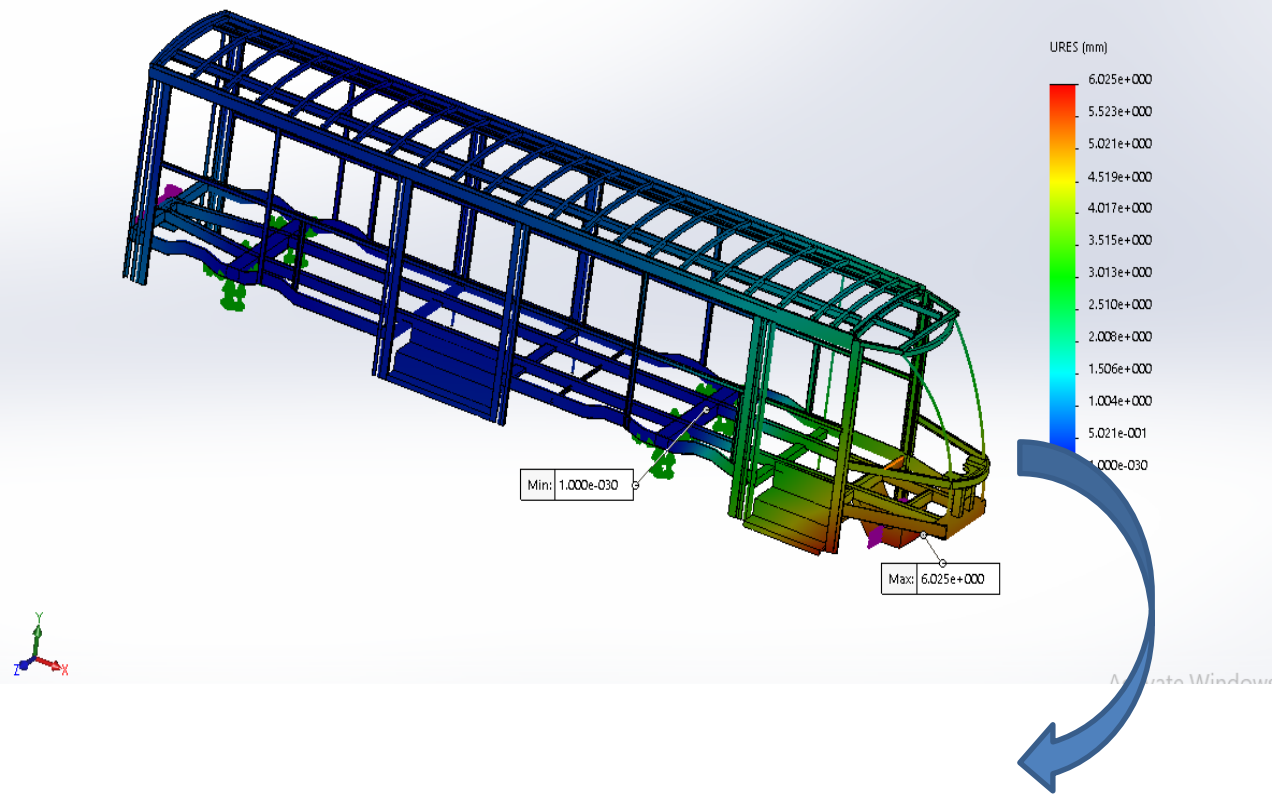


Figure 24: deformation due to left turn.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.5.4.5 Vertical Load

As it has been stated at the beginning of this chapter both dead weight and the weight of the passenger is calculated for estimating the vertical load, this is in accordance with the standard [10].

Load name	Load Image	Load Details
Force-1		Entities: 48 face(s) Type: Apply normal force Value: 70867 N

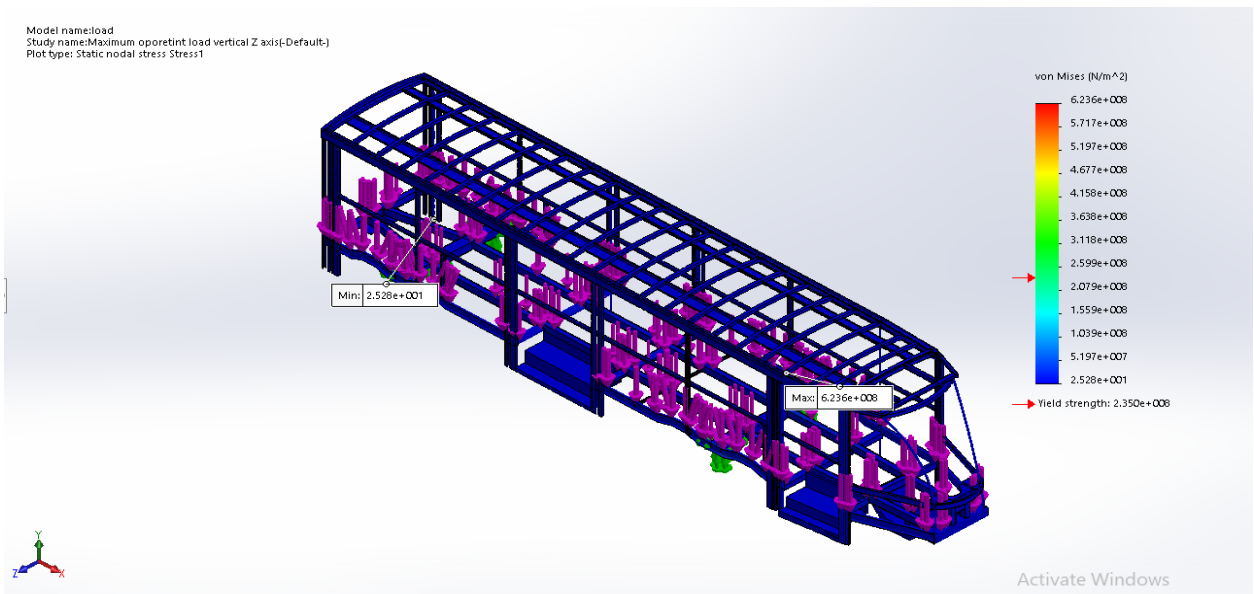


Figure 25: Maximum operating load.

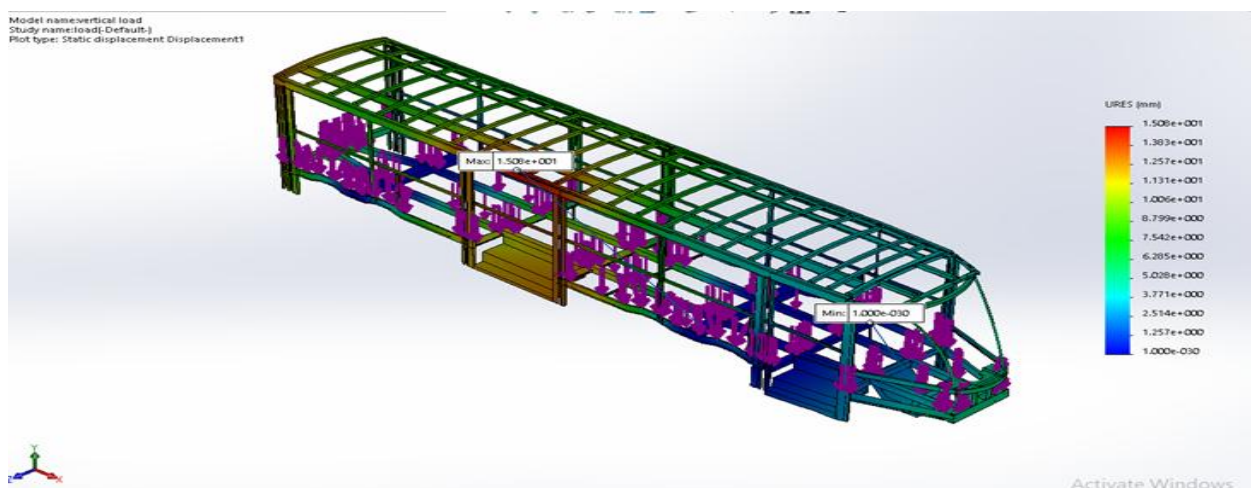


Figure 26: Total deformation due to operating load.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.6. FE ANALYSIS METHOD OF FIBER GLASS COMPOSITE AA-LRT CAR

3.6.1. Define engineering data

The specific material property of the selected fiberglass composite material is stated in the table below.

Table6: Mechanical properties of fiber glass material [41].

<u>Material E-Glass Fiber</u>			
property	Minimum	maximum	Units
Elastic modulus	72	80	Gpa
Poisson s ratio	0.21	0.23	
Shear modulus	30	36	Gpa
Mass density	2540	2600	Kg/m ³
Tensile strength	1950	2050	Mpa
Compressive strength	4000	5000	Mpa
Yield strength	1462.5	1537.5	Mpa
Thermal expansion	4.9	5.1	10 ⁻⁶ /k
Specific heat	800	805	j/kg.k
Thermal conductivity	1.2	1.35	W/m.k

Table7: Material properties used in simulations [42].

