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

Weight optimization of single speed electric vehicle transmission housing

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

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School of Mechanical and Industrial Engineering

Weight Optimization of Single Speed Electric Vehicle Transmission Housing

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Submitted in accordance with the requirements for degree master of science

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This is to certify that the thesis prepared by Bethlehem Tamiru, entitled: weight optimization of single speed electric vehicle transmission casing, do here by declare this thesis is my original work and that it has not been submitted in full for a degree in any university/institution, which compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

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ABSTRACT

An electric vehicle is a vehicle powered by an electric motor, instead of an internal combustion engine, and the motor run using the power stored in the batteries. Electric Vehicles are known as zero emissions vehicles and are much environment friendly than gasoline powered vehicles.

Even though electric vehicle brings an eco-friendly, green solution to the automotive industry sector, there exist drawbacks when compared to conventional gasoline-powered cars. The main drawback is that electric vehicles on average travel a shorter range than gasoline powered vehicles due to the heavy weight, and this puts pressure on the battery pack which forced to drain out faster. To optimize the energy consumption of electric vehicles the reduction of transmission housing weight is important. The main objective of this research work is to develop an optimized composite version of an existing aluminum transmission housing for single speed electric vehicle.

The selected composite material characterized using AUTODESK HELIUS COMPOSITE and the free-size optimizations executed using one of the finite element analysis software ANSYS OptiSlang. The optimized T1000-3501-6Epoxy with T800-3501-6Epoxy laminate checked for the static and modal deformation. From the ANSYS Optislang optimization the weight of the transmission housing reduced by 22%, where the weight of Aluminum 6061-T6 was 5.4kg and the optimized weight by using composite + Aluminum material was about 4.19kg which satisfies the constraint conditions.

Keywords: EV transmission housing,T1000-3501-6Epoxy,T800-3501-6Epoxy,ANSYS Optislang

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

w_f:weight of Fiber (gm)

v_f: Volume of fibers, (cm^3)

w_m: weight of Matrix (gm)

v_m:Volume of matrix(cm^3)

w_c: weight of composite specimen (gm)

v_c: Volume of Composite specimen(cm^3)

ρ_f:Density of Fiber (gm/cm^3)

ρ_m: Density of Matrix (gm/cm^3)

W_f:Weight Fraction of Fiber

V_f: Fibers Volume fraction

W_m: Weight Fraction of Matrix

V_m: Matrix Volume fraction

L: the total length of the helical gearbox

a_1 and a_2: The center distance of the gear set

i_1 and i_2: the gear ratios of the gearbox,

$d_{11}, d_{21}, d_{12}, and\ d_{22}$: Pitch diameter of the gear unit

LIST OF ABBREVIATIONS

EV-Electric vehicles

ICE- Internal combustion engine

ZEV- Zero emissions vehicles

CMC's- Ceramic matrix composites

PMC's- Polymer Matrix Composites

MMC's -Metal Matrix Composites

CFRP -Carbon fiber reinforced plastics

ACCC- Aluminum conductor/composite cables

PEVs- Plug-in battery powered electric vehicles

PHEVs- Plug-in hybrid electric vehicles

FEA- Finite element analysis

DOF- Degree of freedom

CHAPTER ONE

1. INTRODUCTION

An electric vehicle is a vehicle powered by an electric motor, instead of an internal combustion engine, and the motor run using the power stored in the batteries. The batteries must be charged frequently by plugging into any main (120 V or 240 V) supply(Bansal 2014). Electric Vehicles are known as zero emissions vehicles and are much environment friendly than gasoline powered vehicles(A. R. Anon 2016).

Electric vehicles have been a reality for more than 200 years, but it's only in the last decade or so that the world has truly woken up to their potential as a viable, cleaner urban transport alternative to the combustion engine. During this electric vehicle renaissance much of the focus has been on developing improved power sources like batteries and fuel cells.

Energy capacity per unit battery weight for Electric vehicle is very high from 60 to 96 Wh kg^{-1}. If an automobile is equipped with 20 kWh lithium batteries, their weight might reach 200 kg. Such batteries are not only heavy but also occupy a large space 450–600 Litres inside the vehicle. The cost of batteries is high, up to 1,300 USD per kWh(D Berjoza and Jurgena 2017).

To achieve a range of 99Km per charge by using modern lithium-ion batteries, the weight of an automobile reaches 1,350 kg. In order to an electric automobile to achieve a travel range that is like the travel range of internal combustion engine, the weight of the electric automobile must be increased to 2,000 kg(D Berjoza and Jurgena 2017).

Electric vehicles on average travel a shorter range than gas powered cars. Most models ranging between 96-192Km per charge and some luxury models reaching ranges of 480-800Km per charge(Dainis Berjoza and Jurgena 2017). And this is because electric vehicles are heavy, and this weight puts a pressure on the batteries and forced the battery to drain out faster. Therefore, the optimization of electric vehicle is important.

Number of studies has been made on the problem of developing new technology that addresses the optimization of weight of the electric vehicle components based on the weight distribution. Based on the weight proportion of some electric automobiles the weight of the battery pack can reach 28% of the curb weight of the automobile and the drive train of the electric vehicle can also reach up to 23% of the basic weight of the electric vehicle. The drive train contains the electric motors which is 34% of the drive train and differential(Jameson 2015). The transmission housing which is 2% of the drive train attract the attention of the research area.

The powertrain housing has certain functional requirements which include the ability to with stand shock load, the compatibility with the transmission of fluid, and the ability to dissipate excessive heat based on which it was designed through the years.

Therefore, to optimize the energy consumption of electric vehicles, the reduction of powertrain weight is important. Optimizing the weight of the typical electric transmission can be possible by substitution of the housing material with materials of lower weight. The main aim of this work is to design and analyze the single speed powertrain casing.

1.1 Background

EV has a much longer history than most people realize. EVs were seen soon after Joseph Henry introduced the first DC-powered motor in 1830. The first known electric car was a small model built by Stratingh in the Dutch town of Groningen in 1835(Rai 2019). There were no rechargeable electric cells at that time. An EV did not become a viable option until the Frenchmen Gaston Plante and Camille Faure respectively invented and improved the storage battery.

EVs are known as ZEVs and are much environment friendly than gasoline- or LPG-powered vehicles. EVs don’t have ICEs in them. Instead, electrical energy is stored in a storage battery or ultracapacitor, converted from chemical energy in a fuel cell, or converted from mechanical energy in a flywheel. This electrical energy is used to power an electric motor, which then turns the wheels and provides propulsion. Since no fuel is burned in an EV, they don’t produce the pollution that ICE vehicles do. As EVs have fewer moving parts, maintenance is also minimal. EVs are also far more energy efficient than gasoline engines and they are very quiet in operation (Hodkinson and Fenton 2000).

Unfortunately, EVs have a serious disadvantage that played a large role in the takeover by ICE vehicles: limited range. EVs could only travel on the order of 536Km or so on a single charge(Dainis Berjoza and Jurgena 2017), and that only under good conditions and also, recharging takes hours. ICE vehicles can go much farther on a tankful of gas and could be quickly refueled.

During electric vehicle renaissance period much of the focus has been on developing improved power sources like batteries and fuel cells. Batteries typically account for one third or more of vehicle weight and one fourth or more of the life-cycle cost of an electric vehicle(Bull 2017). Modern electric automobiles are equipped with lithium-ion batteries. The most popular battery capacity is 20-22 kWh. The weight of batteries is increased by extra elements (Dainis Berjoza and Jurgena 2017).

1.2 Statement of problem

Even though electric vehicle brings an eco-friendly, green solution to the automotive industry sector, there exist drawbacks when compared to conventional gasoline-powered cars. The main drawback is that electric vehicles are heavy, and this puts pressure on the battery pack which forced to drain out faster.

Based on a comparative analysis against the components the distribution of weight across the Tesla Model S assemblies, the weight of the drive train is about 23.23%, which is the second weight proportion next to the battery pack, the gear box of this Tesla model is 17% of the power train which is the third weight proportion next to electric motor, inverter and wheels.

To optimize the energy consumption of electric vehicles the reduction of powertrain weight is important. Therefore, the development of effective light weight transmission housing, which is 12% of the gear box, for single speed electric vehicles attracts the attentions of the current research area.

1.3 Objective

1.3.1 General objectives

The main objective of this research work is to develop an optimized composite version of an existing aluminum transmission housing for single speed electric vehicle while maintaining the stiffness of the initial model and satisfying the failure criterion.

1.3.2 Specific Objective

The specific objectives of the study are;

- Select appropriate composite material and characterize using Autodesk Helius composite.
- Perform composite optimization using ANSYS Optislang.
- Compare the optimized composite version of the transmission housing with that of the aluminum transmission housing.

1.4 Scope of the study

The scope of this project ranges from the weight optimization of the transmission housing based on the electric vehicle specifications to the design of the transmission housing for the rigidity, modal analysis and to the characterization of the developed composite transmission housing. The selected composite characterization is performed by Autodesk Helius composite and the free-size optimization process is performed using ANSYS Optislang. This thesis work is limited to analyze the effect heat conductivity of the composite transmission housings.

1.5 Methodology

Based on the defined problem statement and specifications of the electric vehicle transmission housing the research methodology starts with the literature review especially on areas related to the tittle provided. Then after the proper material selection taken place. The selected carbon fiber reinforced polymer characterized using Helius composite.

The free-size composite optimization performed as setting the results of the bending stiffness, and deformation and modal stiffness parameter as a constraint conditions for the composite optimization, using ANSYS Optislang. The results of the composite version of the transmission housings, from the ANSYS Optislang compared with that of the existing Aluminum version of the single speed transmission housings. Finally, the conclusion has reach depend on the results of the study and recommend for future work.

1.6 Organization of the paper

This work is organized in five chapters. The first chapter is devoted to brief description of electric vehicles; the thesis background; problem of the statement; general and specific objectives. The second chapter presents literature review on electric vehicles, materials used for the transmission housing, types of optimization, the analysis on the transmission housing and the research gap revealed. The third chapter deals with the analytical program which focused on materials, dimensions, methods, conditions and the composite optimization of the single speed transmission housing using ANSYS Optislang. The fourth chapter addresses composite optimization results and discussion. The last chapter devoted to draw conclusions, recommendations and future works.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Electric Vehicles

The first automobiles to be built were all EVs, using energy stored in rudimentary lead-acid batteries to drive DC electric motors. Only in the 1910s did gasoline-powered vehicles begin to make serious inroads in the automobile market(Bull 2017). An electric vehicle is a vehicle powered by an electric motor, instead of an internal combustion engine and the motor is run using the power stored in the batteries. The batteries have to be charged frequently by plugging into any main supply. EV has a much longer history than most people realize. EVs were seen soon after Joseph Henry introduced the first DC-powered motor in 1830(Hodkinson and Fenton 2000).

Unfortunately, EVs have a serious disadvantage that played a large role in the takeover by ICE vehicles: limited range. By limited range we mean that EVs could only travel on the order of 536 km or so on a single charge, and that only under good conditions, lead-acid batteries lose energy capacity when they become cold, so in cold weather the range of a vehicle could be reduced by as much as 50% or even more. Also, recharging takes hours. ICE vehicles can go much farther on a tankful of gas and could be quickly refueled.

EVs have been in continual use since the 1900s in various applications. Today these quiet vehicles with no tailpipe emissions are no longer limited to golf carts. New advances in battery technology, system integration, aerodynamics, and research and development by major vehicle manufacturers has led to the producing of electric vehicles that will play a practical role on city streets.
The modification of the electric vehicles since from the recent study on Renault equipped with a 41Kwh battery pack of the new generation which is only 10kg heavier than 22Kwh battery pack of the previous generation(CHENG 2016).

Main components of EV

- MOTORS: The motor is the main component of an EV, as represented in figure 1. It is very important to select proper type of motor with suitable rating. It is also confusing to compare electric motors to gas engines. For accurate identification, a motor should be identified by name or model number(CHENG 2016).
- DC/DC CONVERTER: An electric car normally uses a 12 V auxiliary battery to power all of the original 12 V accessories: lights, horn, and so on. However, unlike a gas car, there is no alternator to keep this battery charged. One option is to use deep-cycle 12 V batteries, as heavy duty as possible. This is not adequate if night driving is intended. As the battery

drains in use, the headlights will grow dimmer and the turn signals flash more slowly. This taps the full battery pack voltage and cuts it down to a regulated 13.5 V output, similar to an alternator. By tapping the full pack, there is no uneven discharge. Current requirement is so low that there is little effect on range. This also eliminates the need for a separate 12 V charging circuit for the auxiliary battery(CHENG 2016).

- BATTERY: The battery is the main energy storage in the electric vehicle. The battery infact governs the success of the electric vehicle (Dainis Berjoza and Jurgena 2017). Recently there are massive works being reported in battery development. The battery such as Li-ion is now being used by new generation of electric vehicle. For low cost solution, the lead-acid battery is still dominant part of the market. All the research is looking towards the fast charging for batteries. MIT reported (Bansal 2014) the technology of a crystal structure that allows 100 times of charging speed than conventional Li-ion battery. Another alternative is to use ultra-capacitor.
- ALUMINUM SPACE FRAME: an aluminum space frame augmented by high strength steel pillars and bumper beams, that supports the above components as well as the formed aluminum body panels.

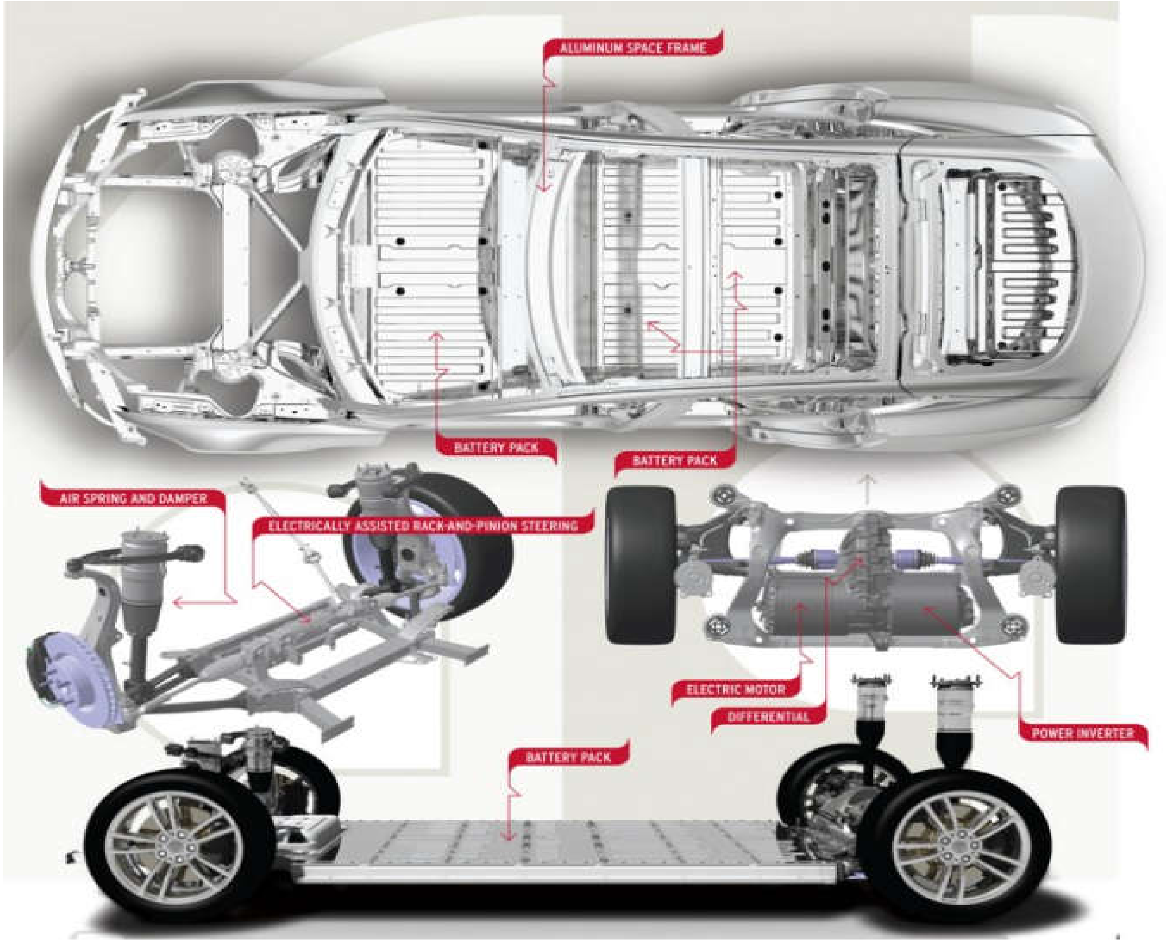


Figure 1 Main components of Electrical vehicles(Rai 2019)

One of the parameters of electric vehicles that can affect their dynamic and range characteristics is their weight. Weight is also an essential factor for electric automobiles, especially in cases where large-size batteries are used, which are intended for traveling long distance. Converting a vehicle with an internal combustion engine into an electric one, it is possible to vary its batteries and their placement. It is also possible to choose batteries of various capacities for serial electric vehicles, not only the costs of electric vehicles but also such performance characteristics as dynamics and travel range per charge depend on the number of batteries and the total weight of the electric vehicles.

The research developed and approbated an algorithm for calculating comparative parameters for electric automobiles. One of the technical parameters of vehicles is their weight. The weight of vehicles and its distribution on axles can affect such performance parameters as fuel consumption and acceleration dynamics. An analysis of the historical trends in vehicle weight change shows that auto manufacturers used the designs of massive automobiles, not seeking lower vehicle weight.

Later, from the 1970s to the middle of the 1980s, the use of lightweight materials became popular, and steel was replaced with lightweight composite materials in vehicle design(André and Gonçalves 2015). Consequently, the average weight of the same class automobiles decreased, on average, by 15–20%. However, a too large decrease in the weight of vehicles resulted in lower passenger safety and design durability.

An analysis of the parameters regarding battery capacity and range showed that higher performance electric automobiles or models were as follows: Tesla brand electric automobiles, Volkswagen e-Golf Kreisler, Chevrolet Bolt EV and Renault Zoe ZE 40, yet in terms of energy consumption per km distance travelled the electric automobiles with lower capacity batteries and lower weight were more economically efficient(Hodkinson and Fenton 2000).

