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Determination and Static Analysis of the Chassis Model for Electric Vehicles

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Abstract

Vehicle technology with an internal combustion engine emerged at the end of the 19th century. Although it is not very well known, the first prototype studies of the electric vehicle coincide with the same period. Today, factors such as global warming, pollution and the decrease in fossil fuel reserves accelerate the transition to electric vehicle technology. In this context, a new system structure is needed for electrically driven systems differently from traditional vehicle structures. In this study, a chassis design for an electric vehicle is carried out. While designing, the part where the battery pack will be placed has been modeled and simulated with the help of the ANSYS program to protect the battery and electronic components that are particularly sensitive to impacts. In order to be successful in abuse tests such as Crush and Crash tests specified in the regulations and standards, the material selection and design should be done correctly. In this context, the right materials are determined as a result of the researches and 3D simulations are made and crash tests are carried out in the simulation environment. As a result, tube type chassis was chosen among many chassis models and 7079 aluminum alloy was found suitable as raw material. According to the simulation results, it is seen that the design and the selected alloy are suitable.

Keywords: Electric vehicle; Battery; Electric vehicle chassis; Chassis model; Electric vehicle static analysis; Static analysis; Crash and crush.

1. INTRODUCTION

Conventional vehicles will be replaced by electric vehicles in the near future. For this reason, improvement studies on electric vehicles are of great importance. The battery pack constitutes a large part of the cost of electric vehicles. This cost rate can go up to 40%. In addition, the battery pack is highly flammable due to the lithium cells it contains. The design of the structure where the electric vehicle battery pack is located is of great importance in terms of both preventing financial losses and protecting human life [1].

The first generation electric vehicles were built on the same chassis as conventional vehicles. This limits the vehicle interior volume, which is important for passengers. The reason of using conventional vehicle chassis was to try to reduce the production costs of electric vehicles. However, today, brands only use chassis designed specifically for the use of electric vehicles. Electric vehicles have battery packs weighing between 300-700 kg. This weight is an element that will completely change the design of the vehicle. Considering that batteries are sensitive to impact and flammable, it is clearly seen how important the chassis design of electric vehicles is. The only concern in this regard is not the weight or flammability of the batteries. In addition, since electric vehicles are heavier than conventional vehicles, the designed chassis is expected to be lightweight as well as durable. There are many studies on this subject in the literature. Iterative algorithms are proposed for determining the optimal chassis design of an electric vehicle. These algorithms balance the capacity of the battery pack and the dynamic properties of the chassis. Moreover, it seeks to optimize the tradeoff between the mass of the vehicle, its energy consumption, and the travel time. The design variables of the chassis include geometrical and inertial values, as well as the characteristics of the powertrain [2].

With increasing emphasis on lightweight construction design and efficient packaging of new electric powertrains, some techniques have been developed to solve these problems. In order to overcome the difficulties encountered in battery pack designs and to provide a combined solution to these difficulties, methods for integrated topology and packaging optimization (iTOPO) have been developed to create dynamic component-structure interactions. The examples allow simplified components for battery modules and electric motors to be incorporated into the basic vehicle structure and to integrate up to 43 components simultaneously into a 3D design space. The study results show less than a 10% difference in compatibility despite the addition of various complex integration requirements (e.g., multiple geometries, packing symmetry) of the solution algorithms [3].

If a battery pack fails to meet the desired design criteria, thermal runaway, vibration or vehicle impact can lead to potential failure of lithium-ion (Li-ion) battery packs due to their high sensitivity to ambient temperature, pressure and dynamic mechanical loads. Among various factors, the safety and reliability of battery packs pose the biggest challenges in large-scale electrification of public and private transportation sectors. Simple mechanical features can be integrated into battery packaging design to minimize the probability of failure and mitigate the aforementioned safety risks. Furthermore, the key components of a robust battery pack must be closely studied and the materials have been identified to design these components and to meet their functional requirements.