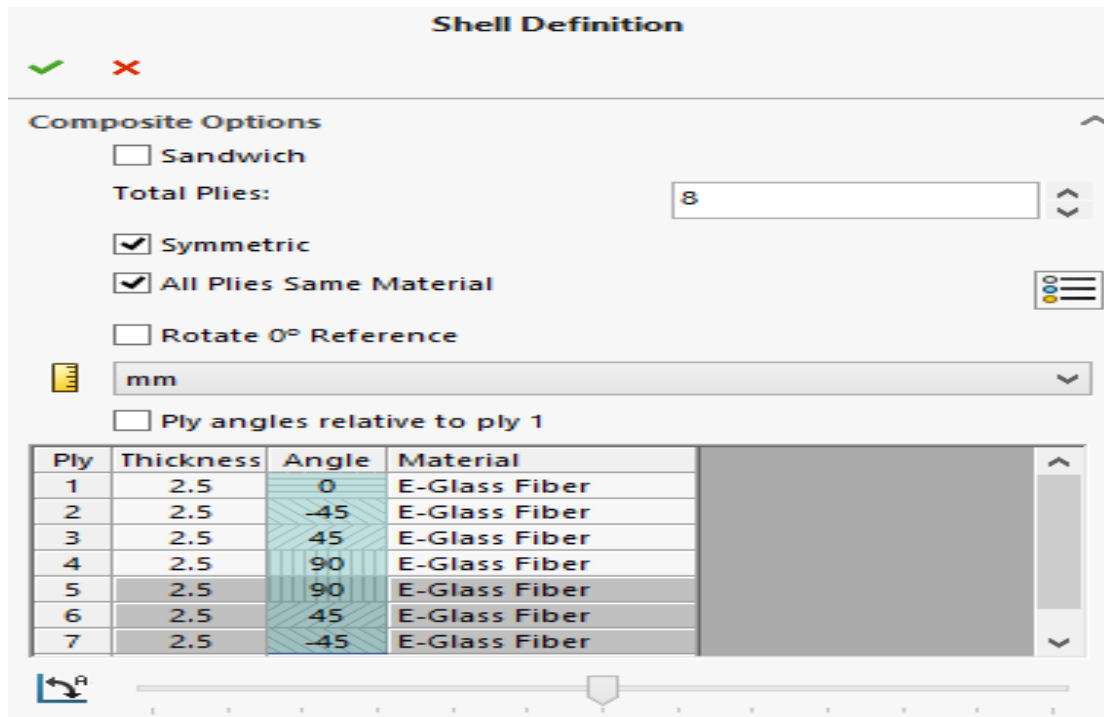
Young's Modulus – E (GPa)	Poisson's Ratio – v	Shear Modulus – G (GPa)
Ex= 150 Ey= 15 Ez= 15	Vxy= 0.33 Vyz= 0.03 Vxz= 0.29	Gxy= 5.7 Gyz= 7.26 Gxz= 5.7

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

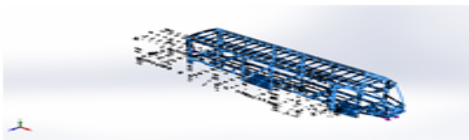
3.6.2. Composite material model

The number plies used of the composite affect the strength if it is below the value it needs to be or result a heavy body structure it is more than the required.

According to the study by [43] for the number of pile ranging from 4-12 it found that increasing the number of pile decrease the maximum deflection and maximum deflection .but increasing the number of piles may complicate the joining thus taking this in account for this thesis number of pile which 8 is taken and the result founds good.



Material Properties

Model Reference	Properties
	Name: E-Glass Fiber
	Model type: Linear Elastic Orthotropic
	Default failure criterion: Max von Mises Stress
	Yield strength: 1.4625e+009 N/m ²
	Tensile strength in x: 1.950e+009 N/m ²
	Compressive strength in x: 4e+009 N/m ²
	Elastic modulus in x: 1.5e+011 N/m ²
	Elastic modulus in y: 1.5e+010 N/m ²
	Elastic modulus in z: 1.5e+010 N/m ²
	Poisson's ratio in xy: 0.33
	Poisson's ratio in yz: 0.03
	Poisson's ratio in xz: 0.29
	Mass density: 2540 kg/m ³
	Shear modulus in xy: 5.7e+009 N/m ²
	Shear modulus in yz: 5.7e+009 N/m ²
Shear modulus in xz: 7.26e+009 N/m ²	
Thermal expansion coef in x: 4.9e-006 /Kelvin	

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

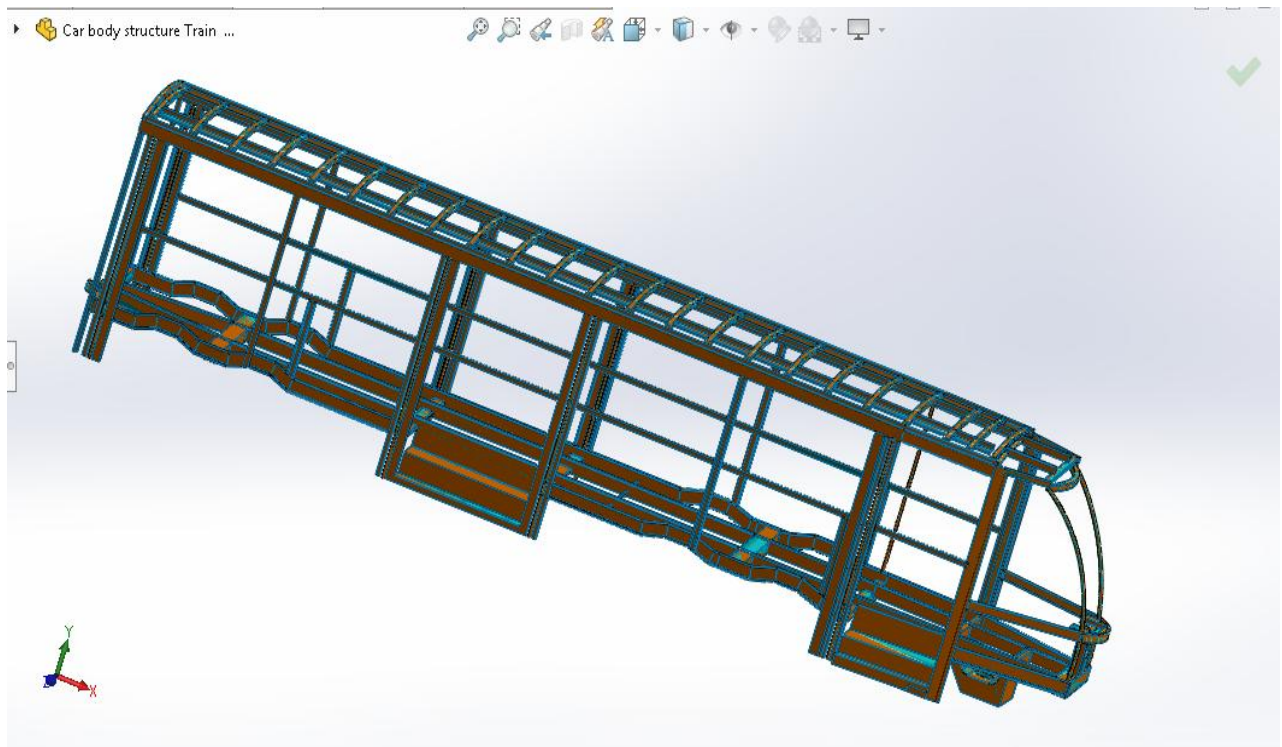


Figure 27: fiberglass models

3.6.3. Mesh parameters

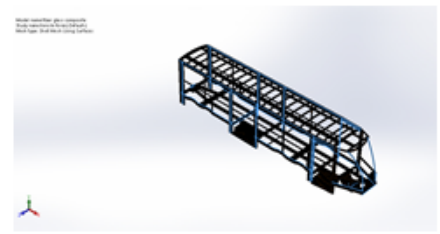
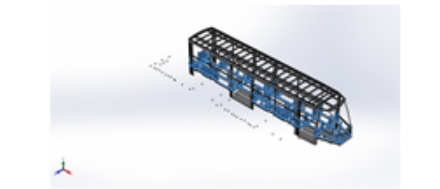
The model consisted of 107211 elements and nodes 195376 and the mesh with fine sizing was selected. Along with the mesh type of shell mesh using surface and average element size of 239.453mm.the detail mesh parameters are given below

Study name	Static composite
Mesh type	Shell Mesh Using Surfaces
Mesher Used	Standard mesh
Element size	239.453mm
Tolerance	11.9727mm
Mesh quality	High
Total nodes	195376
Total elements	107211
Time to complete mesh(hh:mm:ss)	00:04:18