To perform an in-depth examination of the effects of increasing the weight of batteries for electric automobiles on such performance parameters as fuel consumption per km distance travelled, range per battery charge, acceleration intensity, maximum acceleration etc., it is necessary to design a mathematical model for simulation of interrelationships among the parameters and to compare the calculated data with road experimental data. It is intended to design the model at the future stages of the research(Dainis Berjoza and Jurgena 2017).

2.2 Materials for transmission housing

When considering different materials for a transmission casing, there have to be a consideration on the functions of the casings. The primary functions to be considered can be identified as follows:

- Resist internal loads created by transmission of torque from input shaft to output shaft.
- Transmit beam loads resulting from powertrain mounting requirements
- Contain lubricating fluid
- Transfer internally generated heat out through casing.

The primary requirements of a transmission housing are rigidity and excellent vibration damping properties. Earlier casings were generally casted from cast iron or steel since Cast iron tends to be brittle, with its relatively low melting point, castability, machinability, resistance to deformation, and wear resistance, due to this cast iron has become used for the casing material for several years.

2.2.1 Aluminum

Cast aluminum alloy is usually used for gearbox casing to reduce weight. Aluminum has a density of only 2.7 g/cm3, approximately one-third as much as steel,7.83 g/cm3. One cubic meter of steel weighs about 220Kg and a cubic meter of aluminum, only about 77Kg (Davis 2001). Such light weight, coupled with the high strength of some aluminum alloys, which exceeds that of structural steel, permits design and construction of strong, lightweight structures.

Cast Aluminum 6061-T6 alloys used for the transmission casing of electric vehicles. Aluminum 6061-T6 contain silicon and magnesium approximately in the proportions required for formation of magnesium silicide (Mg2Si), thus making them heat treatable. Although not as strong as most aluminum alloys, Cast Aluminum 6061-T6 alloys have good formability, weldability, machinability, and corrosion resistance, with medium strength. Alloys in this heat-treatable group strengthened after forming to full T6 properties by precipitation heat treatment(Sirohi et al. 2018).

The Mg_2Si phase, which is the basis for precipitation hardening, is unique in that it is an ionic compound and is not only anodic to aluminum but also reactive in acidic solutions. However, either in solid solution or as submicroscopic precipitate, Mg_2Si has a negligible effect on electrode potential. Because these alloys are normally used in the heat-treated condition, no detrimental effects result from the major alloying elements or from the supplementary chromium, manganese, or zirconium, which are added to control grain structure. Aluminum alloys containing magnesium and silicon provide moderate strengths and good corrosion resistance in relation to other heat-treatable aluminum alloys. Because they are easily extruded, they are available in a wide range of structural shapes, as well as sheet and plate products(Davis 2001).

2.2.2 Magnesium

The transmission housing used in most racing vehicles are used to be built out of magnesium, a very light metal often used in motorsport applications. Magnesium is a good compromise between performance and manufacturing efforts. Although a composite housing is theoretically a better solution, since carbon fiber is lighter and stronger than most metals, its complicated manufacturing process may deem the composite solution unviable(André and Gonçalves 2015).

2.2.3 Composite materials

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

Composite materials are engineering materials in which two or more distinct materials are combined together but remain uniquely identifiable in the mixture, having strong fibers surrounded by a weaker matrix material to obtain better properties different from those of the individual components.

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 and the geometry and orientation of the fibers in the composite. Composite Laminates are sheet constructions which are made by stacking layers, also called plies or lamina, in a specified sequence, as described on figure 2. The layers are often in the form of prepreg (fibers pre-impregnated with partly cured resin) which are consolidated in an autoclave.

A laminate may have more than 4 layers and the fiber orientation changes from layer to layer in a regular manner through the thickness of the laminate. The figure 2 describes how the laminate is formed from the ply or lamina (Mcilhagger, Archer, and Mcilhagger 2015).

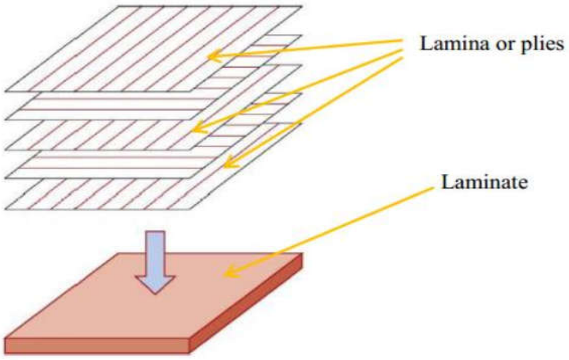


Figure 2 Composite Laminate(Mcilhagger et al. 2015)

The use of composite materials in automotive applications has gradually evolved over the past two decades. With new materials and processing techniques being continuously developed for the plastics and automotive industries, there is potential for a more rapid expansion of these types of application in the future. PMC applications, both for small components and for more complex casings, could be a potential major growth area. This could have a significant impact in the automotive and associated supply industries if the required developments result in cost effective manufacturing processes for these larger types of components (Prof. R. Velmurugan 2016).

Many plastics manufacturers are carrying out extensive research and development efforts with the aim of realizing the potential benefits of PMC structures for the automotive industry. These potential benefits include weight reduction, which may be translated into improved fuel economy and performance, improved overall vehicle quality and consistency in manufacturing, part consolidation resulting in lower vehicle and manufacturing costs, improved ride performance (reduced noise, vibration, and harshness) and lower investment costs for plants, facilities, and tooling although this is dependent on cost/volume relationships. However, there are still areas where major uncertainties still exist that will require extensive research and development prior to resolution. Examples of these are high speed, high-quality manufacturing processes with acceptable economics, satisfaction of all functional requirements, particularly crash integrity and long-term durability, plus the ability to repair and recycle(Farahikia et al. 2016).

A first consideration in the journey to reduce the weight of a transmission casing is obviously to consider a lighter base material. However, the immediate issue faced is whether a lighter material is available that improves the mechanical properties required for the application. To maintain the cycle times required to produce casings in volume, injection molding techniques could be considered. This leads to the use of reinforced plastics such as polyamides with carbon, glass fiber reinforcement or to high property plastics such as special Peek plastics(Perremans et al. 2018).

Carbon fiber reinforced plastics possess many extraordinary properties, such as low density, excellent mechanical properties, good resistance to environmental impacts, etc., and have been considered as one of the most important structural materials in modern industry. In recent years, besides of the traditional sectors of industry, CFRP found many new industrial applications, such as civil engineering, automotive, and power distribution, etc. As an example, in 2014, China, 10% of the total consumed carbon fibers were used for CFRPs in rehabilitation of civil engineering structures, and 8% were used for ACCC, and about 58% were used for traditional sport goods(Xian, Wang, and Engineering 2018). CFRPs are dependent on the manufacturing methods, fiber type, fiber volume content, fiber orientation, resin types, and interface between fiber and resin matrix. Among those factors, the carbon fiber–resin matrix adhesion is considered to be one of the most important factors influencing the shear strength and fatigue properties of the CFRPs(Zahari 2014).

CFRP have an extraordinary property which attracts the attention of the current research area, carbon fiber has high strength to weight ratio, is very rigid, carbon fiber is corrosion resistant, and chemically stable and it is electrically conductive. Carbon fiber have high fatigue Resistance, good tensile strength, high Thermal Conductivity in some forms and Low coefficient of thermal expansion but carbon fibers are Relatively Expensive(Xian and Wang 2016).

Carbon Fiber: Carbon is a unique material with many attractive engineering qualities. It is valuable for its lubricating properties, for high strength and resistance to oxidative and chemical attack, compatibility of the fluid/lubricant, high Strength to Weight Ratio, and Carbon Fiber is very Rigid. There are different types of carbon reinforcing fibers, among them T800 is used for the optimization of the transmission housing. T100 carbon fiber is an intermediate modulus which is the world’s highest tensile strength fiber. This type of carbon fiber is suitable for light weight and tensile strength initial applications and commonly designed to develop pressure vessels for aerospace(Lawrence et al. 2010).

T800 carbon fiber is also an intermediate modulus with high tensile strength and with an excellent balanced composite properties and mostly this carbon fiber are designed to develop the weight saving demand of aircraft (Wang et al. 2013).

Epoxy: The most commonly used thermoset resins are epoxy, vinyl ester, polyester and phenolic. Among these thermoset matrix materials, the epoxy resin is selected for the development of the housing due to their valuable advantages such as excellent adhesion, good performance at elevated temperatures and better mechanical and electrical properties. In addition to that they have low shrinkage upon curing and good chemical resistance. It has very low viscosity, long average pot life at room temperature, consistent performance and doesn’t contain any hazardous extenders(Liu, Deng, and Zhang 2017).

During the selection of material, the characteristics of the composite, the ways of fiber arrangement, the ease of the manufacturing process, the types of the matrix used for the composite and some other criteria are taken into consideration. In addition to this, the selection of the material for this specific research work is basically focusing on the optimization of the weight of the transmission housing.

2.3 Optimization

Optimization is a process of obtaining the absolute best design for a particular design condition. There may be the existence of a large number of local optima or non-differentiable objective functions.

In order to better understand numerical optimization, as described on figure 3, one should be introduced to the basic concepts that regulate and guide its process: design space, design variables, objective function and design constraints. The group of independent parameters that are allowed to change while searching for the best design are called design variables.

The objective function is the dependent variable that the optimizer attempts to either minimize or maximize. Since it is a function of the design variables, changing the values of these variables should change the value of the objective function. The requirements are function of design variables or system responses and are called design constraints(André and Gonçalves 2015).

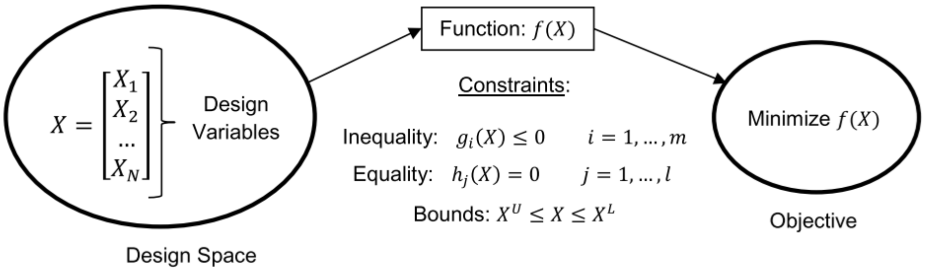


Figure 3 General optimization problem (André and Gonçalves 2015)

2.3.1 Composite Optimization

A new era in the production of composite materials began when leading aircraft companies decided to innovate and start using carbon fiber reinforced materials in the design and manufacture of composite airframes for their commercial airliners(Mcilhagger et al. 2015).

Composite components also played a major role in the world of motorsport, allowing engineers to fabricate parts that were both lighter and stiffer, therefore improving the performance and the safety of their cars. The usage of carbon fiber components in racing cars began with Formula One in 1981, the first Formula One car to use a carbon fiber composite monocoque chassis(Westall 2016).

Nowadays, carbon fiber is used for structural, aerodynamic and other body parts in the majority of motorsport disciplines including DTM cars, World Rally cars, Formula Racing series, GT cars and Endurance prototypes(André and Gonçalves 2015).

In 2014, BMW became the first automotive company to launch a volume production car featuring a passenger cell constructed of carbon fiber reinforced polymer(Mcilhagger et al. 2015). Although there are different forms of composite materials, the most commonly used is the composite laminate where thin plies of various orientations are stacked and bonded together to form a shell structure.

There are three different optimization process, of the composite optimization process is a free-size optimization that focuses on material distribution in terms of orientation and thickness. This is achieved by allowing the thickness of each 'super-ply' of a unique fiber orientation to change freely throughout the model, obtaining a thickness contour for each fiber orientation. A concept design of ply layout and thickness results from the interpretation of the thickness contours(André and Gonçalves 2015).

The second type of composite optimization is a ply-based sizing optimization in which the interpreted ply-based model further optimized under all design constraints. And the last one is of composite optimization consists of a stacking sequence optimization in which the final design is refined to satisfy all manufacturing and performance constraints(Kumar and Patil 2016a).

2.3.2 Topography Optimization

Topography optimization is an advanced procedure of shape optimization usually performed on shell structures(Zhuang 2012). In topography optimization no material is added to or removed from the structure. Instead, geometrical changes to the shape of the structure optimize its performance under specific load cases. The structure's compliance, its natural frequencies or its moment of inertia are a few examples of responses that can be optimized using topography optimization.

Structural topology optimization methods have existing and been improving theoretically since 1980s; however, in industry, with respect to the certain conditions, proper modification is always desired. Gearbox housing maintains the position of the shafts to ensure the precision of gear engagement in all operational states(André and Gonçalves 2015).

Its main contribution to the final design was to show what kinds of patterns were likely to optimize the structure, in this case to minimize the displacement at the selected node. A possible pattern suggested by the converged solution and consisting of channels parallel to a diagonal was implemented in the form of a pattern grouping constraint at the last iteration. In this example, the diagonal emerging from the node where the load is applied was selected.(Zhuang 2012)

2.4 Transmission housing analysis

(Vikhe 2016b)conducted the study of Optimization of three stage Commercial gearbox casing using Finite Element Analysis Method is carried out and the main objective is to hold out analysis of powertrain casing and finding out effective design of gear case with relevance cost. Based on the shape optimization method of the gearbox housing, can be able to reduce the weight by 13% and also the difference between the natural frequency and gear mesh frequency is about 9.8%.

The optimization process carried out on the gearbox casing used in an LMP1 race car of the World Endurance Championship. The work undertakes topography and composite optimizations with the objective to reduce the overall weight of the structure. Topography optimization was carried out, but it was ultimately skipped since it never delivered significant improvements to the stiffness of the casing. The final composite design is approximately 44% lighter and 1.31% stiffer than the initial model. Compared to the magnesium gearbox casing, which weighed 12kg, the optimized design is considerably lighter at 9,631kg (André and Gonçalves 2015).

The weight of the housing calculated for four different materials. Al alloys has minimum weight. Grey cast iron HT200, grey cast iron FG260, structural steel and Al alloys provides excellent structural rigidity by eliminating lower order frequency and reduces the chances of resonance against harmonic excitation. Materials mechanical properties have dominating effect on natural frequencies, mode shapes and weight (Sirohi et al. 2018).

The optimization of connecting bolts number using Detuning principle has been carried out. At zero displacement condition when all 37 connecting bolts were constraint, natural frequency reaches in a higher order range of 1651- 3566 Hz. This higher order range of frequency makes the model a conservative design when critical frequency for medium duty vehicle varies from 0 to 100 Hz (Kumar et al. 2014)

Truck transmission gearbox casing is subjected to vibration induced by the harmonic excitation, meshing excitation, load fluctuations, gear defects, varying speed and torque conditions. Noise and vibrations are the reasons for the transmission failureThe objective of this research work is to simulate the relation between dynamic vibrations of transmission and fixed constraint of vehicle frame (Kumar and Jaiswal 2014). Transmission casing is tightly fixed on vehicle frame using connecting bolts. 37 connecting bolts were used to fix the casing on vehicle frame. First 10 inherent natural frequencies and corresponding mode shapes were evaluated. The FEA simulation results show that the natural frequency of one bolt unconstraint condition varies from (1637.2 – 2674) Hz.

CHAPTER 3

3. MATERIALS, METHODS AND CONDITIONS

3.1 Materials

In this analysis, as shown in figure 4, the carbon fiber/epoxy composite materials with a considerable composition are used as the materials for the development of the transmission housing. The initial laminate for the design space presented in table 1 reveals the fiber orientations considered for optimization: $[0°/-45°/90°/45°]_{2S}$ for T1000 unidirectional carbon fiber and $[0°]_{2S}$ for T800 carbon fiber cover. Because this is a symmetrical laminate, the sequence in which the plies are introduced before the optimization process is relevant.

Table 1 T1000-3501-6Epoxy with T800-3501-6Epoxy cover

Ply #	Lamina	Initial Thickness (mm)	Angle(deg.)
1	T800-3501-6 Epoxy	0.50	0
2	T1000-3501-6 Epoxy	0.50	0
3	T1000-3501-6 Epoxy	0.50	90
4	T1000-3501-6 Epoxy	0.50	45
5	T1000-3501-6 Epoxy	0.50	-45
6	T1000-3501-6 Epoxy	0.50	-45
7	T1000-3501-6 Epoxy	0.50	45
8	T1000-3501-6 Epoxy	0.50	90
9	T1000-3501-6 Epoxy	0.50	0
10	T800-3501-6 Epoxy	0.50	0

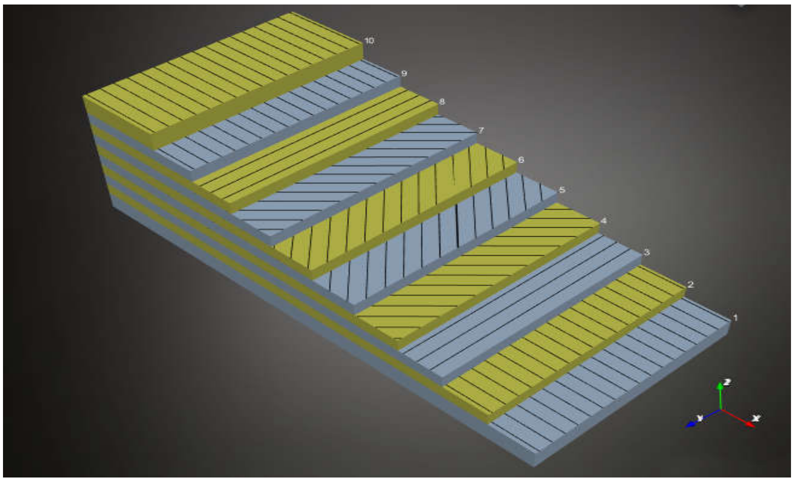


Figure 4 Ply stack sequence of material used for the transmission housing

3.2 Dimensions

The 3D modelling of the transmission housing is done by using CAD modeling software Solid works, as shown in figure 5. This is done by performing detail design by taking the design data from a selected type of vehicle.