To minimize battery-related problems, the following design criteria should be taken into consideration. Firstly, the movement of cells within the package should be restricted due to battery pack failures due to thermal runaway, mechanical vibrations, and vehicle impact. Restricting this movement will provide a higher degree of protection against all of them. Secondly, there are a number of mechanical design features. Effective in controlling the associated battery cell movement, i.e. cell spacers, a rigid battery mounting frame, and deformable electrode terminals. Thirdly, it is obvious that the benefits of incorporating a gas vent mechanism also prevent the development of high-pressure events in the battery pack. Additionally, the use of a hollow gas exhaust duct can provide additional dumping. [4].

In this study, a new chassis design will be realized for an electric vehicle, taking into account the placement of the battery pack. By examining the existing chassis designs in the literature, the most suitable structure for electric vehicles will be preferred. Then, the strength analysis of the designed structure will be carried out using the ANSYS program. In addition, the weight and durability of the raw material to be used in the chassis manufacturing for the electric vehicle will be determined. As a result of this examination, the most suitable alloy material for the newly selected chassis model will be determined.

2. ELECTRIC VEHICLES

The first electric vehicle in history was invented in Vermont, America by Thomas Davenport in 1835. Vehicle working principle; It was a small locomotive vehicle using two electromagnets, a pivot, and a battery. During the same period between 1832-1839, the electric vehicle was discovered by Robert Anderson in Aberdeen, Scotland [5].

The vehicles invented in those years did not have the ability to be charged. In 1897, the first electric taxis were used on the streets of New York. One of the most current and strongest brands and models at the moment is Tesla Model S Long Range. This vehicle travels 525 km in a full load [6].

EV's converts electrical energy into mechanical energy with the help of electric motors. They also store electrical energy through batteries. The engines of electric vehicles are simpler than the vehicles with internal combustion engines.

Due to the increase in fuel costs of diesel and gasoline vehicles and because of the environmental effect of petrol-engine [7], people started to be interested in electric vehicles. With the development of battery technology, people's demand for electric vehicles will increase.

Electric vehicles are very economical in terms of fuel and harmless to the environment. Since there is no exhaust emission in electric vehicles, air pollution is almost nonexistent. Electric vehicles work very quietly. On the downside, the necessary infrastructure for electric vehicles has not been established completely yet. Besides that, with full filling, it goes to limited distances and filling times are quite long compared to fuel filling time. Also, the purchase price of electric vehicles is higher than conventional vehicles.

The battery pack is the main energy storage unit of electric vehicles. The battery capacity of the vehicle directly affects the range of the vehicle. Energy recovery technologies such as regenerative braking are also used to increase the efficiency and range of electric vehicles. Figure 1 shows the general structure of an electric vehicle.

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An electric vehicle basically consists of a battery pack, motor driver, electric motor, battery management system (BMS), power distribution unit (PDU) and on board charger [8].

The battery pack is the vehicle's energy source. The electric motor is the component that converts the electrical energy into mechanical energy that enables the vehicle to move. The motor driver is an electronic component that can provide bidirectional energy flow, controlling the electric motor and sending the regenerative braking energy to the battery. BMS is the unit that monitors the SOX functions of the cells in the battery pack and decides accordingly. SOX function contains three basic information as SOC, SOF and SOH. With BMS, the battery's state of charge (SOC), functionality status (SOF) and health status (SOH) are detected. In addition, voltage imbalances between cells are detected and regulated by BMS.

The PDU is located between the battery pack and the motor driver. PDU is an enclosure fitted with multiple components incorporating various voltages, amperages, and functions connected via internal busbars, cable harnesses, and accessed externally via specific connectors.

On board charger is a circuit on the vehicle itself allows AC charging (low power). To charge at higher powers (fast charge), it is necessary to use a DC charging topology and an external charging station [9].