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM



Figure 28: Meshing of fiber glass tram body

Mesh Control Name	Mesh Control Image	Mesh Control Details
Control-1		Entities: 1 Solid Body (s) Units: mm Size: 119 Ratio: 1.5
Control-2		Entities: 50 face (s) Units: mm Size: 50 Ratio: 1.5

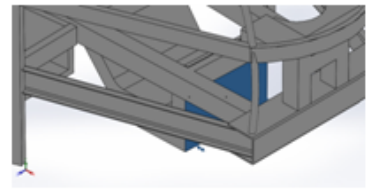
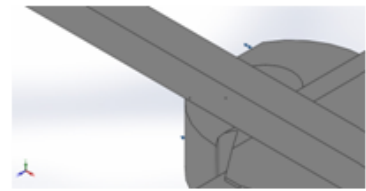
NB: Since the same material has been taken throughout the cross-section, it adequate to calculate the von-misses deformation, however to study the future performance of the composite it needs the analysis for the delamination, fiber tension and compression.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.6.4 Tensile force

The tensile force which are applied at the front and back of the structure is presented as shown below:

Table8: Tensile load

Load name	Load Image	Load Details
Force-4		Entities: 1 face(s) Type: Apply normal force Value: -75000 N
Force-5		Entities: 1 face(s) Type: Apply normal force Value: -75000 N

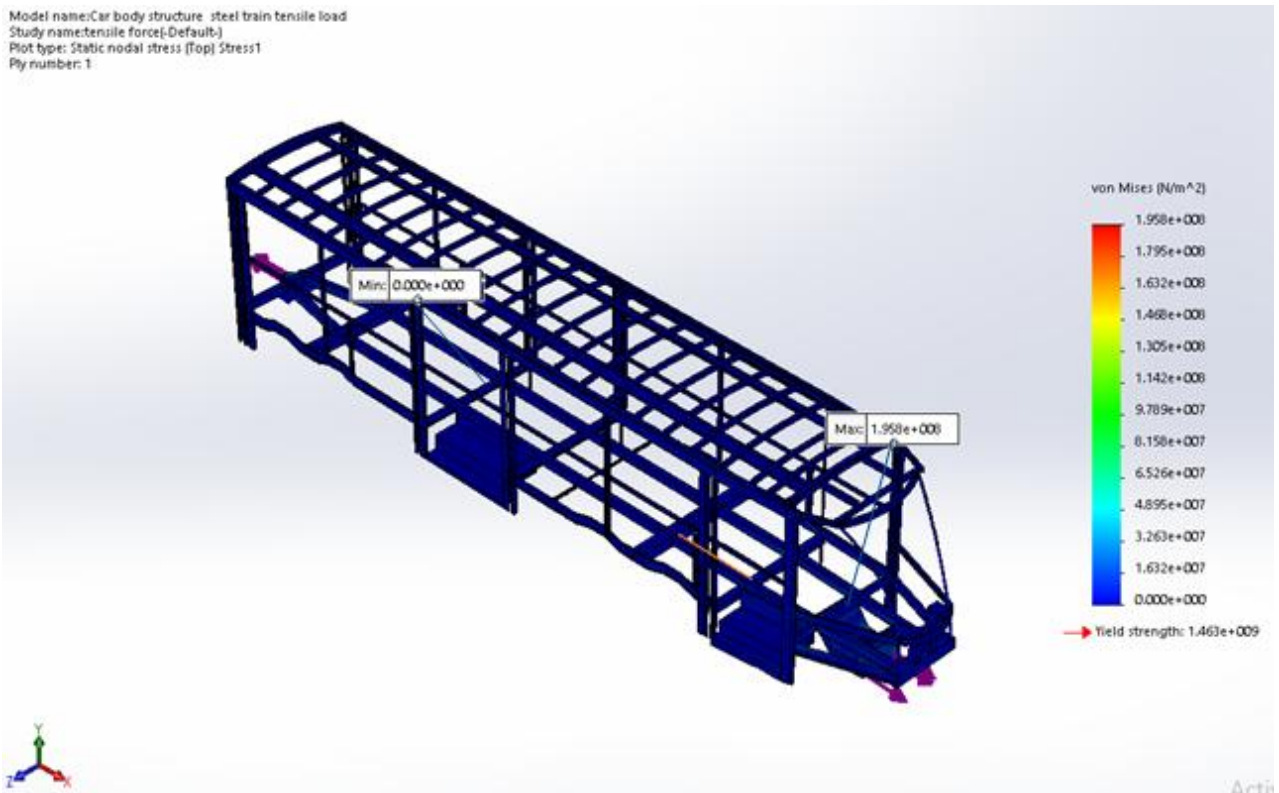


Figure 29: Tensile force at buffer

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

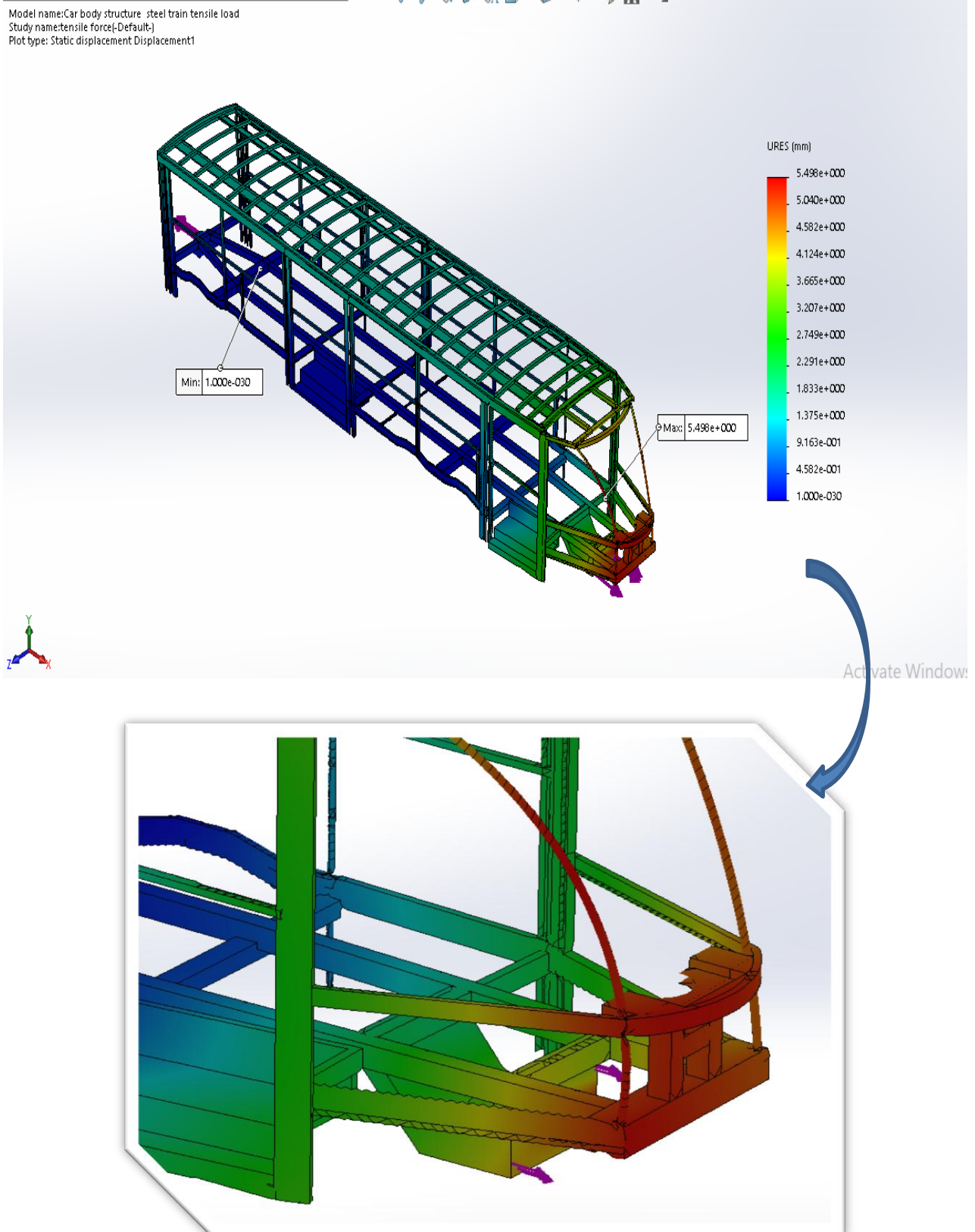


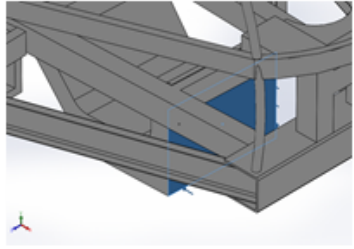
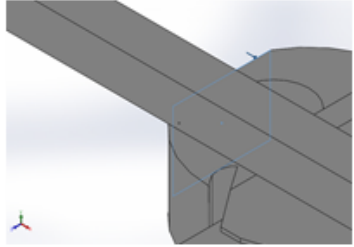
Figure 30: Deformation due to tensile force at buffer