The selected type of the half of the transmission housing contains the significant load of the transmission since the selected half contains the input and output bearing load, the shaft loads and the weights of the gears the detail design analysis done on the right side of the transmission housing. In practice, the length of the helical gearbox is decided by the length of L which is determined by the following equation:

$$L = \frac{d_{11}}{2} + a_1 + \frac{d_{22}}{2} + a_2 \tag{1}$$

$$a_1 = \frac{d_{21}}{2}\left[\frac{1}{i_1} + 1\right] \tag{2}$$

$$a_2 = \frac{d_{22}}{2}\left[\frac{1}{i_2} + 1\right] \tag{3}$$

$$L = \frac{d_{11}}{2} + \frac{d_{21}}{2}\left[\frac{1}{i_1} + 1\right] + \frac{d_{22}}{2} + \frac{d_{22}}{2}\left[\frac{1}{i_2} + 1\right]$$

$$L = \frac{d_{21}}{2}\left[\frac{2}{i_1} + 1\right] + \frac{d_{22}}{2}\left[\frac{1}{i_2} + 2\right] \tag{4}$$

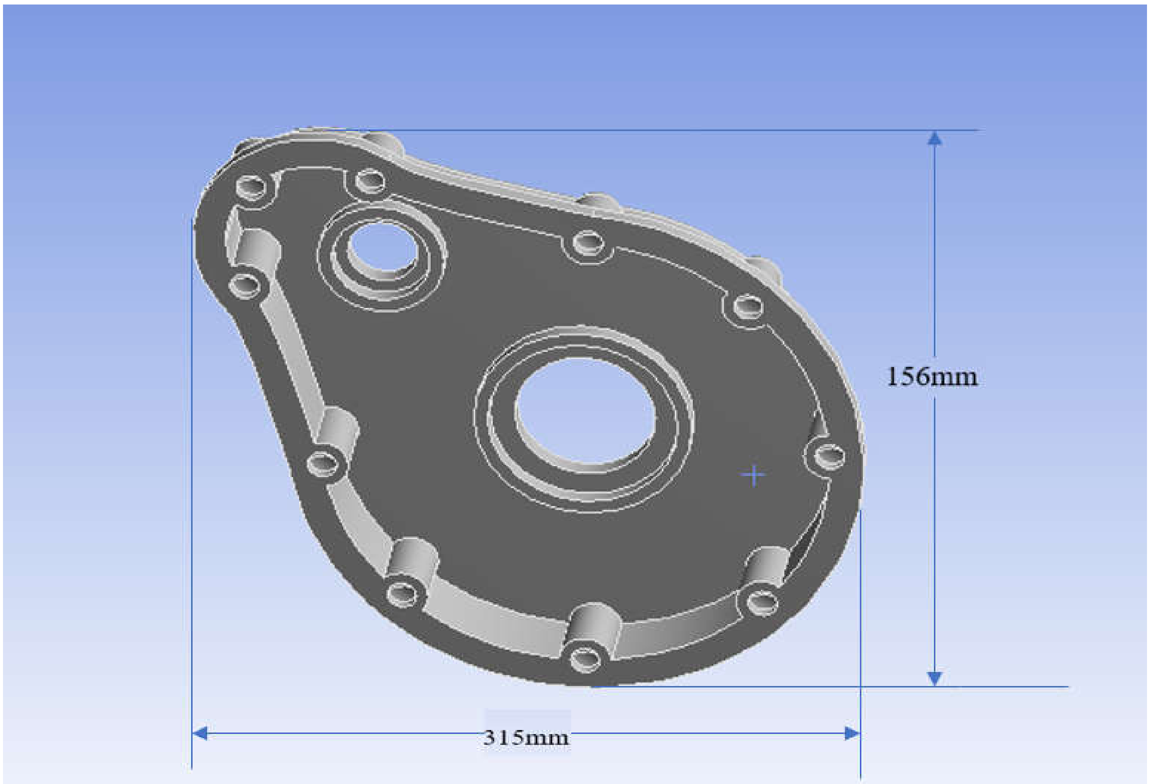


Figure 5 The dimensions of single speed transmission housing adopted from Tesla Model S

3.3 Methods

3.3.1 Characterization of CFRPs

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

- **Fiber, matrix weight fraction (W_f, W_m)**

$$fiber\ weight\ fraction = \frac{weight\ of\ fiber}{total\ weight}$$

$$W_f = \frac{w_f}{w_f + w_m} \tag{5}$$

$$matrix\ \ weight\ fraction = \frac{weight\ of\ matrix}{total\ weight}$$

$$W_m = \frac{w_m}{w_f + w_m}$$

$$w_f + w_m = w_c$$

$$W_f + W_c = 1 \tag{6}$$

- **Fiber matrix volume fraction (V_f, V_m)**

$$v_f = \frac{w_f}{\rho_f}$$

$$v_m = \frac{w_m}{\rho_m}$$

$$v_c = v_f + v_m \tag{7}$$

$$fiber\ volume\ fraction = \frac{volume\ of\ fiber}{total\ volume}$$

$$V_f = \frac{v_f}{v_f + v_m} = \frac{v_f}{v_c} \tag{8}$$

$$V_f = \frac{w_f \times \rho_m}{w_f \times \rho_m + w_m \times \rho_f}$$

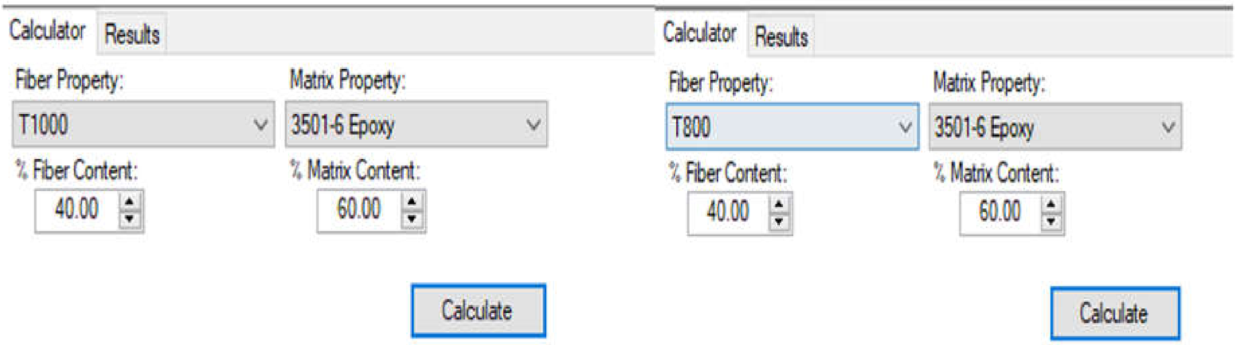
$$matrix\ volume\ fraction = \frac{volume\ of\ matrix}{total\ volume}$$

$$V_m = \frac{v_m}{v_f + v_m} = \frac{v_m}{v_c} \tag{9}$$

$$V_m = \frac{w_m \times \rho_f}{w_m \times \rho_f + w_f \times \rho_m}$$

$$V_f + V_m = 1 \tag{10}$$

Based on the measures, the composite with composition ratio of fiber and matrix 40% carbon fiber and 60% epoxy resin is selected. Using Autodesk Helius composite, used to create the selected type of lamina based on micromechanics concept as mentioned above.



Fiber Property: T1000
Matrix Property: 3501-6 Epoxy
% Fiber Content: 40.00
% Matrix Content: 60.00

Fiber Property: T800
Matrix Property: 3501-6 Epoxy
% Fiber Content: 40.00
% Matrix Content: 60.00

Figure 6 the formation of T1000-3501-6 Epoxy and T800-3501-6 Epoxy lamina based on micromechanics concept

After defining the composition ratio, as defined in figure 6, can calculate the properties of the designed lamina using Autodesk Helius composite package, The reduced stiffness matrix for a ply also calculated “Q-bar”,as shown in figure 28,29 which is from the material properties of k^{th} orthotropic lamina layer.

The ABD matrix also be calculated and if the laminate is balanced and symmetric the entire matrix B, [B] is zero, as shown in figure 30. In Classical Laminate Theory, the [A], [B], and [D] matrices collectively form the laminate stiffness matrix. The laminate stiffness matrix is used to express laminate resultant forces per unit width.

3.3.2 Initial Model

For the initial model of the transmission housing of the single speed electric vehicles, all finite elements were modeled in Aluminum, whose mechanical properties are presented in Table 2.

Table 2 Mechanical properties of Al 6061-T6 for transmission housing(Sirohi et al. 2018)

	Property	Value	Unit
1.	Density	2700	Kg/m^3
2.	Young's modulus	69	GPa
3.	Poisson's ratio	0.33	------
4.	Bulk modulus	67.6	GPa
5.	Shear modulus	25.9	GPa
6.	Tensile strength	275	MPa
7.	Compressive strength	250	MPa
8.	Ultimate strength	310	MPa

The load cases are initially tested on several iterations of the FE model. The goal is to evaluate the resulting stresses, displacements and the resonance frequency of the initial model so then the composite version of the material will be guarded based on those conditions. The initial model results, which are the maximum stress, maximum displacements and the frequency, as presented on table 3, are considered as the constraints for the composite optimization process.

Table 3 Static and modal analysis of the initial model under regulation load cases

Initial model Material	Mass [Kg]	Static Analysis		Modal Analysis	
		Max. Stress (Von-Mises stress) [MPa]	Max. displacements (Total Deformation) [mm]	Frequency [Hz]	Max. displacements (Total Deformation) [mm]
Al 6061-T6	5.4	304.38	0.42214	1303.5	866.92

3.3.3 Composite Optimization

Optislang method of optimization for composite structures was selected to design a composite interpretation of gearbox housing. This method allows for the conception that was aimed to design lightweight and rigid composite structures.

To build the laminates of the final composite model, two types of carbon fiber materials were used, as mentioned on the characterization of the lamina, T800 and T1000. Their mechanical properties are summarized in table 4.

Table 4 Mechanical Properties of T800 and T1000(Wang et al. 2013)

Materials	σ^{t}_{11} [MPa]	σ^{c}_{11} [MPa]	σ^{t}_{22} [MPa]	σ^{c}_{22} [MPa]	τ_{12} [MPa]	t [mm]	ρ [Kg/m^3] (*1000)
T1000	2699.1	1287.9	17.37	179.1	118.8	0.126	1.540
T800	783	567	750.6	522	110.7	0.230	1.500
Materials	E_{11} [GPa]	E_{22} [GPa]	εf_{11} [%]	εf_{11} [%]	ϑ_{12}	G_{12} [GPa]	
T1000	141	7.55	1.737	0.252	0.34	3.09	
T800	60	61	1.17	1.152	0.04	4.39	

T1000 carbon fiber is an intermediate modulus which is the world’s highest tensile strength fiber. This type of carbon fiber is suitable for light weight and tensile strength initial applications and commonly designed to develop pressure vessels for aerospace (Lawrence 2010b).

T800 carbon fiber is also an intermediate modulus with high tensile strength and with an excellent balanced composite properties and mostly this carbon fiber are designed to develop the weight saving demand of aircraft (Wang et al. 2013).

For composite optimization of all the elements on the mesh which are the design space and non-design space were attributed to the property of composite laminate instead of PSHELL. The composite laminates PCOMPP defines the properties of composite materials in a ply-based definition. Since the main objective of this work is to develop an optimized composite version of an existing aluminum powertrain housing for single speed electric vehicle while maintaining the stiffness of the initial model and satisfying the failure criterion.

The initial model to which the developed composite transmission housing shall be compared to is an aluminum transmission housing. The action performed at preparatory level of the composite optimization was of setting the directions of the elements normal to the inside of the gearbox casing so that the laminates direction would be inwards to the element. For this gearbox housing, the materials orientation is aligned with the global X-axis along the side, upper and lower faces, while along the front and rear faces the material orientation is aligned with the global Y-axis.

Composite optimization was intended to create the initial laminates for non-design spaces. The two laminates were designed symmetrical, since this is a commonly used type of laminates that eliminates coupling between bending and extension, and less prone to bending or twisting caused by the thermally induced contractions that occur during cooling after the curing process.

The initial laminate for the design space presented in table 5 reveals the fiber orientations considered for optimization: $[0°/-45°/90°/45°]_{2S}$ for T1000carbon fiber and $[0°]_{2S}$ for T800 carbon fiber cover. T800 carbon fiber plies were introduced as the first and last layers of the initial laminate given the requirement to feature this particular carbon fiber material in both the covers of the final laminate.

Table 5 Design space initial laminates

Piles #	Material	Orientation (degrees)	Thickness (mm)
1	T800	0	0.50
2	T1000	0	0.50
3	T1000	90	0.50
4	T1000	45	0.50
5	T1000	-45	0.50
6	T1000	-45	0.50
7	T1000	45	0.50
8	T1000	90	0.50
9	T1000	0	0.50
10	T800	0	0.50

The composite optimization process in this specific research is a **free-size optimization** that focuses on material distribution in terms of orientation and thickness. This is achieved by allowing the thickness of each ply of a unique fiber orientation to change freely throughout the model, obtaining a thickness contour for each fiber orientation.

The free-size optimizations are executed using one of the finite element analysis software ANSYS OptiSlang and Autodesk Helius Composite.

The generalized optimization problem can be mathematically defined as follows:

$$X = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} \text{.................Design Variable} \qquad (11)$$

Function F(x)……minimize F(x) objective function, subjected to

$$\left. \begin{array}{ll} g_j(x) \leq 0 & j = 1,2,3, ... \\ h_i(x) = 0 & i = 1,2,3, ... \end{array} \right\} \quad \text{Constraints} \qquad (12)$$

Based on equation 11 & 12 the objective of the function is to minimize the thickness of each ply and will be performed using ANSYS Optislang. The optimization layout on ANSYS workbench is given on figure 7. The primary step on the ANSYS ACP model is to define the characterized materials, the output of Auto desk composite Helius, to the ANSYS Work bench and can be referenced in figure27.

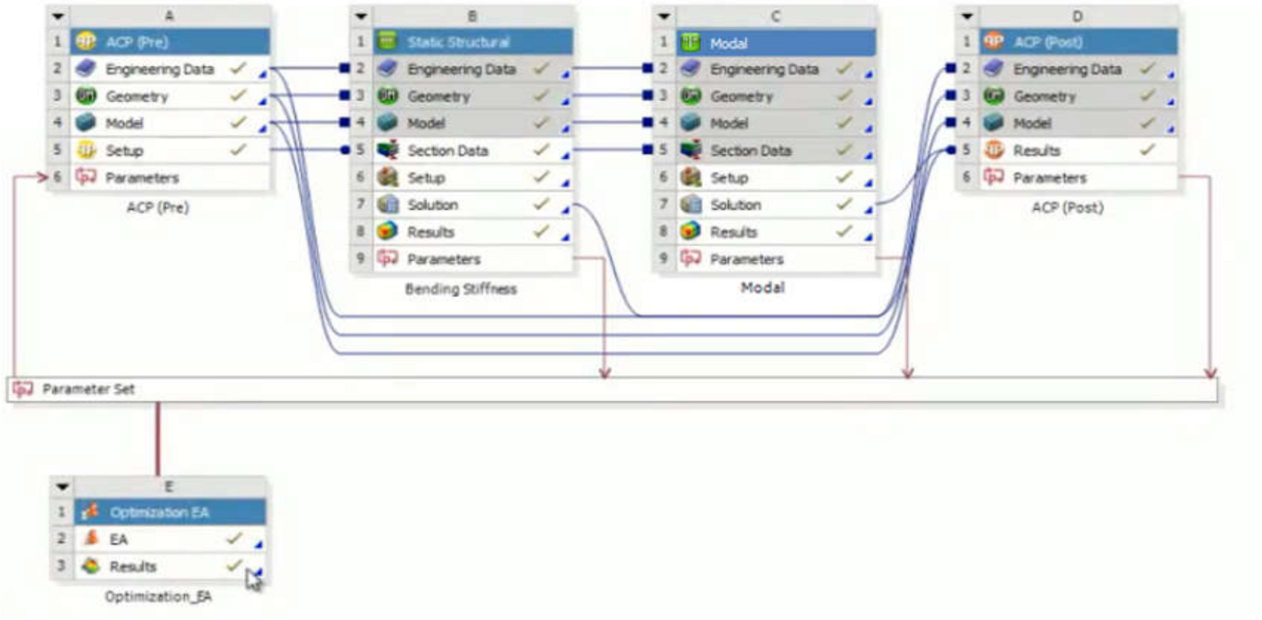


Figure 7 Opti slang Optimization methods layout

3.3.4 Mesh Generation

The transmission housing geometry on this design consists of two different regions: the design space and the non-design space as indicated on figure 8. The non-design (represented as green color in fig 8), space consists of areas around the solid reinforcement supports and other connection points to second gearbox casing that is the important gearbox components.

Therefore, these areas are not subjected to optimization, since their shape and their material has to remain unchanged. An additional cause for incorporating these areas in non-design space is the fact that the objective of minimizing the structure’s weight could result in insufficient material being attributed to these areas, potentially weakening these critical regions and resulting in local failure under service.

The joining of the non-design and design region which are the aluminum and carbon fiber reinforced polymer taken places using ultrasonic metal welding technique. The welding during this process occurs in two steps. First ultrasonic shear waves and the second is a direct weld between the CFRP and aluminum alloy sheet(Balle, Wagner, and Eifler 2009).

After defining the design and non-design spaces of the transmission housing geometry, the meshing process initiated using ANSYS meshing, a component of ANSYS Workbench. In the finite element method, the structure of interest is sub-divided in to discrete shapes called elements. Finite element methods have proved indispensable for physical simulation. These methods discretize the simulated domain.

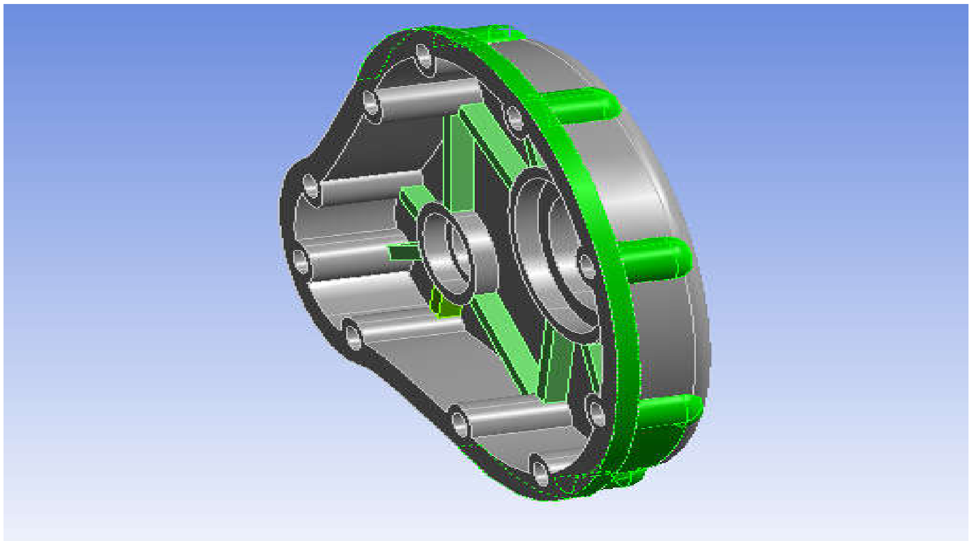


Figure 8 Transmission housing design and non-design regions

The meshing process created 22,600 shell elements and 48,020 nodes. The degree of discretization, associated with the average element size, used in the model was a compromise between the accuracy of the optimization results and reasonable computation times.