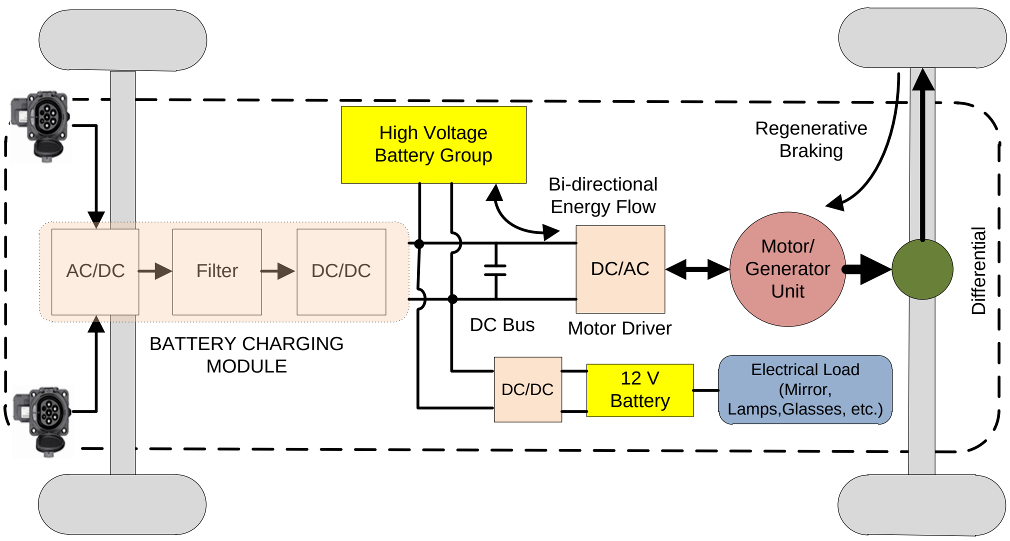

Figure 1. The general structure and energy flow of EVs [10].

2.1 Battery System in Electric Vehicles

The electric energy used to supply the motors in electric vehicles is stored in batteries. Batteries are available in a wide variety of structures. These are lead-acid battery, nickel-based battery and especially lithium battery. Lead-acid batteries are specially used in internal combustion engines as an auxiliary battery. Today, lithium-based batteries are the most commonly used batteries in electric vehicles.

Nickel-based batteries are often used in hybrid electric vehicles. Cycle life of nickel batteries can be up to 2000 cycles. However, energy and power density values are lower than lithium batteries. In addition, the memory effect found in nickel-based rechargeable batteries is not found in lithium batteries. Therefore, lithium batteries do not need to be fully charged.

Today, batteries used in electric vehicles are lithium batteries due to their high energy and power density values. Lithium batteries also have their own varieties. These are chemical compounds formed by lithium with different substances. LMO, LFP, LTO, NMC, NMO, NCA, $LiCoO_2$ chemistries are some of them [11]. These chemistries show different performances in areas such as cost, energy density, power density, reliability, safety, life span. It is necessary to choose the appropriate battery for the application. Figure 2 shows the comparison of the lithium batteries in the spider chart [12]. Generally 10 years lifetime-guarantee is given. The energy density of solid-state lithium batteries is around 400Wh/kg. However, in non-solid state batteries, this value is between 100-265 Wh/kg, 250-670 Wh/L [13]. The battery energy management system is the best way to charge an electric vehicle with a charger. In order to charge the battery in the best way, information about the state of charge, temperature, voltage and current is needed. A microprocessor is used to receive this data and evaluate it in an algorithm.