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.6.5 Compressive force

The Compressive force which are applied at the front and back of the structure is presented as shown below

Table 9: Compressive load

Load name	Load Image	Load Details
Force-1		Entities: 1 face(s) Type: Apply normal force Value: 100000 N
Force-2		Entities: 1 face(s) Type: Apply normal force Value: 100000 N

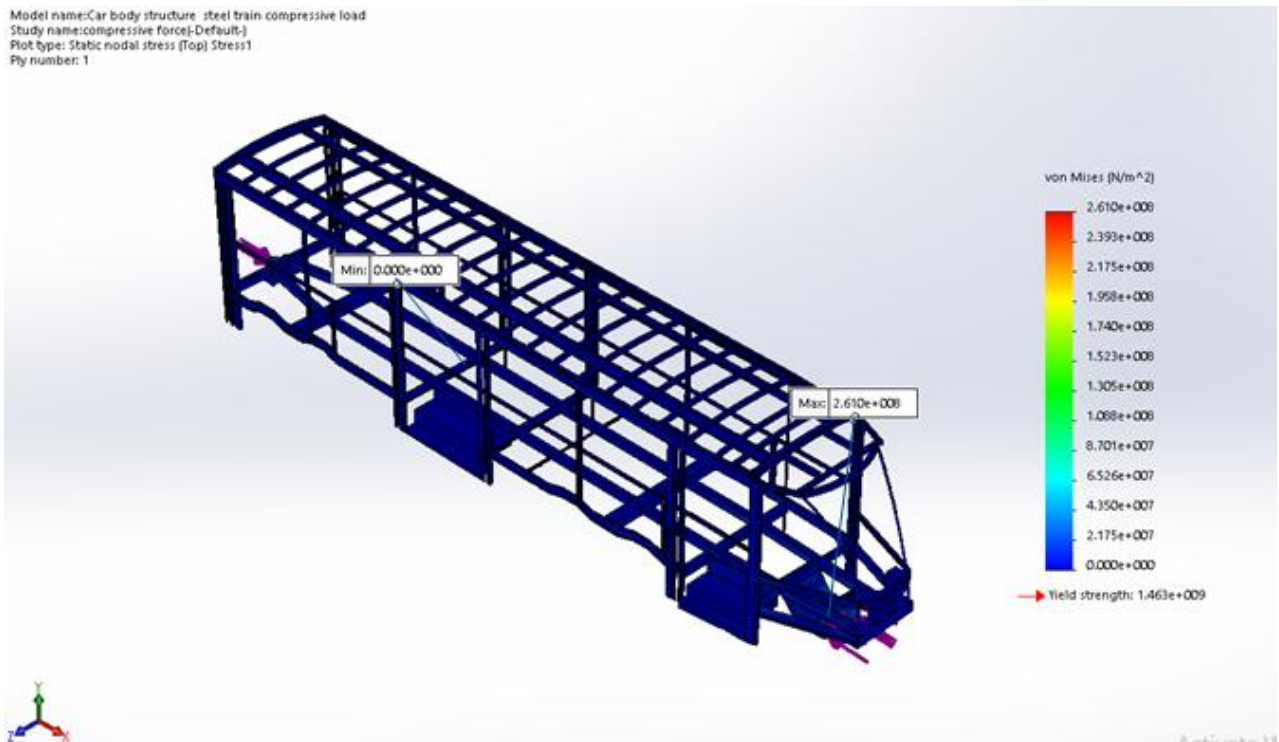


Figure 31: Compressive force at buffer

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

Model name: Car body structure - steel train compressive load
Study name: compressive force{-Default-}
Plot type: Static displacement Displacement1

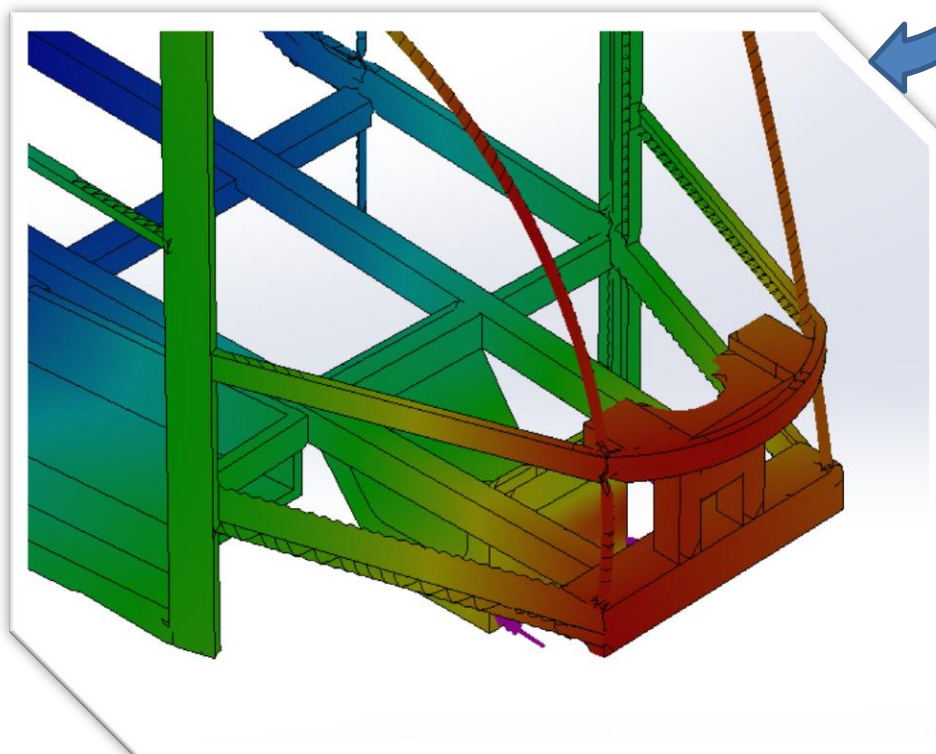
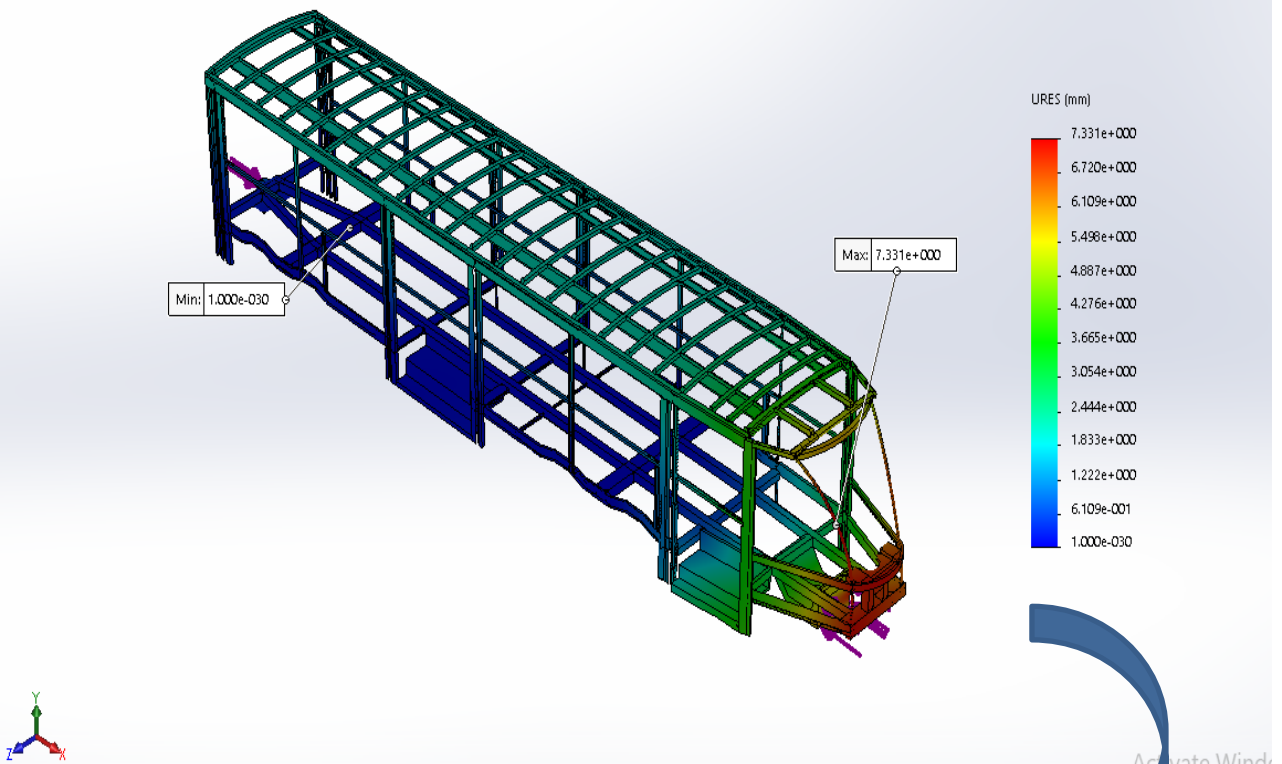


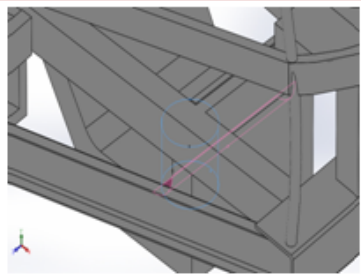
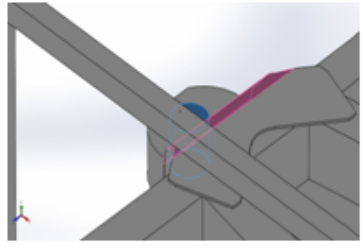
Figure 32: Total deformation due to compressive force.