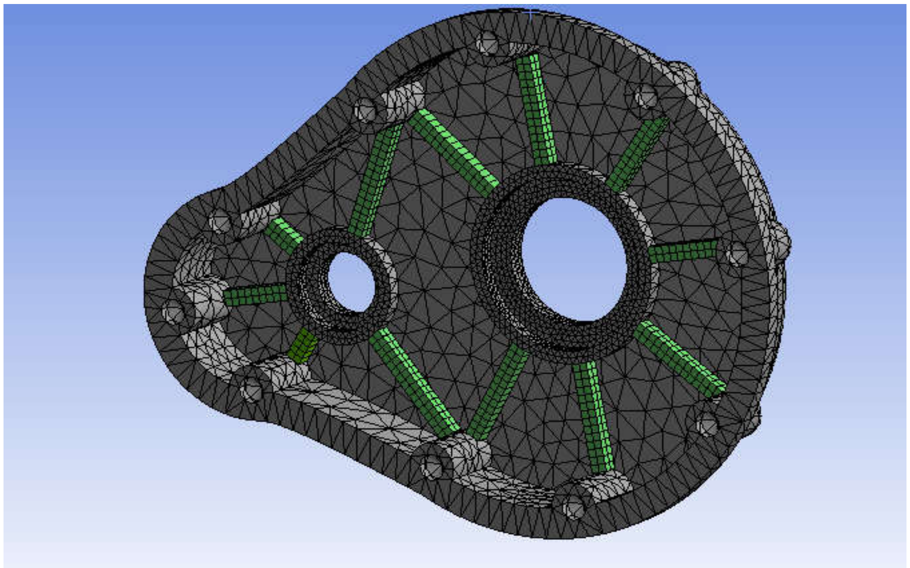


Figure 9 Mesh detail for the single speed transmission housing

3.4 Conditions

When it is mounted to the electric vehicle, Tesla model S, the front of the gearbox housing is fixed directly to the other half of the gear box casing and the back of the housing will be mounted to the electric motor of the system. These mountings translate in to the constraints that were applied to the FE analysis. These are represented on figure 10.

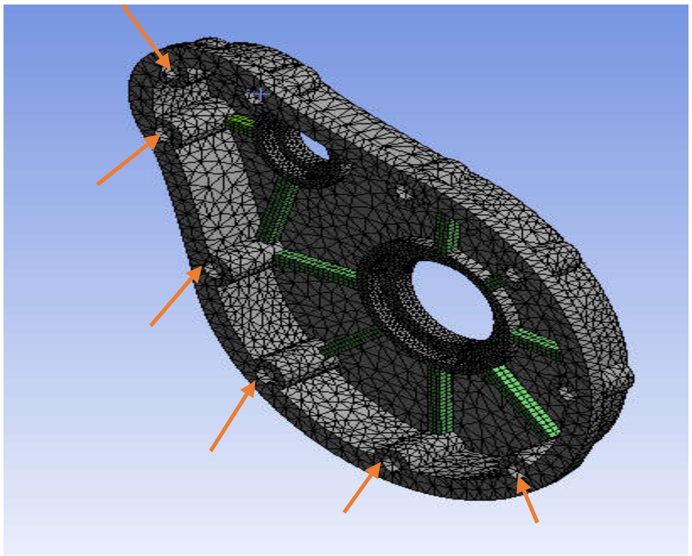


Figure 10 The 10-point constraints of the single speed transmission housing

A static analysis to calculate the effect of steady loading conditions on a structure was performed. A two-stage speed reduction gearbox was designed for an input motor power of 386KW at a running speed of 230Km/hr. The bending strength of the transmission casing from the layout is a constraint conditions, the maximum input torque is 1250Nm the data are adopted from the Tesla model S and the output torque is around 3750Nm. The input bearing load is about 5680N and the output bearing load is 6900N.

The modal analysis is done on natural frequency calculations of the transmission housing in zero-displacement run conditions are done without applying any external load. Natural frequency being inherent characteristics property of any component or assembly no external force applied during the analysis. Damping is neglected for natural frequency calculation. The natural frequencies of gearbox are calculated by using free-free run in ANSYS by without applying the any external load and 10-point constraints. Modal analysis had performed in free-free condition, to find out first 6 natural frequencies of the model. The load cases to be considered in this optimization analysis work are the static load and modal load cases.

4.RESULTS AND DISCUSSION

4.1 Results

From the ANSYS OptiSlang optimization the weight of the transmission housing reduced by 22% where the weight of Aluminum 6061-T6 was 5.4kg and the optimized weight by using composite + aluminum materials is about 4.19kg which satisfies the constraint conditions.

After 160 runs OptiSlang reduces the weight of the composite + Aluminum design by 22%. The stiffens and the failure requirements are all meet at the best design and have reduced the weight of composite design a little less than the original version of the single speed transmission housing.

There are possible bad designs in the analyze design runs as represented on figure 11. Those designs violets the constraint conditions, the bending stiffens or the modal stiffness at a time or one at a time, which was actually lighter than the best design. The best design not violating the stiffness requirements and not showing any failure can be evaluated in detail in ANSYS composite Pre-Post.

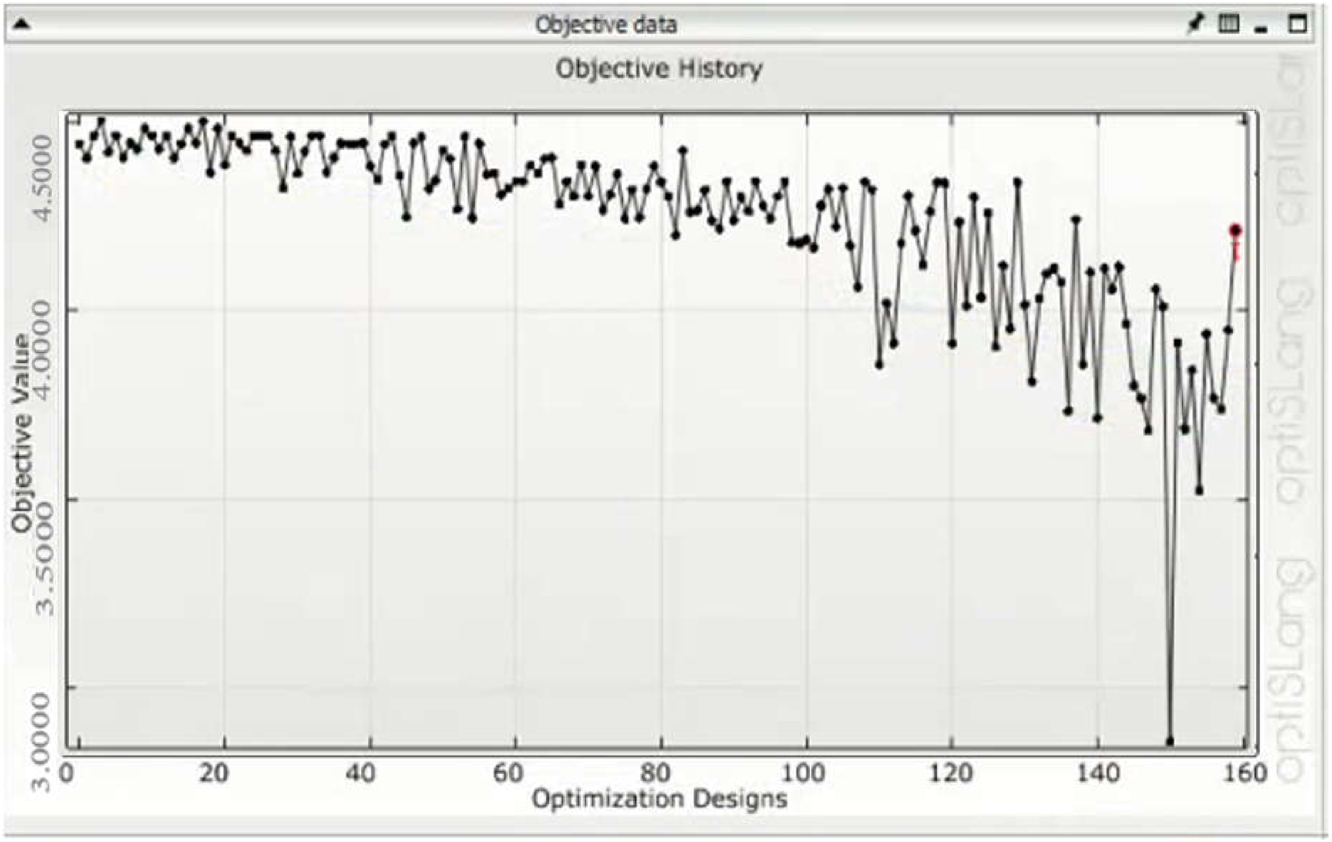


Figure 11 The optimization design variables from ANSYS Optislang

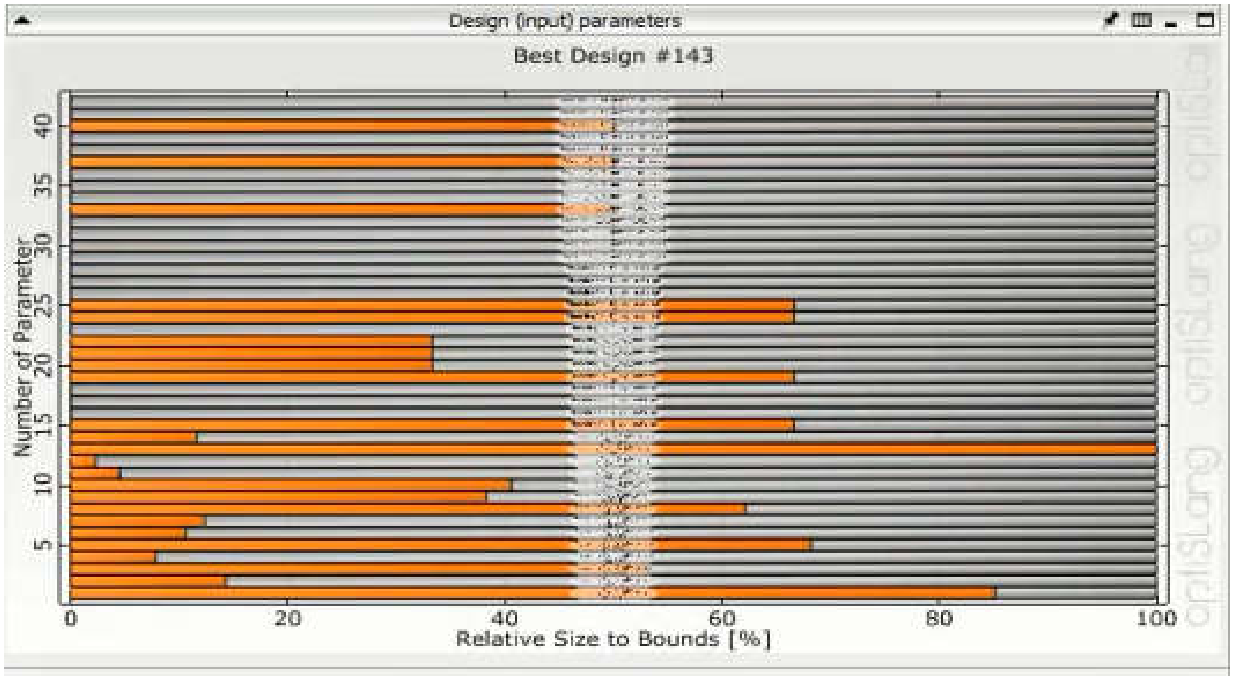


Figure 12 The best design trial that best suites the design constraints

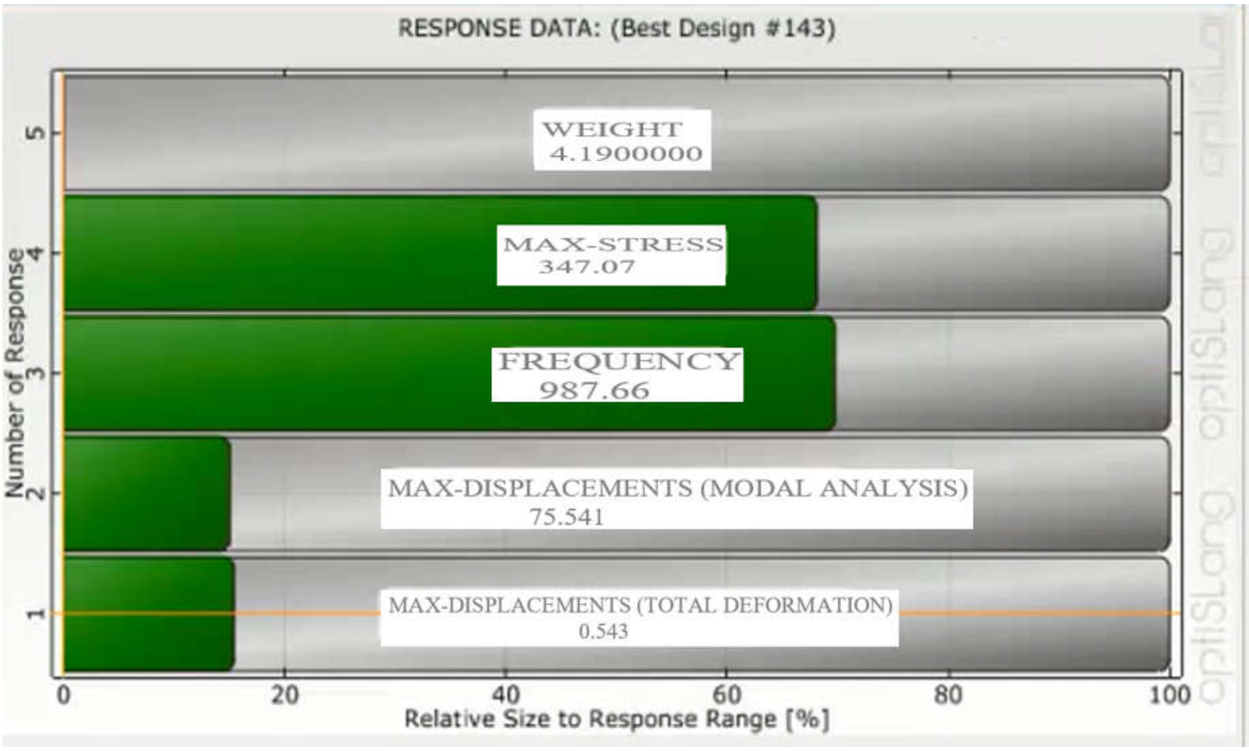


Figure 13 Relative size response to the best design which satisfy the design constraints

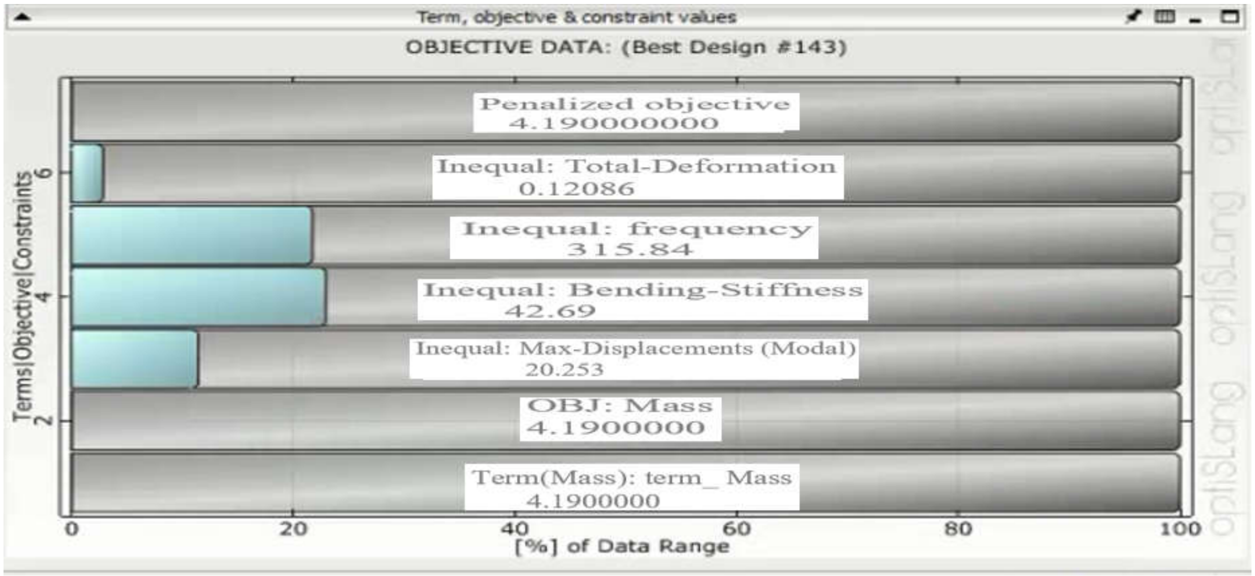


Figure 14 The objective function data of the composite optimization

Table 6 The Optimization variables from ANSYS OptiSlang of the composite + Aluminum housing

Design Variables (OptiSlang trails)	Mass [Kg]	Static Analysis		Modal Analysis	
		Max. Stress (Von-Mises stress) [MPa]	Max. displacements (Total Deformation) [mm]	Frequency [Hz]	Max. displacements (Total Deformation) [mm]
1	3.51	396.25	1.3100	645.09	64.789
2	3.54	456.874	1.2999	656.707	65.674
3	3.45	397.097	1.3994	650.984	60.784
4	3.00	434.443	1.4067	500.962	54.761
5	3.57	385.330	1.289	681.09	66.098
6	3.589	376.878	1.2568	678.078	67.894
7	3.79	417.568	1.000	899.856	68.098
Best design	4.19	347.07	0.54257	987.66	75.54
8	4.00	397.299	0.68975	954.988	75.54
9	3.97	399.568	0.70017	948.856	72.789
10	3.85	399.568	0.7988	928.856	70.984
11	3.73	417.568	1.0087	896.856	69.098
12	3.61	373.807	1.2284	885.829	67.890
13	3.99	363.073	0.71080	939.403	73.789

Table 7 The selected T1000-3501-6Epoxy with T800-3501-6Epoxy cover laminate

Ply #	Lamina	Thickness (mm)	Angle(deg.)
1.	T800-3501-6 Epoxy	0.20	0
2.	T1000-3501-6 Epoxy	0.20	0
3.	T1000-3501-6 Epoxy	0.20	90
4.	T1000-3501-6 Epoxy	0.20	45
5.	T1000-3501-6 Epoxy	0.20	-45
6.	T1000-3501-6 Epoxy	0.20	-45
7.	T1000-3501-6 Epoxy	0.20	45
8.	T1000-3501-6 Epoxy	0.20	90
9.	T1000-3501-6 Epoxy	0.20	0
10.	T800-3501-6 Epoxy	0.20	0

The laminate for the design space presented in table 7, reveals the fiber orientations considered for optimization: $[0°/-45°/90°/45°]_{2S}$ for T1000 unidirectional carbon fiber and $[0°]_{2S}$ for T800 carbon fiber cover. The final optimized laminate is a symmetrical laminate.