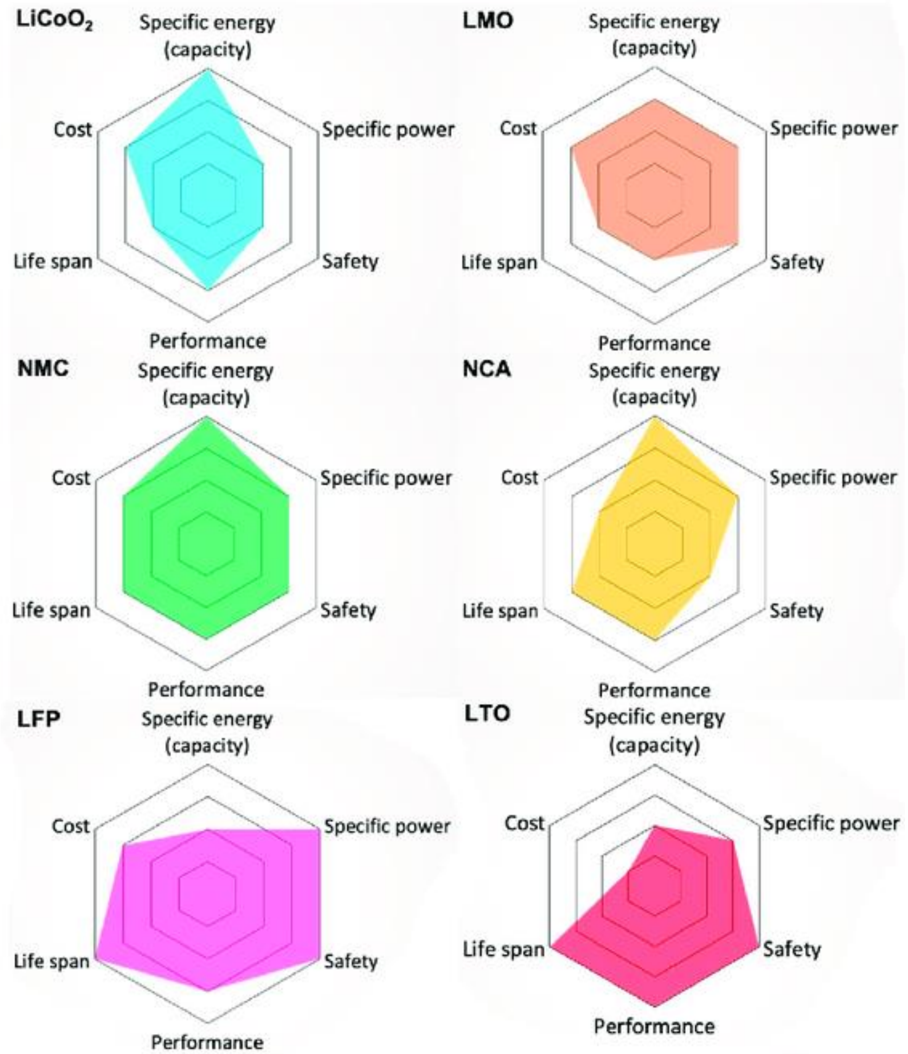

Figure 2. Comparison of various lithium battery chemistries [12].

Today, electric vehicle charging is done with the help of a cable and plug. However, there are many studies on wireless charging. In wireless charging, there is no physical connection between the vehicle and the charging station. Here, energy transfer is carried out electromagnetically. It is expected that this type of charging systems will become widespread in the near future.

In addition to these, battery pack replacement technique is also used in some countries [14]. In this system, the vehicle's battery is removed from its connections at the charging station and replaced with a charged battery. For this, the vehicle and the battery pack must be designed in accordance with this change. This process can be completed in a few minutes. However, today, the increase in vehicle variations causes battery packs to be produced in a wide variety of geometries and capacities. Since this situation will make it necessary to have battery packs belonging to tens or even hundreds of different types of vehicles at charging stations, it does not seem possible to use this technology after electric vehicles become widespread. In Figure 3 the structure of a battery pack is given.

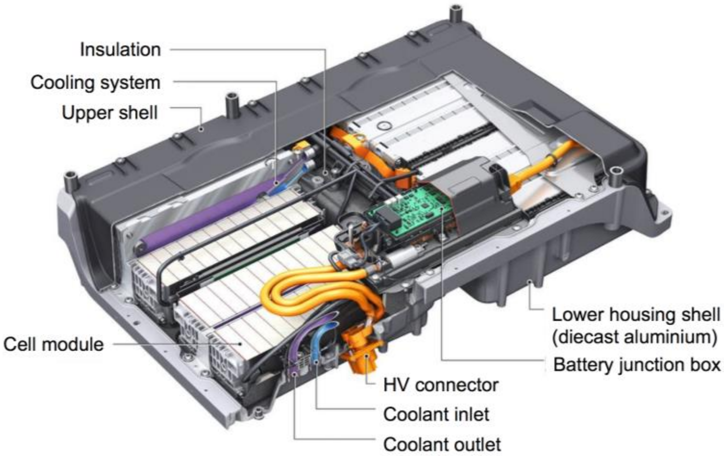

Figure 3. Die-cast aluminium battery enclosure for the Audi e-tron [15].