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.6.6 Turn right

To turn the structure to the right equal and opposite force are applied at the front and back of the structure long lateral direction.

Table10: Right load

Load name	Load Image	Load Details
Force-1		Entities: 1 face(s) Reference: Face< 1 > Type: Apply force Values: -8178 N
Force-2		Entities: 1 face(s) Reference: Face< 1 > Type: Apply force Values: 8178 N

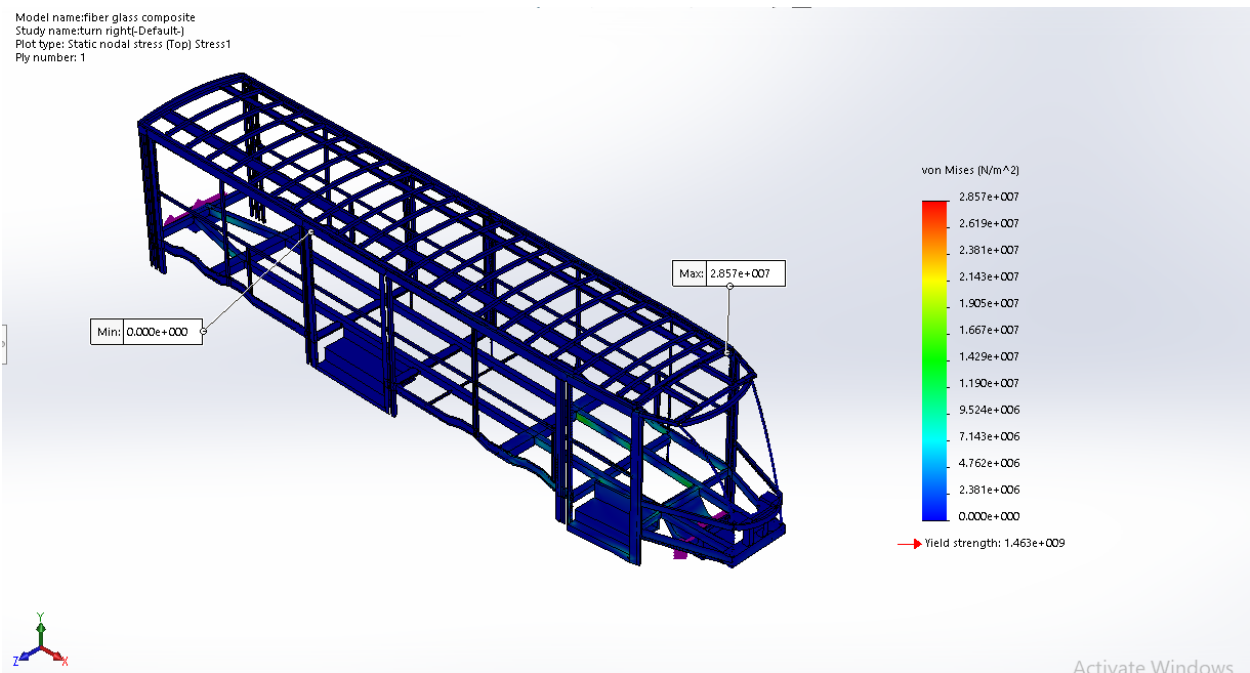


Figure 33: Maximum principal stress due to right turn

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

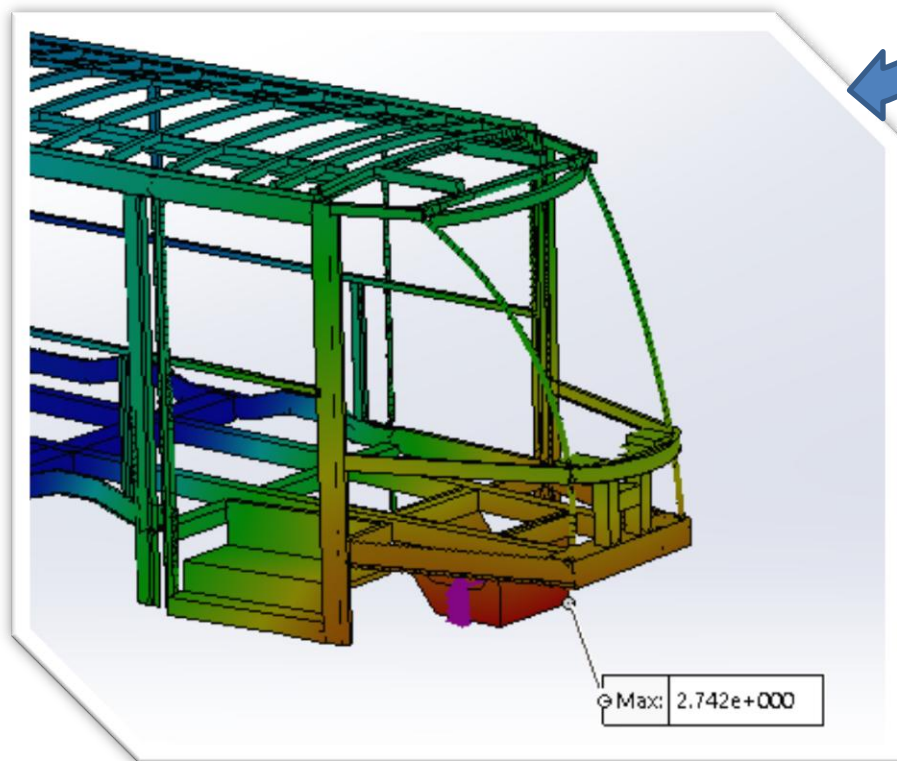
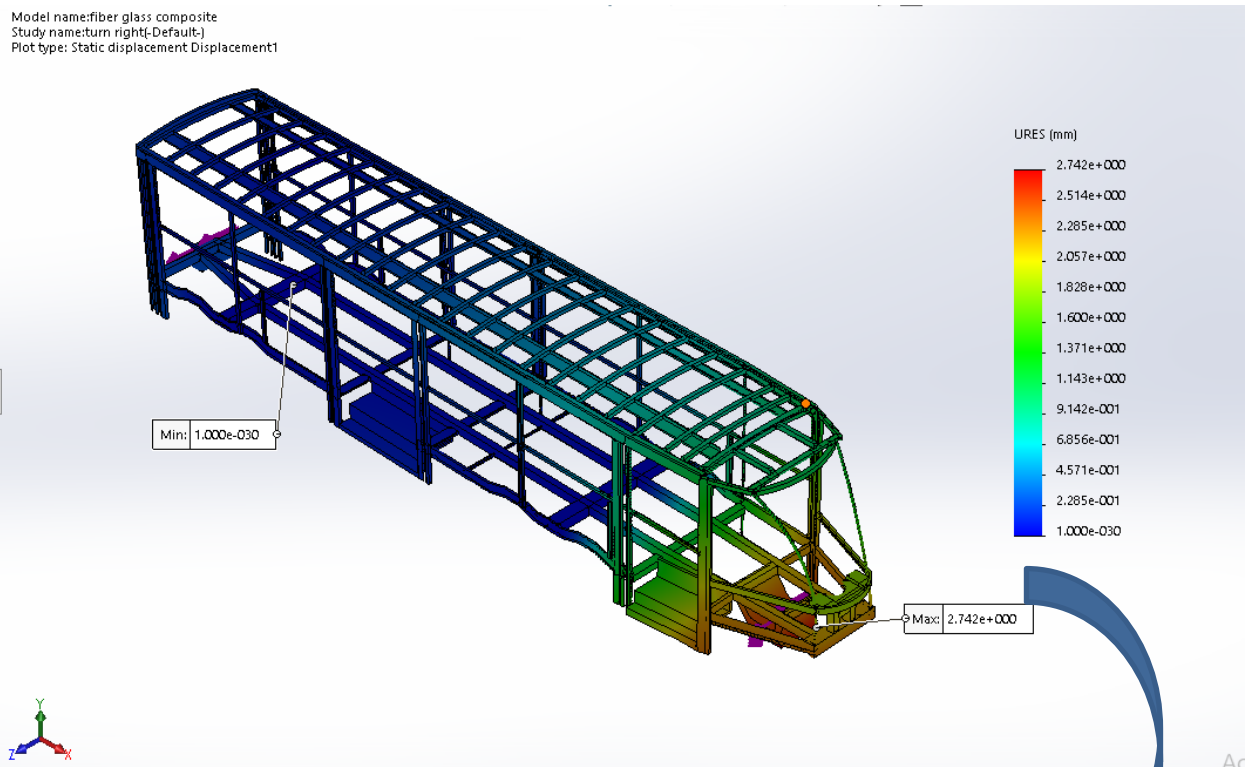


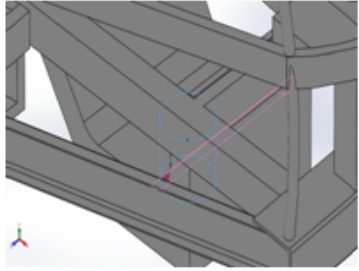
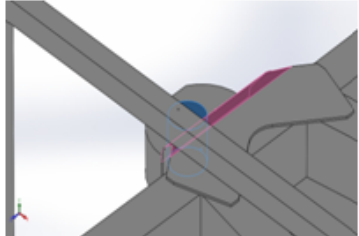
Figure 34: Maximum deformation due to right turn

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

3.6 Turn left

To turn the structure to the left equal and opposite force are applied at the front and back of the structure long lateral direction.