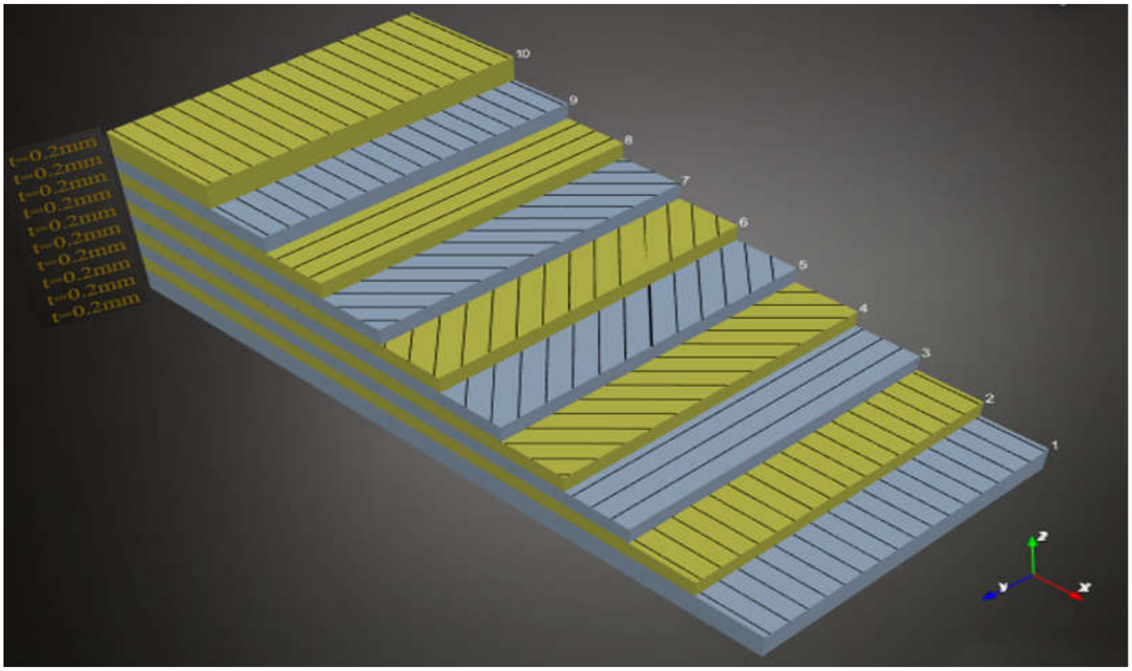


Figure 15 The selected Ply stack sequence of the material used for the transmission housing

4.1.2 Static Analysis Results

The simulations carried out on the optimized transmission housing shows the maximum deflection and the stresses induced in the model depending on the optimized model.

The equivalent (Von Mises) stress values of both the Aluminum and composite+ Aluminum version of the single speed transmission housing of FEA are shown in the figure16 and 17.

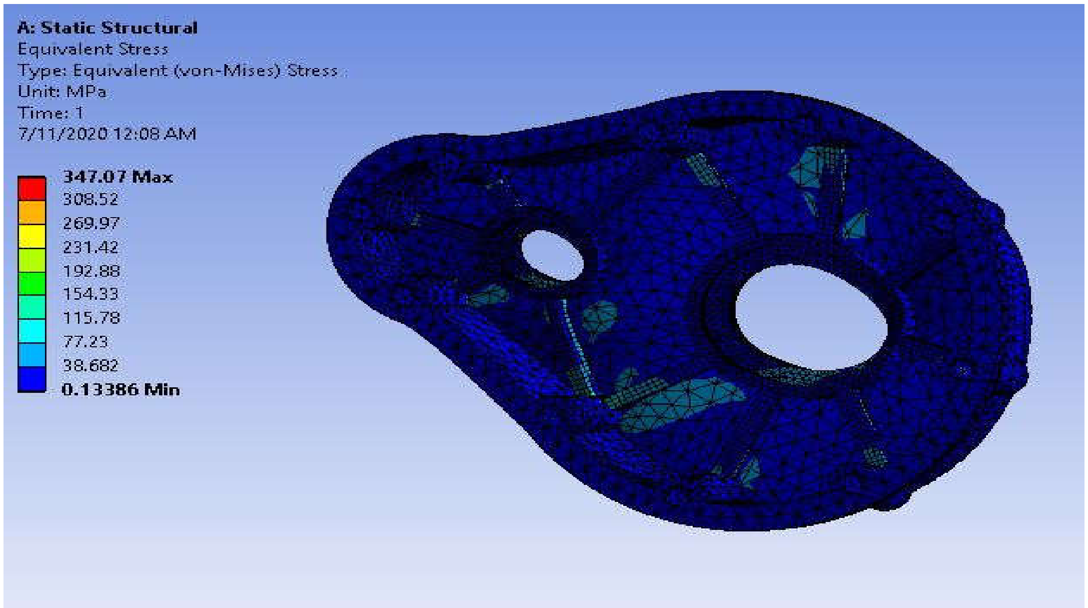


Figure 16 The Von-Mises stress of the T1000-3501-6Epoxy with T800-3501-6Epoxy+Aluminium single speed transmission housing

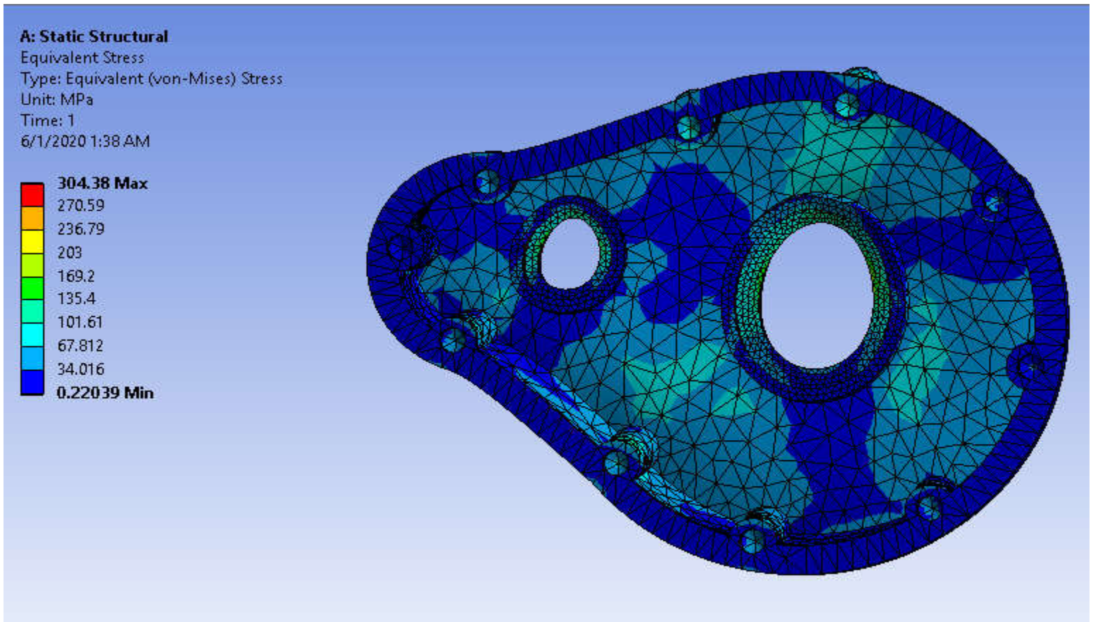


Figure 17 The Von-Mises stress of the Aluminum 6061-T6 single speed transmission housing

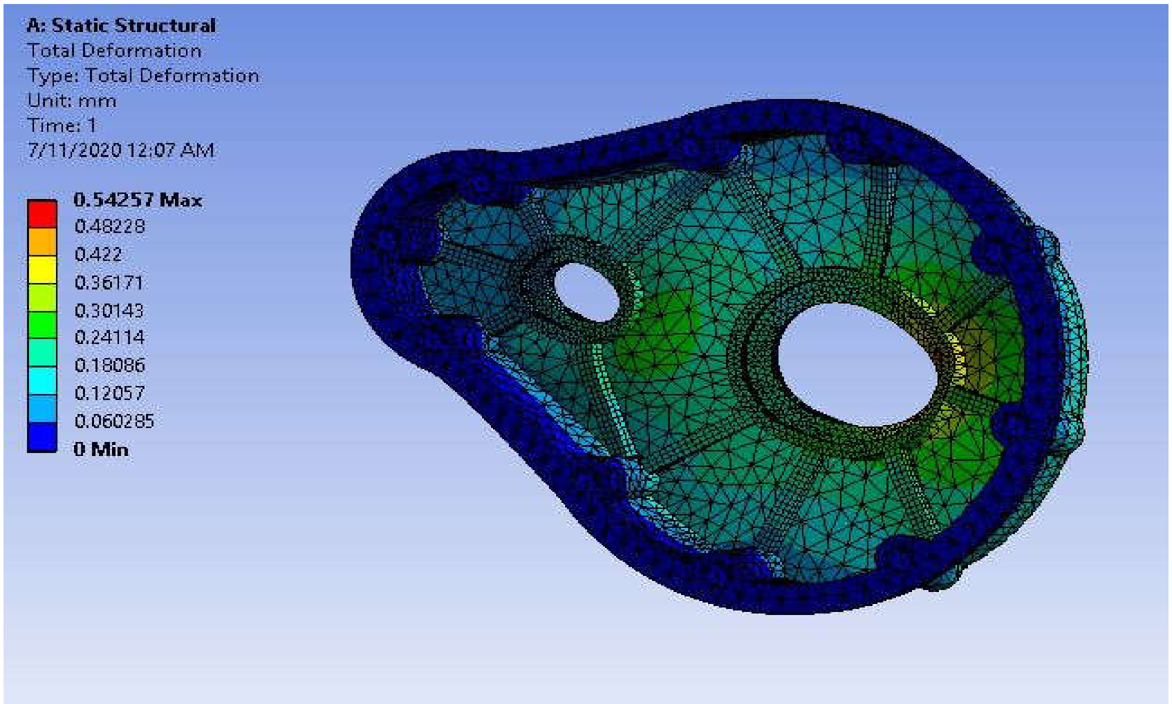


Figure 18 The maximum displacement of the T1000-3501-6Epoxy with T800-3501-6Epoxy + Aluminum transmission housing

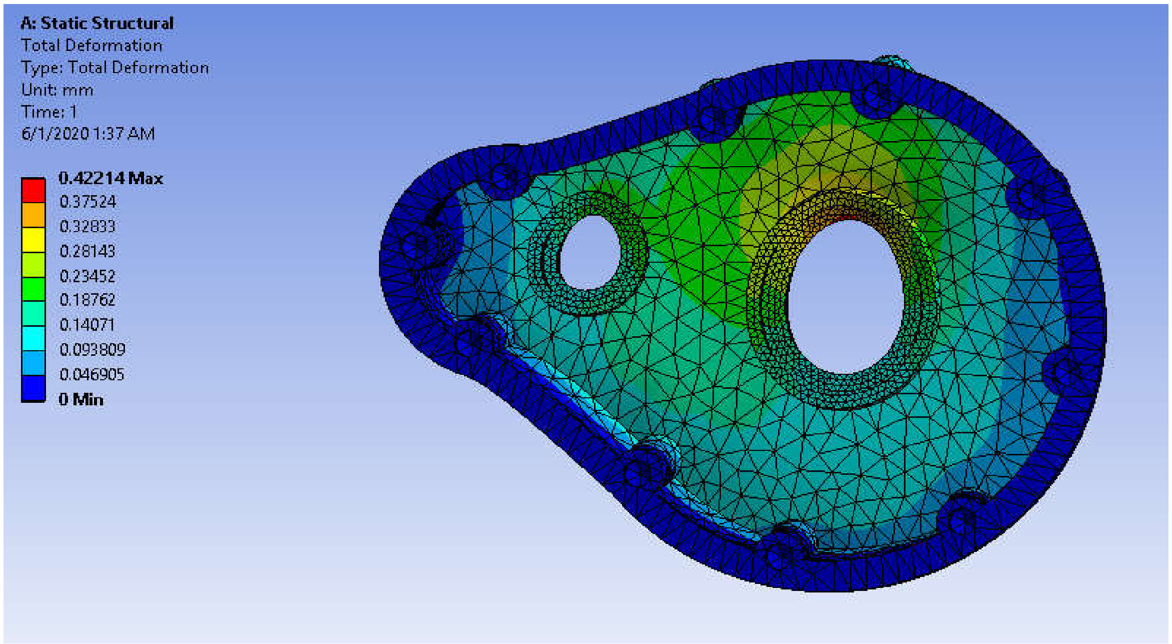


Figure 19 The total deformation of the Aluminum 6061-T6 of the single speed transmission housing

4.1.3 Modal Analysis Results

The zero-displacement constraint-based boundary condition applied by constraining the 10 connecting bolts hole positions against motion. In actual term this boundary condition signifies that the transmission housing is tightly mounted on chassis frame, and connecting to the other half of the transmission housing using 10 connecting bolts and constrained to move in all direction by fixing 6 degree of freedom of housing.

Housing is tightly fixed on vehicle chassis frame using 10 constraint bolts to prevent the looseness condition. ANSYS workbench module has good simulation features. For simulation to obtain the natural frequencies and mode shapes, suitable boundary condition representing practical application was applied.

In software environment to simulate this zero-displacement constraint-based boundary condition connecting bolts hole positions were fixed. So, all DOF is constraint and housing are rigidly fixed on chassis. Loose transmission may cause excess vibration and harm to transmission system. So, the transmission system may be fully tight mounted on chassis using bolts.

Table 8 shows the variation of natural frequencies for optimized transmission housing

Mode	Frequency (HZ) Best design (CFRP)	Frequency (Hz) Aluminum 6061-T6
1	987.66	1303.5
2	1350.8	1846,7
3	1543	2200.4
4	1934.4	2657
5	2383.7	3516.8
6	2546.7	3717

The FEA simulation shows that the natural frequencies of the optimized transmission housing vary (988-2546) Hz, the Aluminum 6061-T6 varies (1304-3717) Hz. The higher order frequency variation shows the excellent structural rigidity by eliminating lower order frequency.

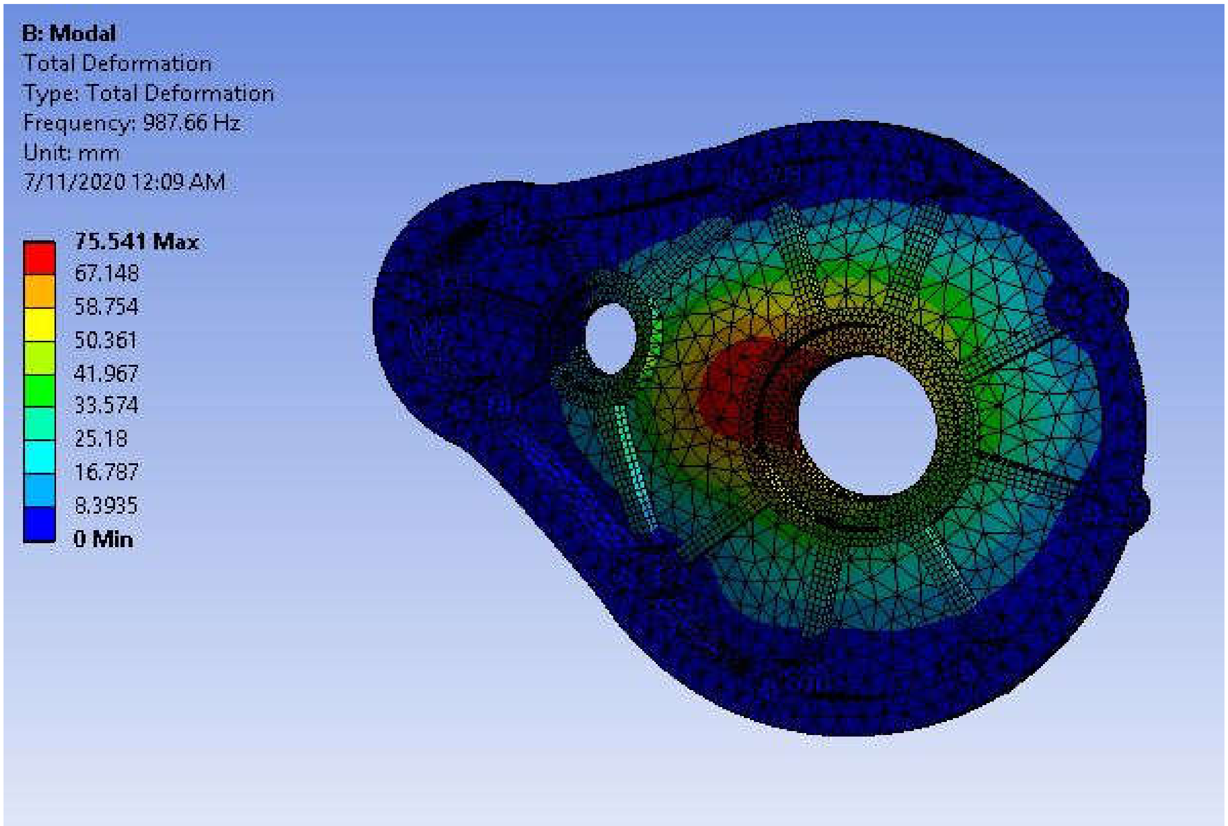


Figure 21 Mode shape of the total deformation of the optimized CFRP+ Aluminum transmission housing