3. CHASSIS DESIGN AND STATIC ANALYSIS

There are many types of materials in the automotive industry. When classifying these materials, different mechanical properties of each material class are taken into account. Function, material, shape and production management should be considered as a whole. It is important that the material to be used is suitable for the design and structure of the vehicle. Some factors need to be considered when designing vehicles. Some of these can be listed as the class, volume, geometry, security level of the vehicle [16].

After these conditions are met, engineers make decisions based on the cost, environmental friendliness, quality, strength and machinability of the materials to be used. And it also checks the security values according to where it is used. In today's vehicles, 55% - 60% metal material, 18% - 25% plastic material and 7% to 15% rubber material are used. In the chassis model designed within the scope of this study, the ratio of steel alloy material is reduced to around 10-15%. The remaining 45% is designed to be aluminium alloy. The main reason for choosing this material is that electric vehicles are heavier than conventional vehicles. Today, the battery pack weight of an electric vehicle designed as a passenger car varies between 300 and 500 kg. In order to reduce this weight difference, aluminium alloys with less specific gravity are preferred.

Mass production in the world first started in the automotive industry in the first quarter of the 1900s. In this process, the chassis and bodies of the vehicles were produced together. This caused difficulties and time loss in terms of flexibility of production. Then the chassis and body were produced separately and connected to the processing through two different channels. The assembly of the chassis and other mechanical parts on it has become easier. Long time ago, vehicles were produced as ground sub-frame. It was formed by profiles connected with a 90-degree angle with the help of rivets, screws and welds. This technique is rarely used in the production of today's vehicles.

Chassis types are examined in 5 groups according to the usage patterns of the vehicles. Ladder type, space type, keel type, bathtub type, monocoque type chassis. There are many chassis designs in electric vehicles. The most commonly used chassis type of these is the metal monocoque chassis. The designed vehicle body has a bathtub-type chassis flat. As the name suggests, it got this name because its appearance and chassis structure resembles a bathtub type. In addition to being a type similar to Backbone and Ladder Frame Chassis type, it is a chassis type produced in accordance with today's modern design and production philosophy. In this design, the driver and passengers are provided with a living space, which can be called a bathtub, and in addition to this main part, the front and rear links carrying the vehicle's undercarriage are mounted to obtain the main skeleton of the vehicle. Generally, materials such as aluminium alloys or carbon fibre are used in this chassis type. Figure 4 shows the bathtub style chassis developed for electric vehicles. A large battery pool is located in the middle of the chassis. The battery pack, which is the heaviest part of the vehicle, is placed in this area and the vehicle's center of gravity is pulled down. In addition, the pack is placed in the middle of the vehicle to minimize damage to the battery pack in the event of an accident. In the realized design, the chassis part of the vehicle consists of five parts. These are the front bumper, the front suspension and engine mount, the battery pool, the rear suspension link and the rear bumper.