Table11: Left load

Load name	Load Image	Load Details
Force-1		Entities: 1 face(s) Reference: Face< 1 > Type: Apply force Values: 8178 N
Force-2		Entities: 1 face(s) Reference: Face< 1 > Type: Apply force Values: -8178 N

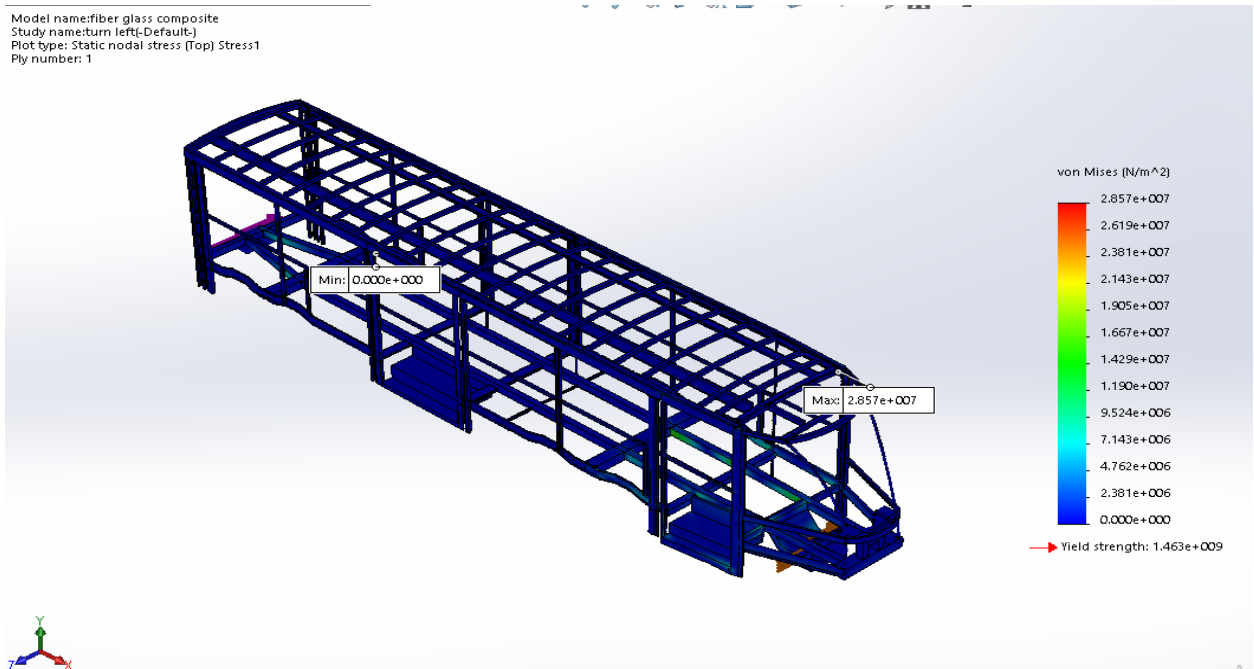


Figure 35: Maximum principal stress due to left turn

Application of Composite Material (Fiberglass) on Addis Ababa Light Railway Car body and its Structural Analysis by FEM

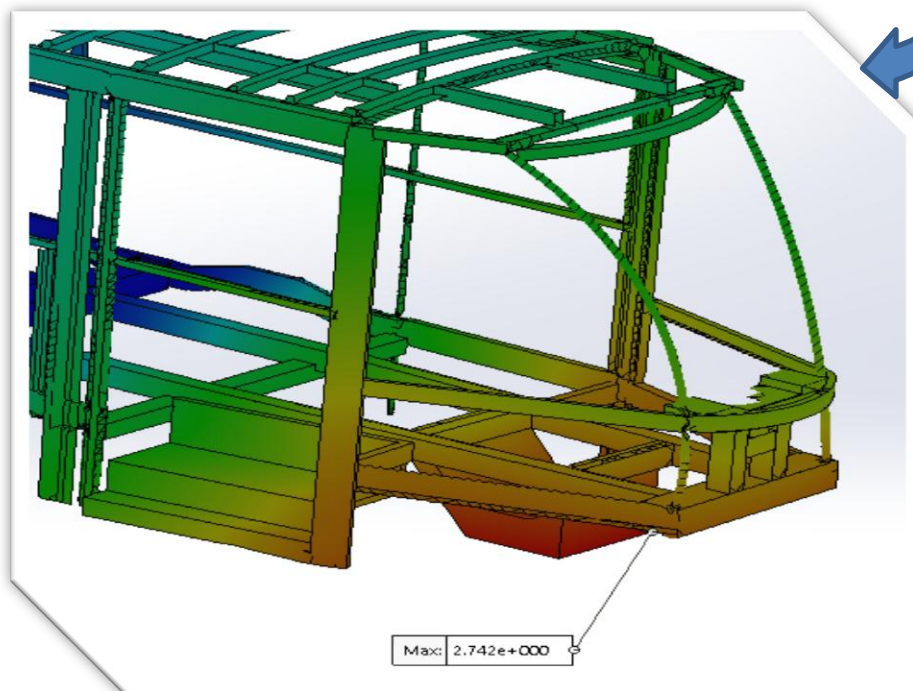
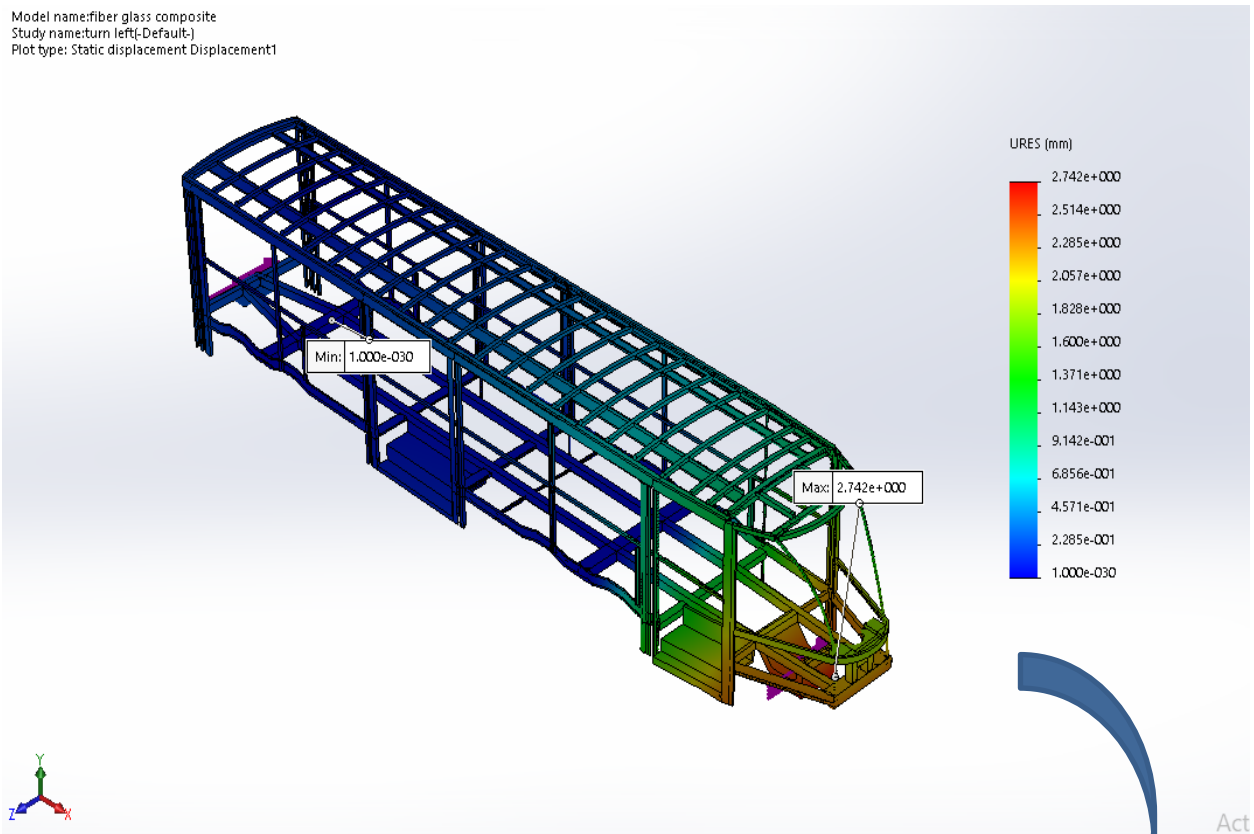