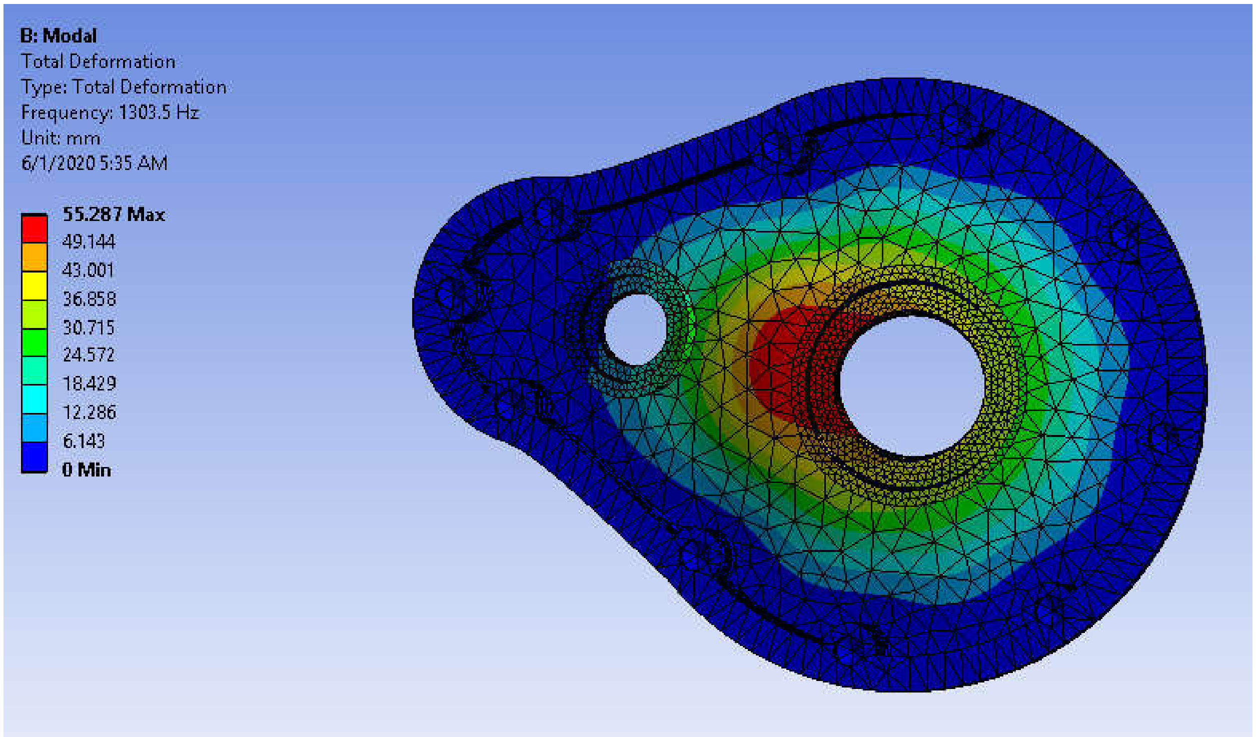


Figure 20 Mode shape of the total deformation of the existing Al 6061-T6 transmission housing

4.2 Discussion

From the Autodesk composite approach, the property of material used for the single speed electric vehicle transmission housing, laminates, T1000-3501-6Epoxy and, T800-3501-6Epoxy (density, tensile strength, compressive strength, the poison's ratio, modulus of rigidity) was developed using micromechanics concepts.

The existing model of the single speed electric vehicle transmission housing was further analyzed to evaluate the resulting stresses, displacements and the resonance frequency of the Aluminum 6061-T6 as illustrated on table 3. The goal is to evaluate the resulting stresses, displacements and the resonance frequency of the initial model so then the composite version of the material will be guarded based on those conditions.

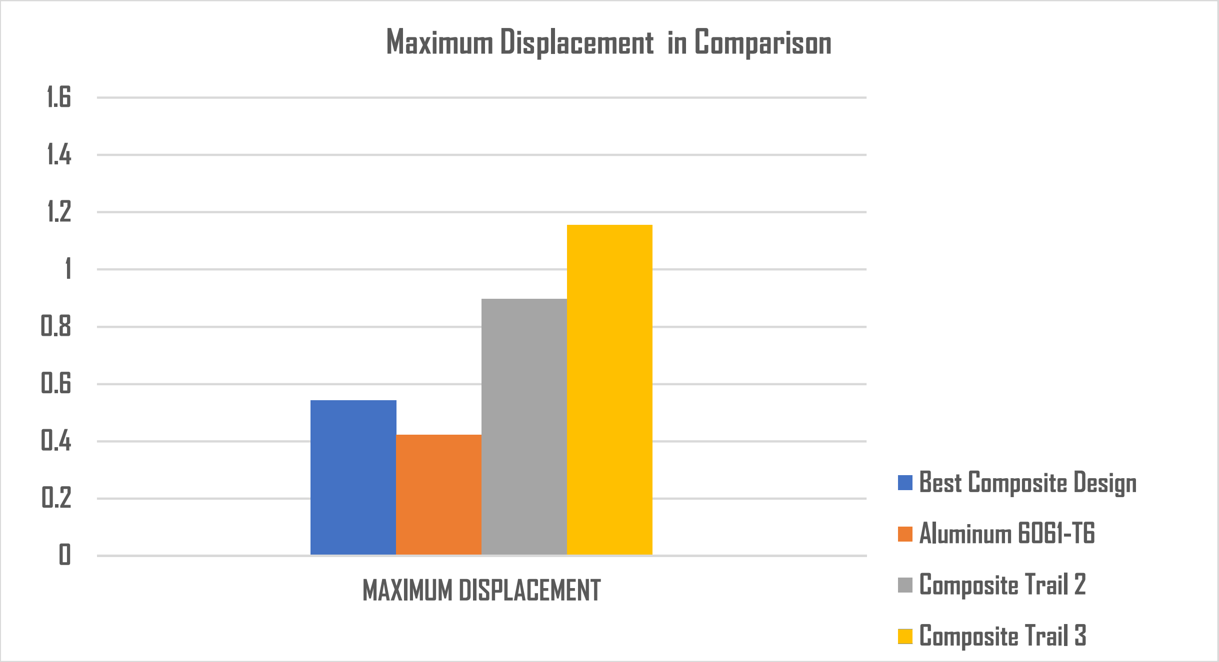


Figure 22 Maximum displacement of the single speed transmission housing in comparison

As it is known the reduction of weight of the transmission housing has vital advantage on the modification of electric vehicles, when the weight decreased by even 3% or gain about 3Kg for the system, so the it can allow the electric vehicles for the release of new generation battery pack.

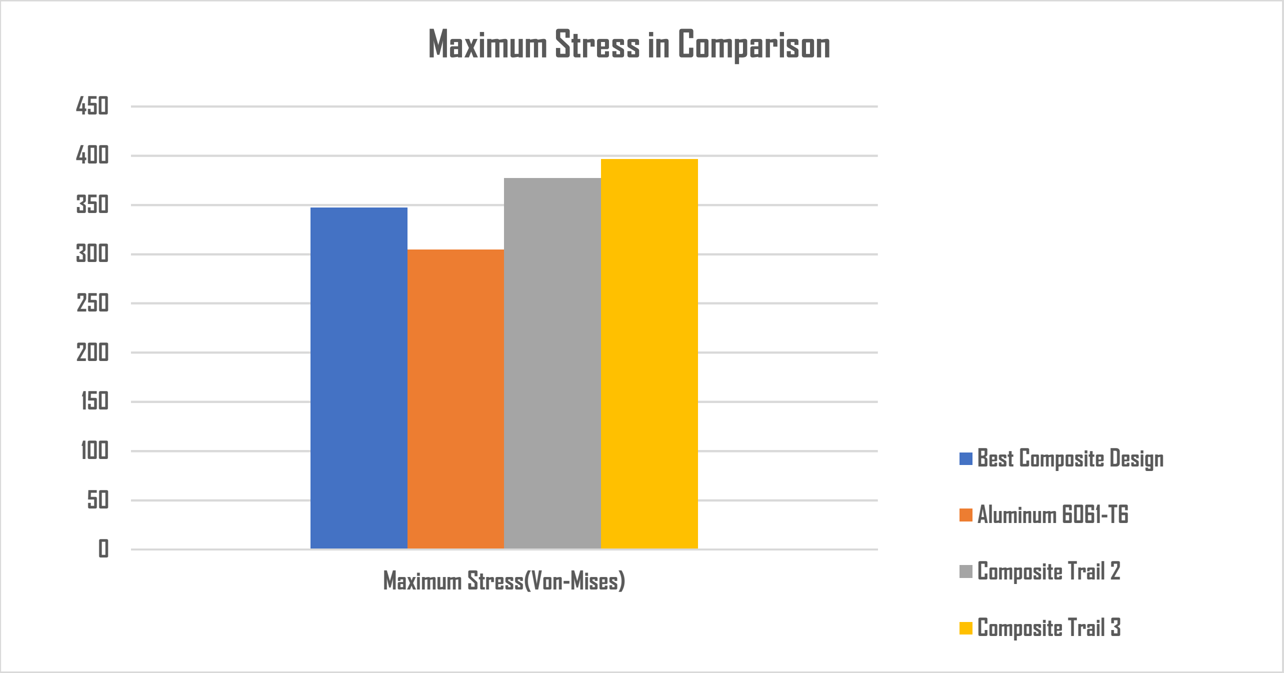


Figure 23 Maximum stress of the single speed transmission housing in comparison

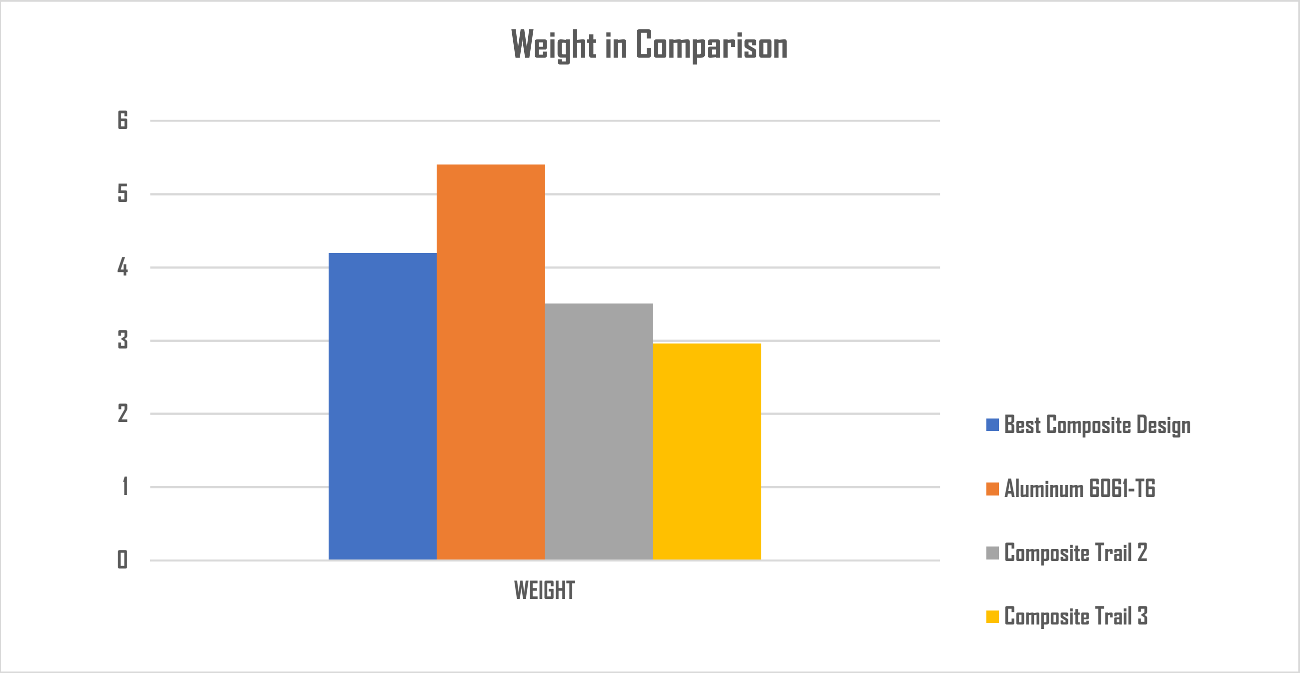


Figure 24 Weight of the single speed transmission housing in comparison

The chart represented in figure 24, illustrates the evolution of the weight compliance of the composite gearbox and the existing version of Aluminum single speed transmission housing model throughout the composite optimization procedure. Variations between the trail stages are due to changes in thickness distribution of the design space laminate. Particular emphasis is given to the reduction of weight that achieves the constraint conditions, which is satisfy the rigidity of the optimized model as of the existing aluminum version of the transmission housings.

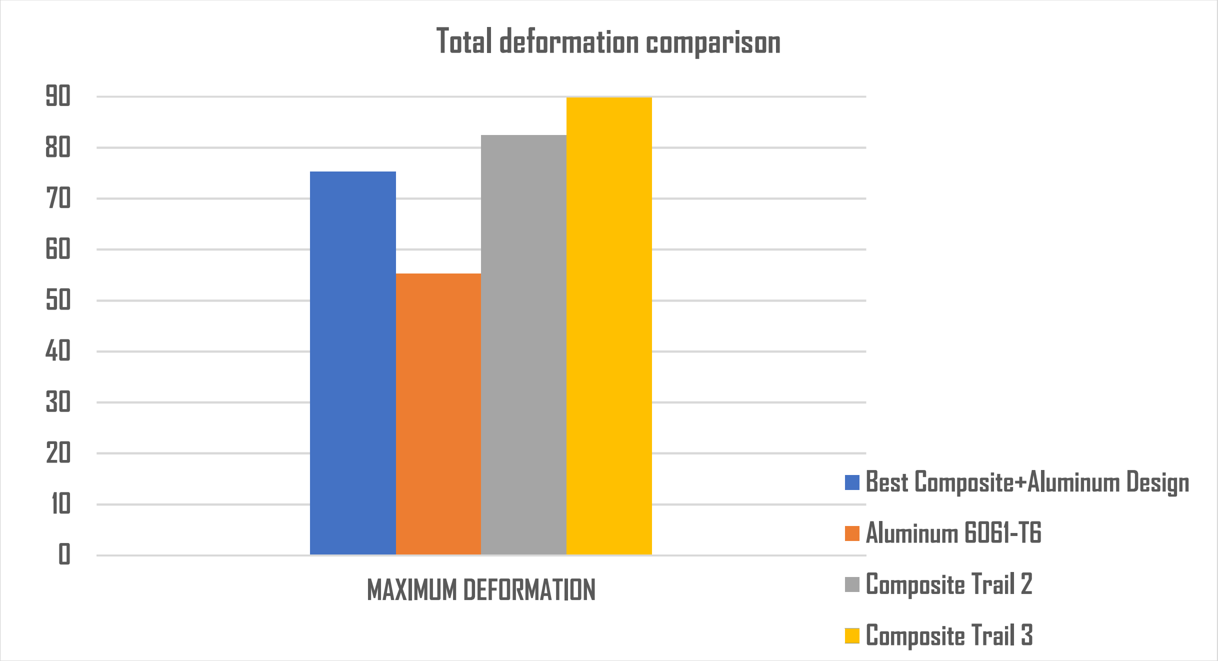


Figure 25 Mode shape of the total deformation of the transmission housings in comparison

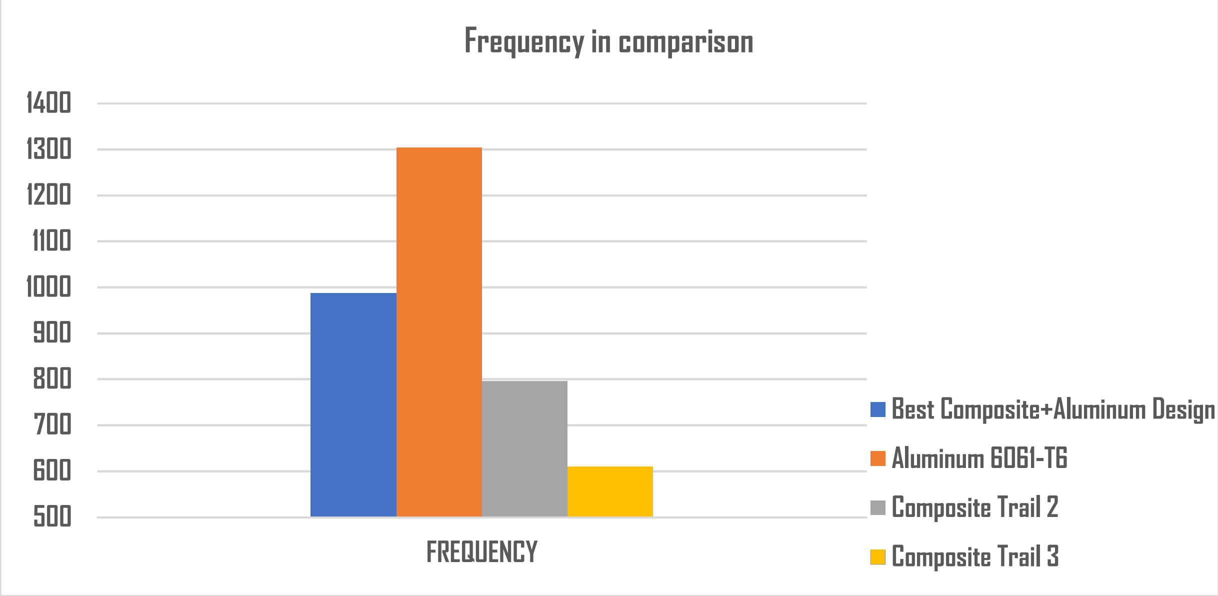


Figure 26 Mode shape of the frequency of the transmission housing in comparison

The static and modal analyses was performed on each trail of the composite optimization at the first instant the all composite optimization, OptiSlang, results violets the constraints conditions, therefore the introduction of reinforcements is necessary. These reinforcements allow the transmission housings to withstand both static and modal load without failure.