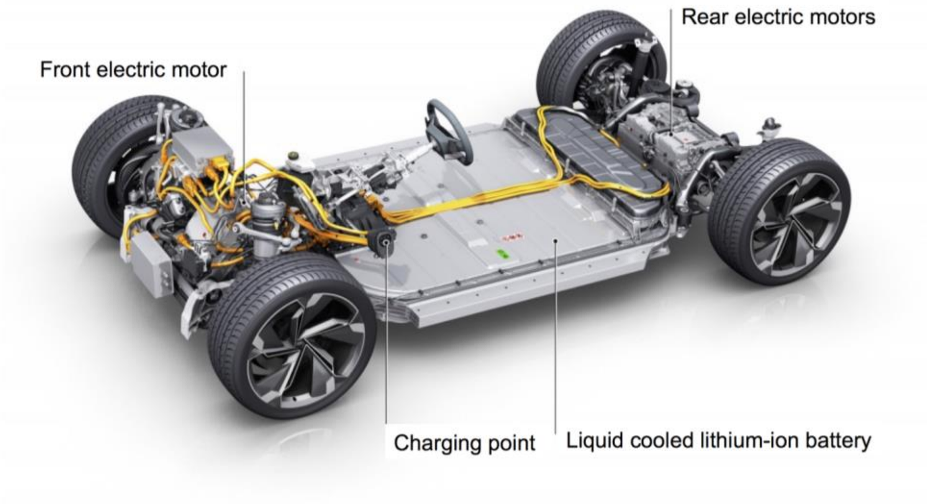

Figure 4. Bathtub style chassis developed for electric vehicles (Audi e-tron) [15].

Chassis materials of some mass production vehicles are given in Table 1. When the table is examined, aluminium is preferred in the simulations because it is the material that increased the vehicle weight the least. Due to its favourable physical properties aluminium 7079 alloy was used in the vehicle chassis. In Figure 5 and Figure 6, the general view of the designed chassis is given.

Table 1. Materials used for battery pack casing in some mass production cars [4].

Vehicle	Material used for battery case
Tesla Roadster	Aluminium
Honda Fit EV	Steel
Chevrolet Volt	Steel
Chevrolet Spark EV	Composite
BMW i3	Aluminium

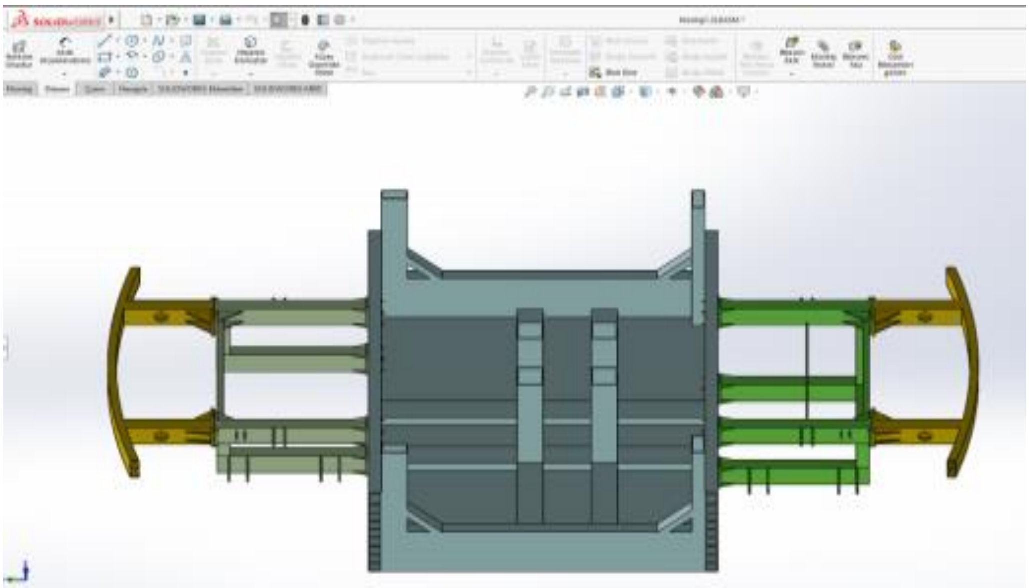

Figure 5. Tub type chassis installation view-1.