Figure 36: Maximum deformation due to left

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3.6.8 Vertical Load

Load name	Load Image	Load Details
Force-1		Entities: 48 face(s) Type: Apply normal force Value: 70867 N

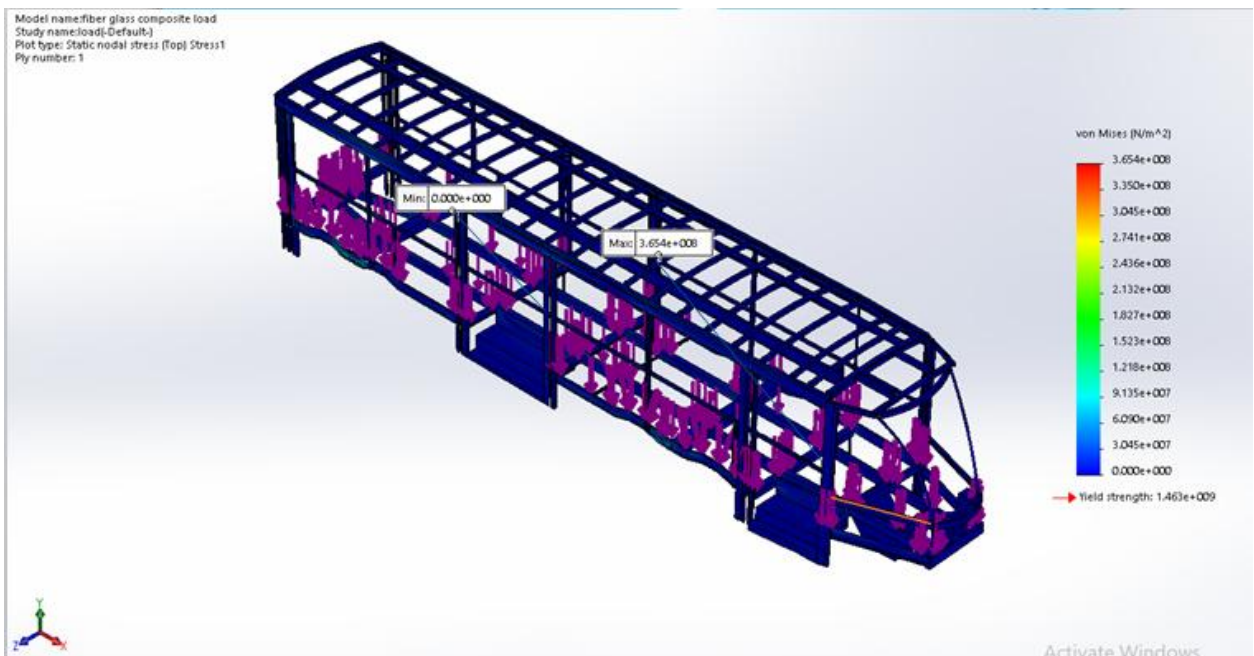


Figure 37: Maximum operational load

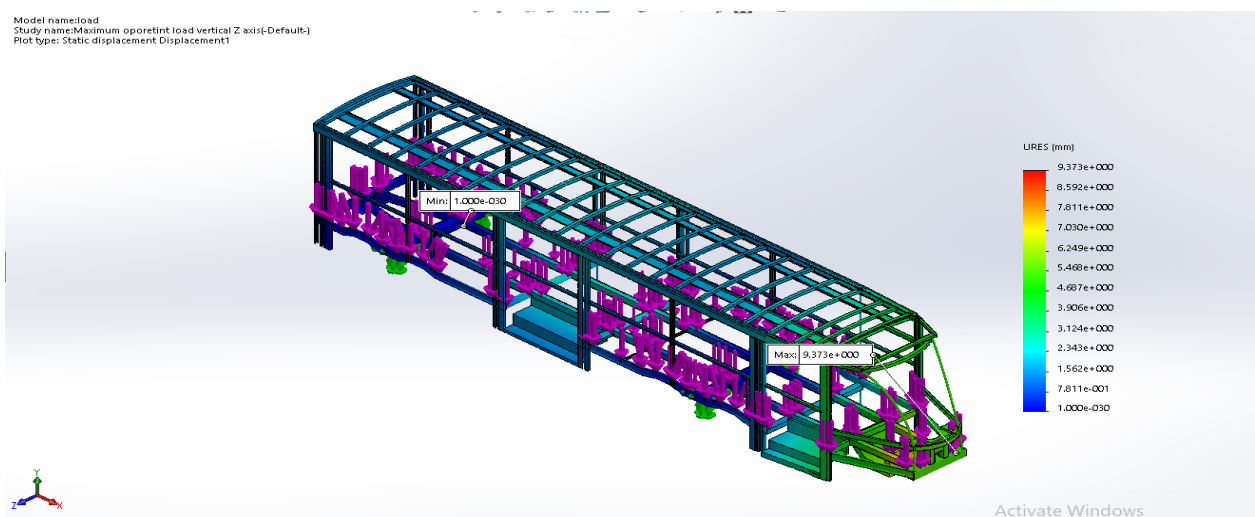


Figure 38: Maximum deformation due to operational load.

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3.6.9 Yelled factor of safety, n

Is the point at which the material converted from being elastic to un elastic material

- ✓ Elastic materials change their shape by the applied load but they return to the original shape after the force is removed. (This good for the train structure).

[It the value of safety factor is **greater one** then it is **good**]

- ✓ Un elastic material doesn't return to the original shape after the force is removed. (But this is not good).

[If the value of safety is **lesser 1** the material become un-elastic which is **not good**]

Safety factor
$$n = \frac{S_y}{V_{stress}}$$

S_y; yield strength, 630 and 1426.25 Mpa for carbon steel and composite respectively.

V_{stress} ; Von-misses stress.

load type	Von misses stress for carbon steel [MPA]	Von misses stress for carbon steel [MPA]	Safety factory for carbon steel	Safety factory for composite
Lateral	82.89 MPA	28.57 MPA	7.6	49.9
Tensile	249.8 MPA	195.8 MPA	2.5	5.7
compressive	431.6 MPA	261 MPA	1.4	5.6
vertical	623.6 MPA	365.4 MPA	1.01	3.78

From the safety factor analysis:

- The vertical load is the critical load among all the loads
- All the safety factor calculation is done based on the yield strength rather than the ultimate strength to check if un elastic deformation may occur or not
- The safety for composite is higher as compared to the carbon steel under similar load condition
- The minimum yield safety factor for the composite is greater than 1.5 (n>1.5)

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CHAPTER FOUR

4. RESULT AND DISCUSSION

The results obtained from solid work modelling of the AALRT using steel and E- glass fiber material have been studied in solid work are presented. The purpose of the modelling is to verifying the vehicle body with the standards, based on proven experience are supported by the evaluation of experimental data and published information. The stress analysed under five different load conditions are presented in table 4.1.

The goal of stress analysis and the deformation presented in this section is to investigate the maximum stress area and verified with the standard and parameterized study of change of stress with both material. The solid work result described in table form found below.

Table12:Maximum principal stress values

Load condition	Steel material	E- glass fiber material
Due to tensile force at the buffer	249.8 MPA	195.8 MPA
Due to compression force at the buffer	431.6 MPA	261 MPA
Due to right turn	82.89 MPA	28.57 MPA
Due to left turn	82.89 MPA	28.57 MPA
Due to operation load	623.6 MPA	365.4 MPA

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Table13: Total déformation value

Load condition	Steel material	E- glass fiber material
Due to tensile force at the buffer	0.009304	0.005498
Due to compression force at the buffer	0.06580	0.007331
Due to right turn	0.006025	0.002742
Due to left turn	0.006025	0.002742
Due to operation load	0.01508	0.009373

The density of E-glass material is 2550 kg/m^3 and the density of steel used was 7850.06 kg/m^3 . With the same volume the mass reduces by 67.5%. From the solid work evaluation the volume is identified, which stands nearly 0.79 m^3 . Based on this total weight of steel vehicle is 6108.67kg and 2006.6kg is the overall weight of E-glass material.