The OptiSlang composite optimization runs about 160 trails in order to achieve the desired goal which is to meet lesser weight under the condition, which are the static and modal constraints. The best design output is about 22% lesser than the existing version of the single speed electric vehicle transmission housing, and the developed maximum stress and the deformation increased with a lesser range since it is light weight as compared to the existing aluminum transmission housing, illustrated on chart figure 22 and 23. The iterated best design developed also have meet the constraints of the modal conditions, as illustrated on chart figure 25 and 26 the natural frequencies of the optimized transmission housing vary (988-2547) Hz, the Aluminum 6061-T6 varies (1304-3719) Hz. The higher order frequency variation shows the excellent structural rigidity by eliminating lower order frequency.

From the ANSYS OptiSlang optimization the weight of the transmission housing reduced by 22% where the weight of Aluminum 6061-T6 was 5.4kg and the optimized weight by using composite materials is about 4.19kg which satisfies the constraint conditions.

The selected best design variables laminate for the design space presented in figure 15 reveals the fiber orientations considered for optimization: 0°, -45°, 90° and 45° for T1000carbon fiber and 0º for T800 carbon fiber cover. The final optimized laminate is a symmetrical laminate.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of this study, the weight optimization of the single speed electric vehicle gearbox casing, was to design a composite + Aluminum version of the transmission housing that is considerably lighter than the initial model which maintained the latter's stiffness and satisfies the strength and vibration criterion.

In this study the optimization of the transmission housing on the single speed has been done by FEM. The material property which has been used for the composite optimization was used to be determined by the Autodesk Helius composite. Based on the outline of the ANSYS optislang optimization, the material property from the Autodesk composite, and the optimization of the transmission housing from the ANSYS Optislang.

As evidenced by the ANSYS Optislang results presented on table 7, the best selected optimizes composite + Aluminum design is 22% lighter than the initial model. Compared to the Aluminum 6061-T6 gearbox casing, which weighted 5.4Kg, the optimized composite design is considerably lighter at 4.19Kg.

Although the final shape does not exactly resemble the inner geometry of the initial transmission housing used in the single speed electric vehicle, due to the introduction of the reinforcements, it is safe to trust that the overall stiffness of the final composite + Aluminum design, since the optimized composite + Aluminum design is close to the original Aluminum 6061-T6 housings.

5.2 Recommendation

This thesis work would be interesting to explore Altair’s HyperStudy software which, unlike ANSYS OptiSlang, allows the user to select and define the algorithm used to perform the optimization of particular interest, which would permit to optimize both the stiffness and the heat conductivity of the composite transmission housing in parallel.

Further optimization could be performed on the reinforcements that were introduced for the composite version of the transmission housings, since their shapes and laminates were manually designed and incorporated in the model. This could potentially allow for an even greater weight reduction.

Furthermore, the optimization of the transmission housing could be performed by considering the impact load as the constraint factors so then the functionality of the optimized single speed electric vehicle transmission housing increased.

Finally, it is important to identify other applications where the optimization carried out in this work would bring great advantages from a performance point of view. In general, metallic shell structures used in motorsport, automotive and aerospace applications would benefit greatly from undergoing composite optimization, the weight reduction through composite optimization is an excellent way of improving the vehicle’s performance, safety and fuel consumption.

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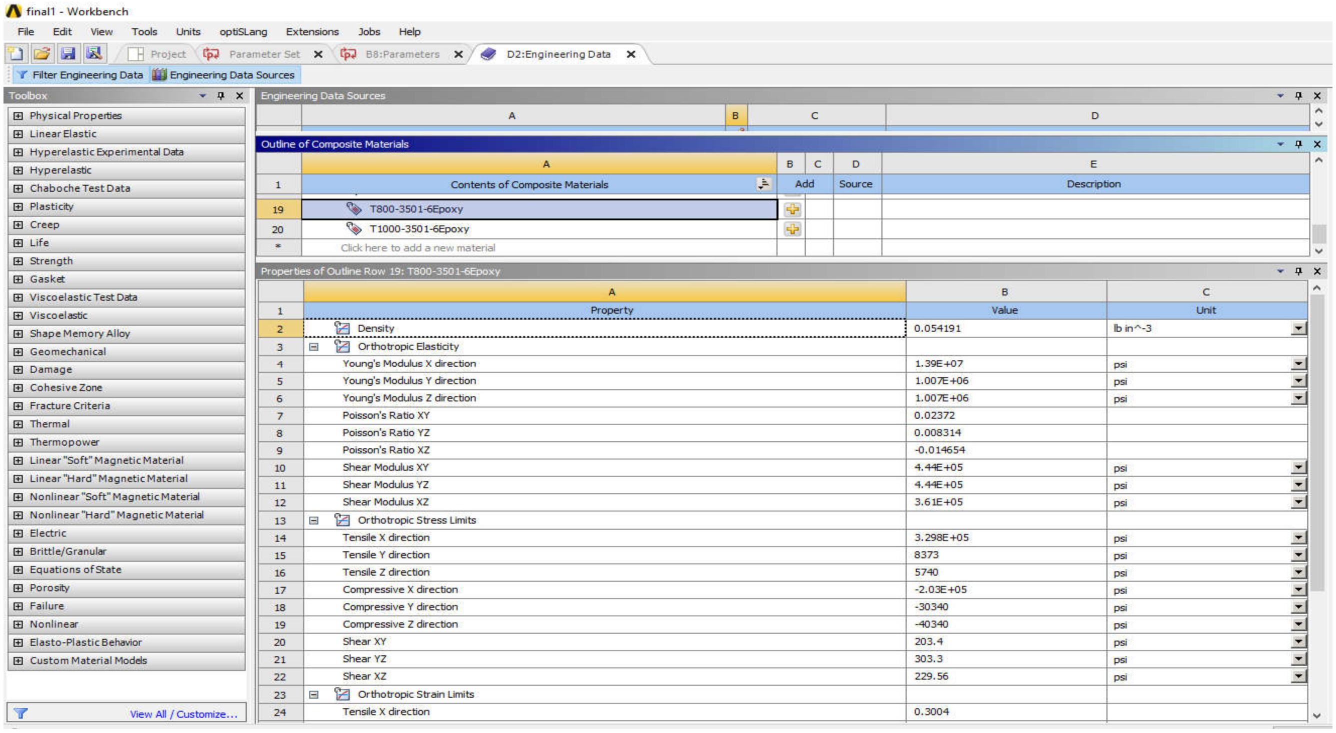
Appendix

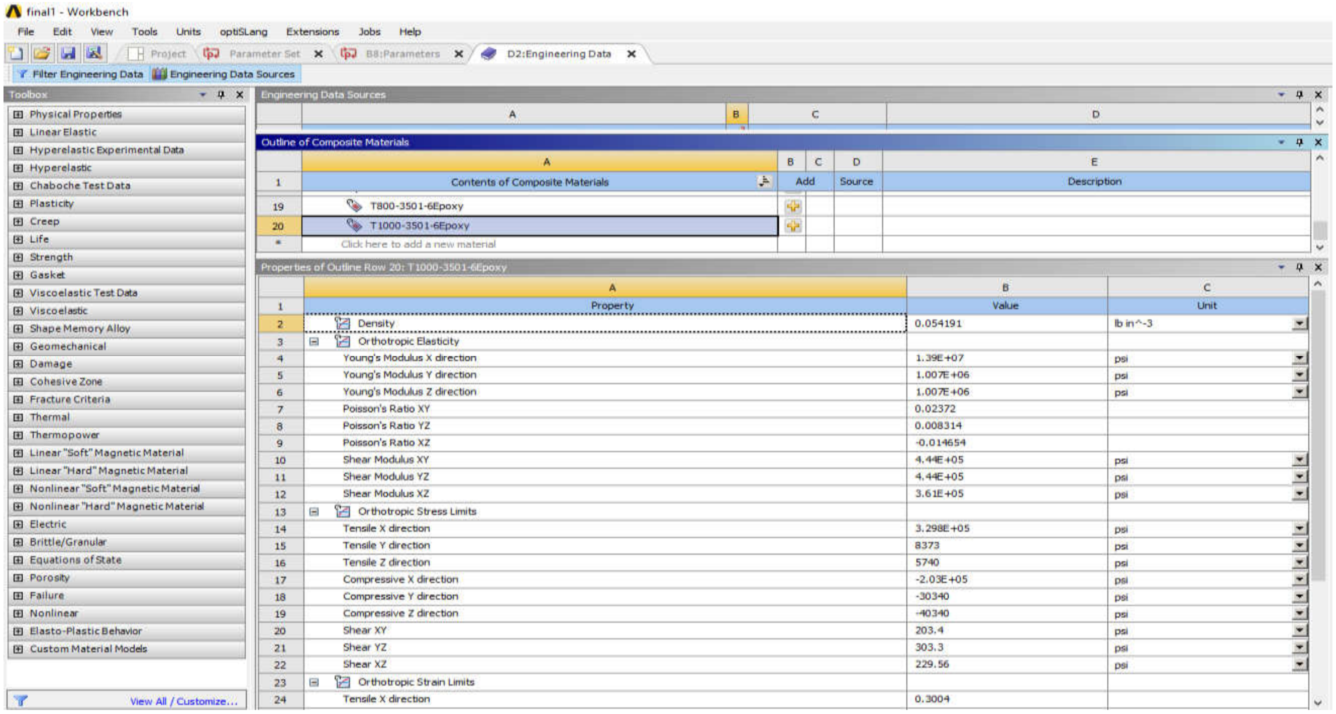


Outline of Composite Materials

	A	B	C	D	E
1	Contents of Composite Materials	Add		Source	Description
19	T800-3501-6Epoxy				
20	T1000-3501-6Epoxy				
*	Click here to add a new material				

Properties of Outline Row 19: T800-3501-6Epoxy

	A	B	C
1	Property	Value	Unit
2	Density	0.054191	lb in^-3
3	Orthotropic Elasticity		
4	Young's Modulus X direction	1.39E+07	psi
5	Young's Modulus Y direction	1.007E+06	psi
6	Young's Modulus Z direction	1.007E+06	psi
7	Poisson's Ratio XY	0.02372	
8	Poisson's Ratio YZ	0.008314	
9	Poisson's Ratio XZ	-0.014654	
10	Shear Modulus XY	4.44E+05	psi
11	Shear Modulus YZ	4.44E+05	psi
12	Shear Modulus XZ	3.61E+05	psi
13	Orthotropic Stress Limits		
14	Tensile X direction	3.298E+05	psi
15	Tensile Y direction	8373	psi
16	Tensile Z direction	5740	psi
17	Compressive X direction	-2.03E+05	psi
18	Compressive Y direction	-30340	psi
19	Compressive Z direction	-40340	psi
20	Shear XY	203.4	psi
21	Shear YZ	303.3	psi
22	Shear XZ	229.56	psi
23	Orthotropic Strain Limits		
24	Tensile X direction	0.3004	



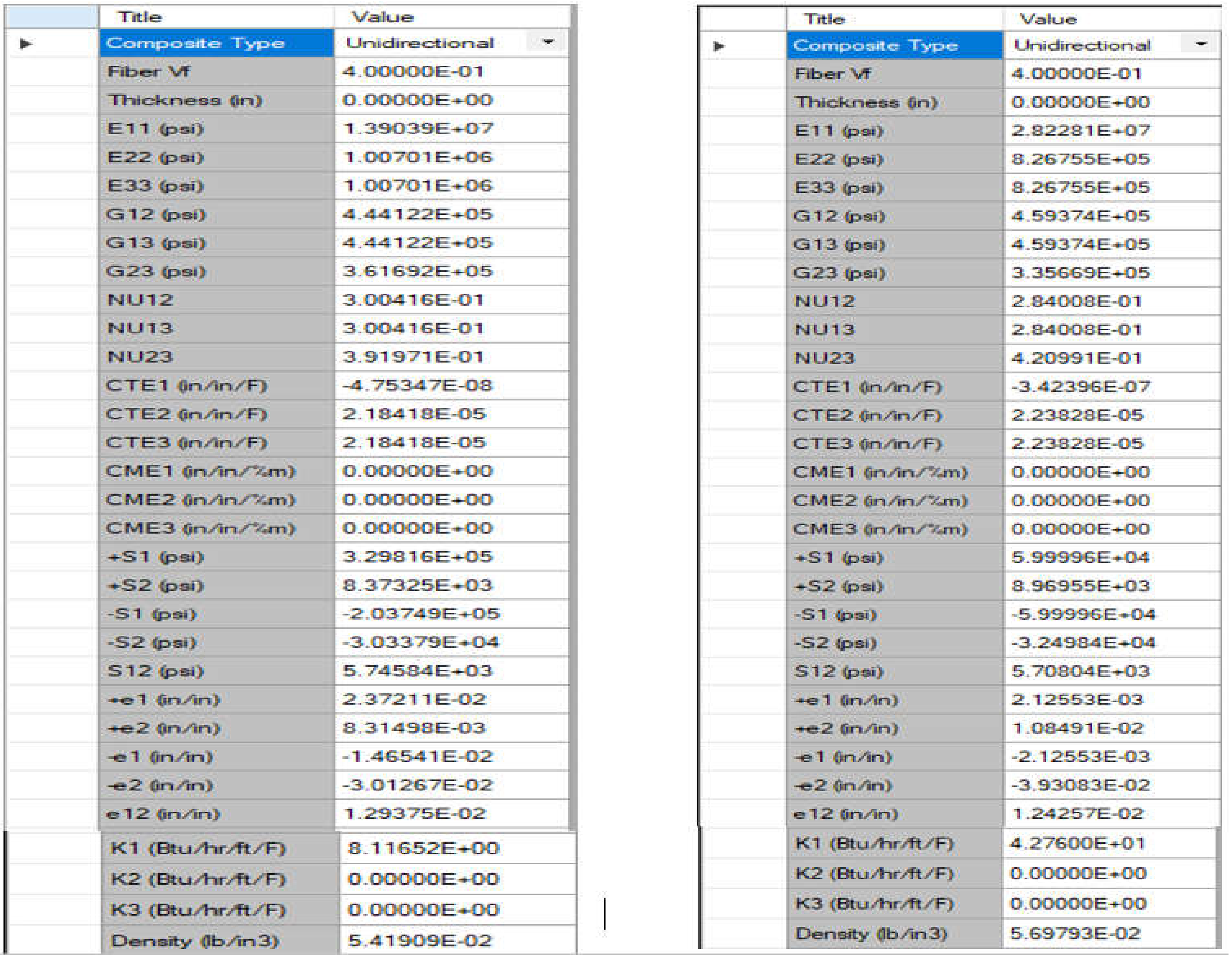
Outline of Composite Materials

	A	B	C	D	E
1	Contents of Composite Materials	Add		Source	Description
19	T800-3501-6Epoxy				
20	T1000-3501-6Epoxy				
*	Click here to add a new material				

Properties of Outline Row 20: T1000-3501-6Epoxy

	A	B	C
1	Property	Value	Unit
2	Density	0.054191	lb in^-3
3	Orthotropic Elasticity		
4	Young's Modulus X direction	1.39E+07	psi
5	Young's Modulus Y direction	1.007E+06	psi
6	Young's Modulus Z direction	1.007E+06	psi
7	Poisson's Ratio XY	0.02372	
8	Poisson's Ratio YZ	0.008314	
9	Poisson's Ratio XZ	-0.014654	
10	Shear Modulus XY	4.44E+05	psi
11	Shear Modulus YZ	4.44E+05	psi
12	Shear Modulus XZ	3.61E+05	psi
13	Orthotropic Stress Limits		
14	Tensile X direction	3.298E+05	psi
15	Tensile Y direction	8373	psi
16	Tensile Z direction	5740	psi
17	Compressive X direction	-2.03E+05	psi
18	Compressive Y direction	-30340	psi
19	Compressive Z direction	-40340	psi
20	Shear XY	203.4	psi
21	Shear YZ	303.3	psi
22	Shear XZ	229.56	psi
23	Orthotropic Strain Limits		
24	Tensile X direction	0.3004	

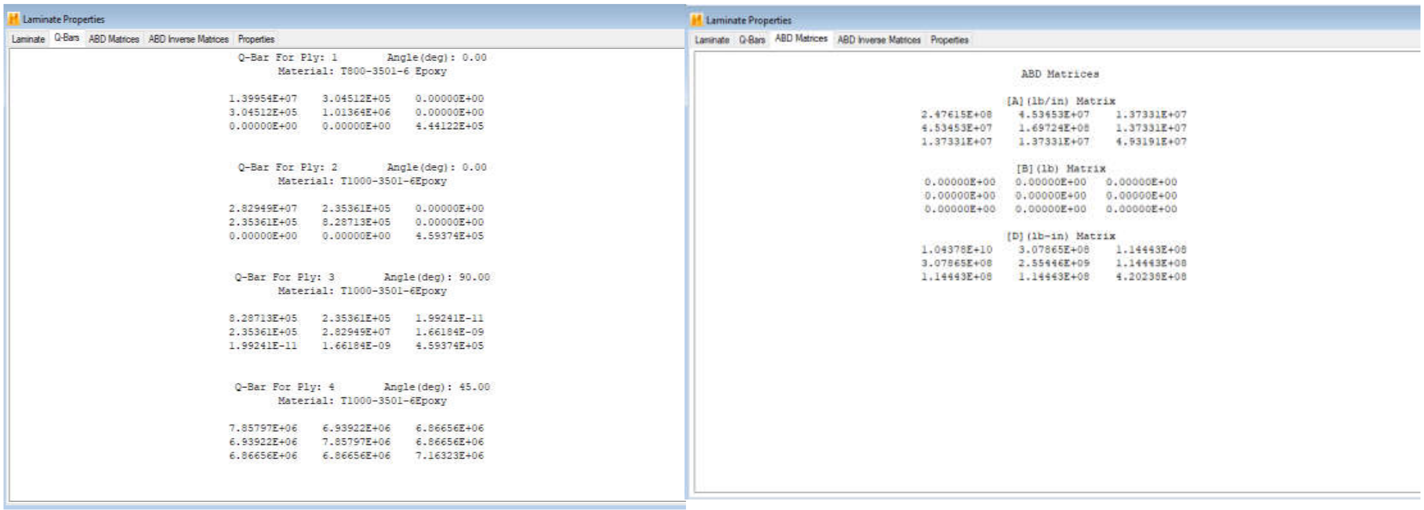
Figure 27 Defining the material properties of the T1000-3501-6 Epoxy and T800-3501-6 Epoxy lamina to the Ansys workbench