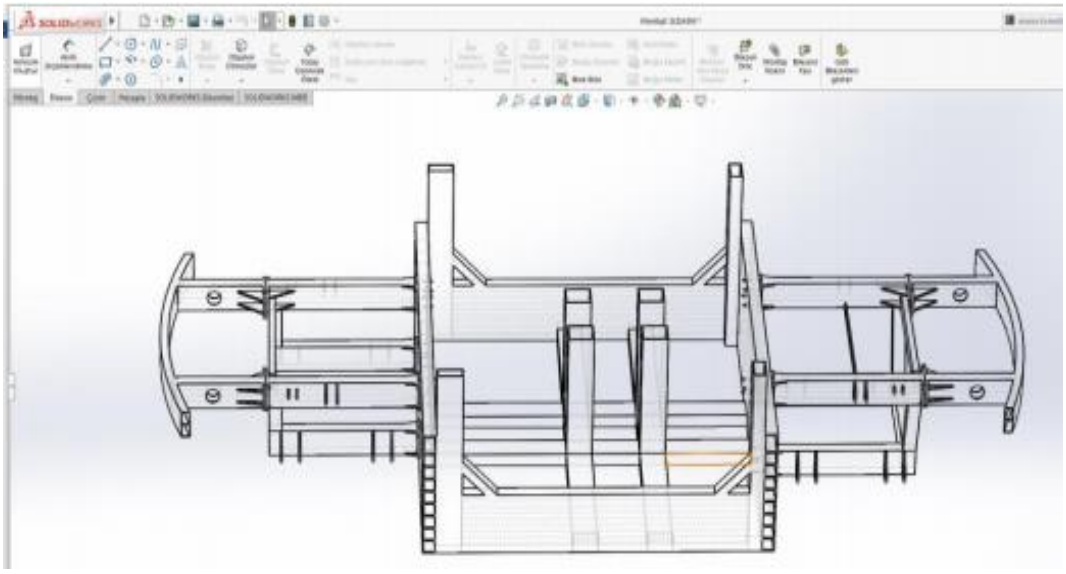

Figure 6. Tub type chassis installation view-2.

The connection types of these 5 main parts are made by welding and galvanized steel bolts. The main parts are made of aluminium 7079 alloy profiles. In this analysis, our analysis results were obtained by using the static structural command in the ANSYS program. The main topics that we create and review are; Solution Information, Equivalent Stress, Total Deformation, Maximum Principal Elastic Strain, Vector Principal Stress, Maximum Shear Elastic Strain. In Figure 7, the sections of the tub chassis, the connection and contact points of these sections and their visuals from different angles are given.

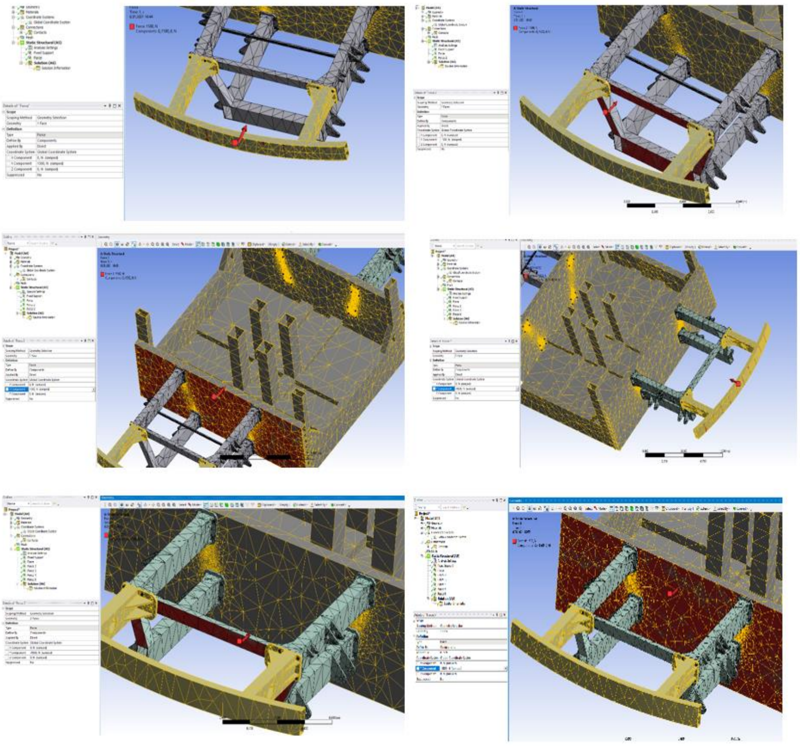

Figure 7. Tub-type chassis zone mesh images and force applied zones.