Due to a compression force of 200KN force applied on both side the maximum principal stress of steel material is 431.6 MPA and using E-glass fiber its value is 261 MPA. Its variation is around 0.40%

Due to a tensile force of 150KN force applied on both side the maximum principal stress of steel material is 249.8 MPA and using E-glass fiber 195.8 MPA. its variations is around 0.22%

Due to acceleration force in the lateral direction that is to the left and right, the stress in the E-glass composite is lower by 0.66% and 0.66% respectively from that of steel.

Previously in the section 3.6.2 we assumes that the number of piles to be eight with 2.5mm thickness and the result shows the assumption was good since it result the required strength without having high weight

Generally from the result of the analysis on model AALRT car, E-glass composite brings lower stress under the different applied loads , lower deformation in accompany with light weight as compared to the existing steel material which is used in the AALRT car body

CHAPTER FIVE

CONCLUSION, RECOMNDATION AND FUTURE WORK

5.1 Conclusion

The result of this analysis shows that, the equivalent stress of the composite material (E-glass fiber)of the rail's body has the smaller value, ranging from 40% to 66% under the compressive force and lateral force respectively. As regards the deformation, it is found that the composite is nearly 32 % lower deformation as compared to the existing carbon steel car body structure. Furthermore this is achieved while reducing the weight by 67%.

This result may give a good insight that the composite work best for the light weight car body structure once cost assessment and the availability of technology for the manufacturing, and the long run performance of the composite assessed well.

5.2 Recommendation

The rail vehicle body shall be designed as stiff as possible to resist the incoming compressive, vertical, quasi static, vibration stress and as the same time, it provides comfort to the passenger on board. The appropriate material must be selected for rail vehicle body to reduce the weight and increase the strength of rail vehicle body improving the comfort of the passenger. However, this passenger rail vehicle structure is made out of steel of different profile that is believed to be available in the market with low cost. Even though, it increases the dead load, operational cost, and efficiency of passenger rail vehicle. It is recommended to use more strong and lightweight structures which are esthetically, structurally, and operationally viable.

As presented in the preceding analyzed, the design of the lightweight railway vehicles body of E-glass fiber is enhanced by strength, stiffness and lightweight system from the existing steel. So it is better for Ethiopian Railway Corporation to use this E-glass fiber for the national railway system by undertaking further study.

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5.3 Future Works

In this thesis, the stresses caused by load and of two different materials, are studied. The future work proposed for the improvement of lightweight railway body, can be summarized in the following points:

- The cost visibility of the manufacturing the composite structure needs to be investigated
- The performance and integrity of the composite pile in the long run shall has to be studied
- The crashworthiness of composite has to modelled and studied
- The effect of dynamic force on train body has to be studied

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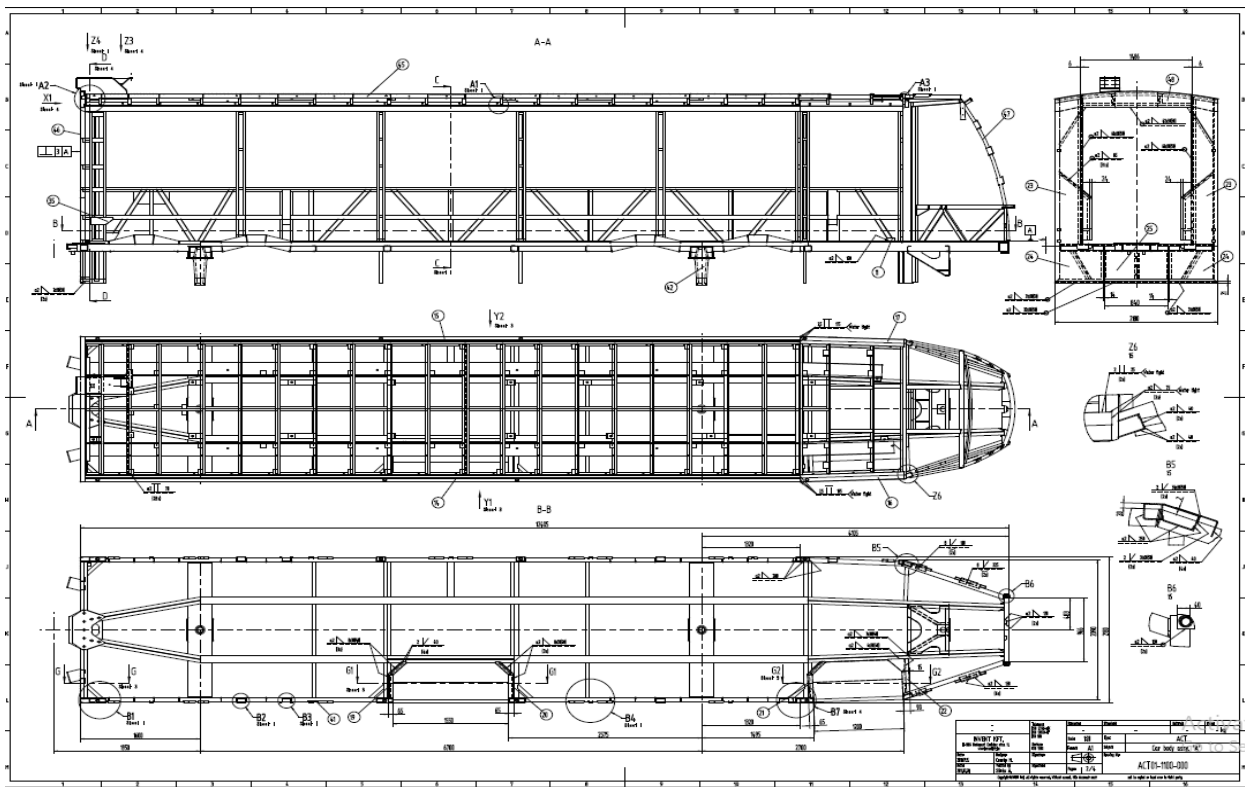
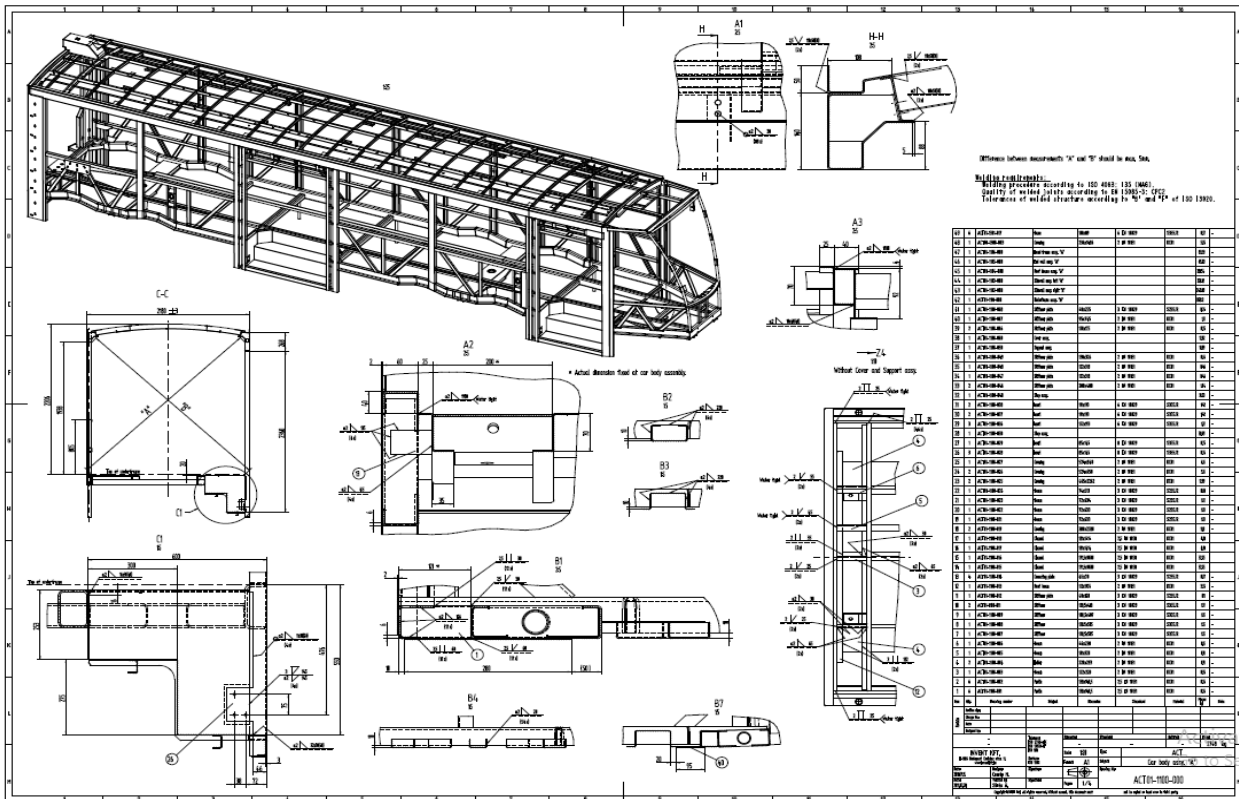
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Appendix



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