Title	Value
Composite Type	Unidirectional
Fiber Vf	4.00000E-01
Thickness (in)	0.00000E+00
E11 (psi)	1.39039E+07
E22 (psi)	1.00701E+06
E33 (psi)	1.00701E+06
G12 (psi)	4.44122E+05
G13 (psi)	4.44122E+05
G23 (psi)	3.61692E+05
NU12	3.00416E-01
NU13	3.00416E-01
NU23	3.91971E-01
CTE1 (in/in/F)	-4.75347E-08
CTE2 (in/in/F)	2.18418E-05
CTE3 (in/in/F)	2.18418E-05
CME1 (in/in/%m)	0.00000E+00
CME2 (in/in/%m)	0.00000E+00
CME3 (in/in/%m)	0.00000E+00
+S1 (psi)	3.29816E+05
+S2 (psi)	8.37325E+03
-S1 (psi)	-2.03749E+05
-S2 (psi)	-3.03379E+04
S12 (psi)	5.74584E+03
+e1 (in/in)	2.37211E-02
+e2 (in/in)	8.31498E-03
-e1 (in/in)	-1.46541E-02
-e2 (in/in)	-3.01267E-02
e12 (in/in)	1.29375E-02
K1 (Btu/hr/ft/F)	8.11652E+00
K2 (Btu/hr/ft/F)	0.00000E+00
K3 (Btu/hr/ft/F)	0.00000E+00
Density (lb/in3)	5.41909E-02

Title	Value
Composite Type	Unidirectional
Fiber Vf	4.00000E-01
Thickness (in)	0.00000E+00
E11 (psi)	2.82281E+07
E22 (psi)	8.26755E+05
E33 (psi)	8.26755E+05
G12 (psi)	4.59374E+05
G13 (psi)	4.59374E+05
G23 (psi)	3.35669E+05
NU12	2.84008E-01
NU13	2.84008E-01
NU23	4.20991E-01
CTE1 (in/in/F)	-3.42396E-07
CTE2 (in/in/F)	2.23828E-05
CTE3 (in/in/F)	2.23828E-05
CME1 (in/in/%m)	0.00000E+00
CME2 (in/in/%m)	0.00000E+00
CME3 (in/in/%m)	0.00000E+00
+S1 (psi)	5.99996E+04
+S2 (psi)	8.96955E+03
-S1 (psi)	-5.99996E+04
-S2 (psi)	-3.24984E+04
S12 (psi)	5.70804E+03
+e1 (in/in)	2.12553E-03
+e2 (in/in)	1.08491E-02
-e1 (in/in)	-2.12553E-03
-e2 (in/in)	-3.93083E-02
e12 (in/in)	1.24257E-02
K1 (Btu/hr/ft/F)	4.27600E+01
K2 (Btu/hr/ft/F)	0.00000E+00
K3 (Btu/hr/ft/F)	0.00000E+00
Density (lb/in3)	5.69793E-02

Figure 28 The properties of T1000-3501-6 Epoxy lamina and T800-3501-6 Epoxy lamina by using Autodesk composite.



```
      Q-Bar For Ply: 1          Angle(deg): 0.00
           Material: T800-3501-6 Epoxy

 1.39954E+07    3.04512E+05    0.00000E+00
 3.04512E+05    1.01364E+06    0.00000E+00
 0.00000E+00    0.00000E+00    4.44122E+05


      Q-Bar For Ply: 2          Angle(deg): 0.00
           Material: T1000-3501-6Epoxy

 2.82949E+07    2.35361E+05    0.00000E+00
 2.35361E+05    8.28713E+05    0.00000E+00
 0.00000E+00    0.00000E+00    4.59374E+05


     Q-Bar For Ply: 3          Angle(deg): 90.00
           Material: T1000-3501-6Epoxy

 8.28713E+05    2.35361E+05    1.99241E-11
 2.35361E+05    2.82949E+07    1.66184E-09
 1.99241E-11    1.66184E-09    4.59374E+05


     Q-Bar For Ply: 4          Angle(deg): 45.00
           Material: T1000-3501-6Epoxy

 7.85797E+06    6.93922E+06    6.86656E+06
 6.93922E+06    7.85797E+06    6.86656E+06
 6.86656E+06    6.86656E+06    7.16323E+06
```

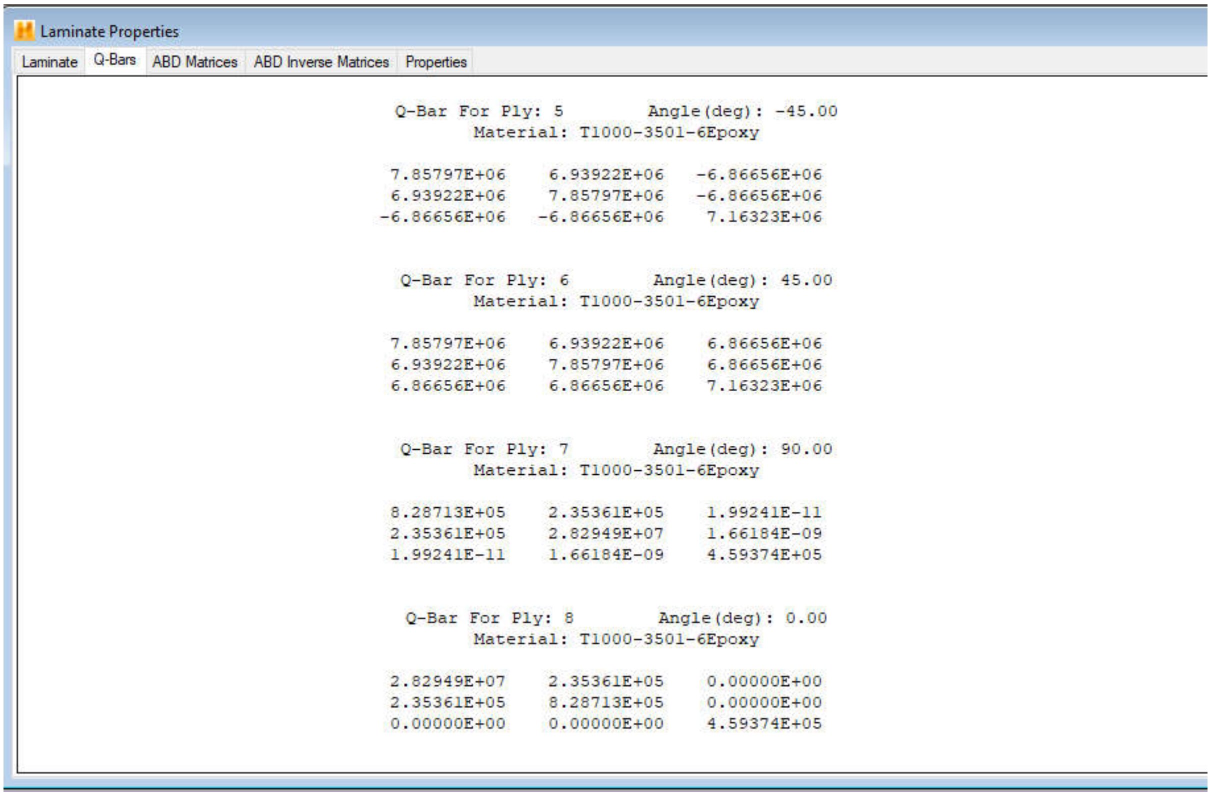
```
                 ABD Matrices

              [A](lb/in) Matrix
 2.47615E+08     4.53453E+07     1.37331E+07
 4.53453E+07     1.69724E+08     1.37331E+07
 1.37331E+07     1.37331E+07     4.93191E+07

               [B](lb) Matrix
  0.00000E+00    0.00000E+00    0.00000E+00
  0.00000E+00    0.00000E+00    0.00000E+00
  0.00000E+00    0.00000E+00    0.00000E+00

              [D](lb-in) Matrix
 1.04378E+10     3.07865E+08     1.14443E+08
 3.07865E+08     2.55446E+09     1.14443E+08
 1.14443E+08     1.14443E+08     4.20238E+08
```

Figure 29 The reduced stiffness for each ply. (Autodesk Helius Composite)



```
   Q-Bar For Ply: 5         Angle(deg): -45.00
         Material: T1000-3501-6Epoxy

  7.85797E+06    6.93922E+06   -6.86656E+06
  6.93922E+06    7.85797E+06   -6.86656E+06
 -6.86656E+06   -6.86656E+06    7.16323E+06

   Q-Bar For Ply: 6         Angle(deg): 45.00
         Material: T1000-3501-6Epoxy

  7.85797E+06    6.93922E+06    6.86656E+06
  6.93922E+06    7.85797E+06    6.86656E+06
  6.86656E+06    6.86656E+06    7.16323E+06

   Q-Bar For Ply: 7         Angle(deg): 90.00
         Material: T1000-3501-6Epoxy

  8.28713E+05    2.35361E+05    1.99241E-11
  2.35361E+05    2.82949E+07    1.66184E-09
  1.99241E-11    1.66184E-09    4.59374E+05

    Q-Bar For Ply: 8         Angle(deg): 0.00
         Material: T1000-3501-6Epoxy

  2.82949E+07    2.35361E+05    0.00000E+00
  2.35361E+05    8.28713E+05    0.00000E+00
  0.00000E+00    0.00000E+00    4.59374E+05
```

Figure 30 The ABD matrices of the lamina. (Autodesk Helius Composite)

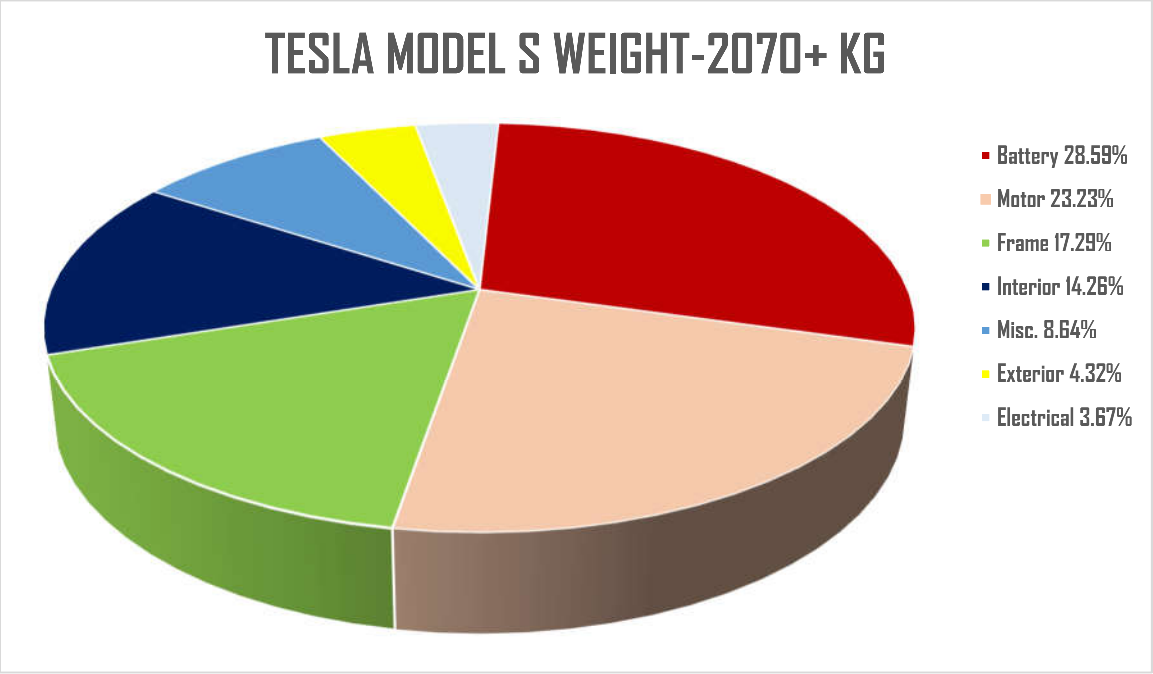


Figure 31 Breaking down the Tesla Model S weight distribution(Anon e.t. 2019)

Table 9 Weight distribution of Tesla model S electric vehicle

Tesla Model S components		**Weight(Kg)**
Battery Pack	Battery pack	596
	Aluminum Space frame	360
Motor/Drive train	Electric motor + Inverter	158
	Gear box	79
	Wheels, tires	113
	Brakes, discs, lines	54
	Air suspension	36
	Rack and pinion	23
Frame	Wiring, lighting	54
	Computer, electronics	23
	HVAC	23
Interior	Front powered seats, rears	90
	Wind shield, windows, hatch	86
	Pano glass and assembly	68
	Carpet, padding, mats	36
	Dash, trim, panels	18
Misc	Paneling, safety control units, air bags, steering wheel assembly	180
Exterior	Doors, frunk, hatch, body	90

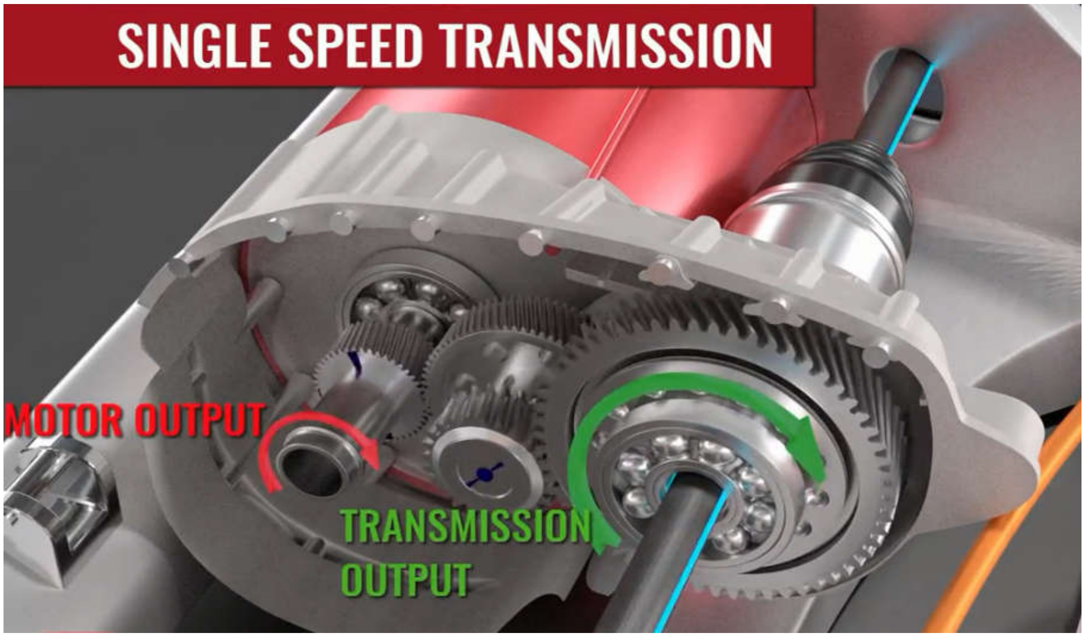
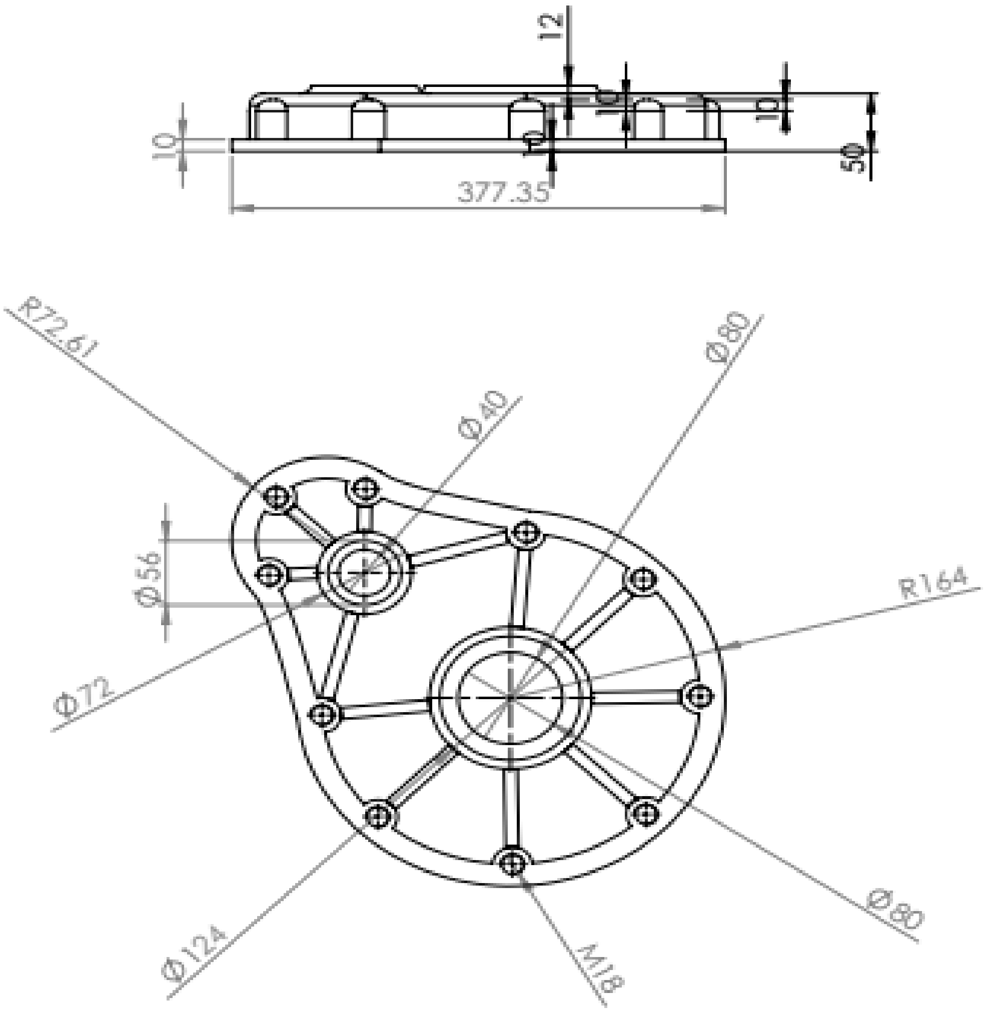


Figure 32 Tesla electric vehicle single speed transmission housing (Anon e.t 2019)



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

WEIGHT:

DWG NO. Single speed transmission housing

A4

SCALE:1:5

SHEET 1 OF 1