The deformations that occur in the whole system as a result of the 1500 Newton force applied from the bumper joint surfaces of the rear suspension are shown in Figure 8, and Figure 9, Figure 10. There are deformations in the front profiles, but they do not show much damage according to the force applied. In order to prevent this deformation, it is necessary to strengthen the upper part support elements. On the other hand, this means an increase in vehicle weight. Since there is not much deformation, it is not necessary to reinforce it with support.

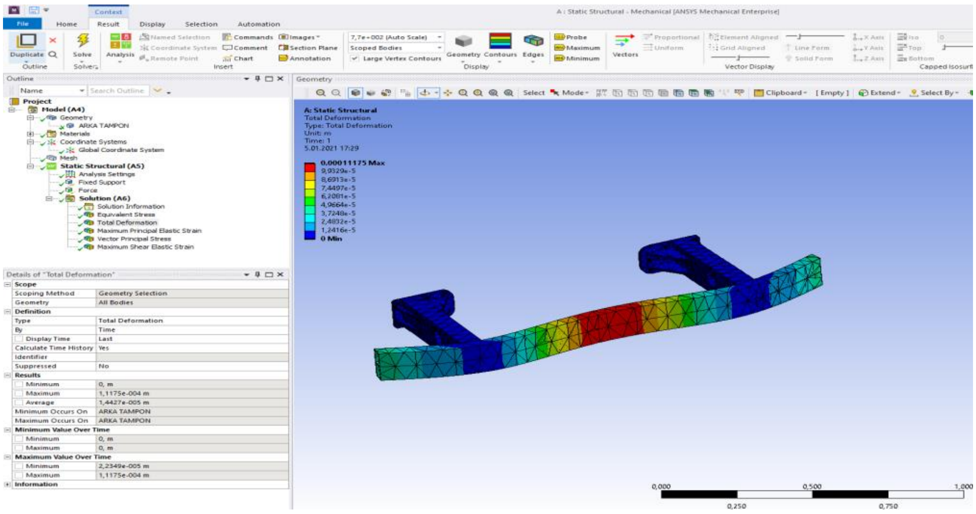

Figure 8. Front and rear bumper total deformation analysis.

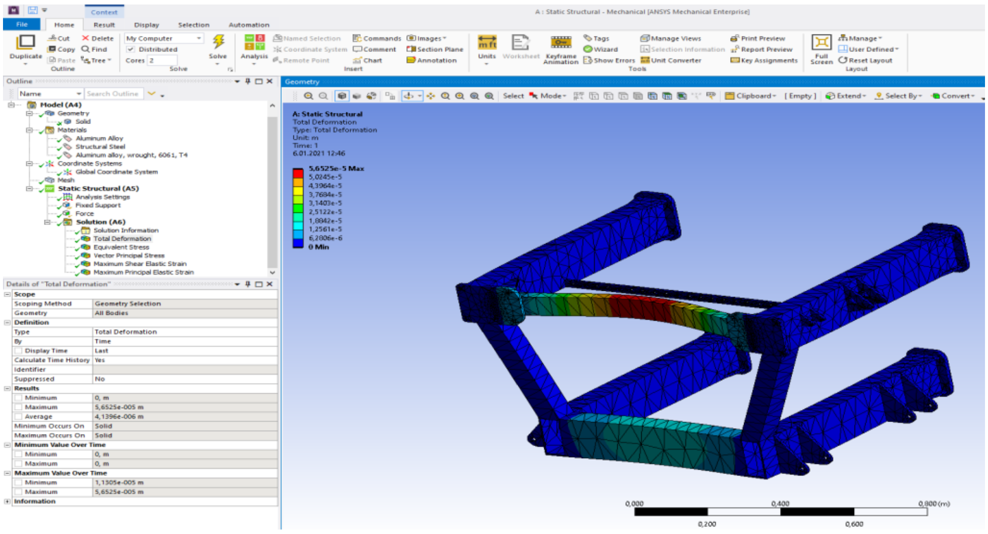

Figure 9. Total deformation analysis of front and rear suspension and motor connected part.

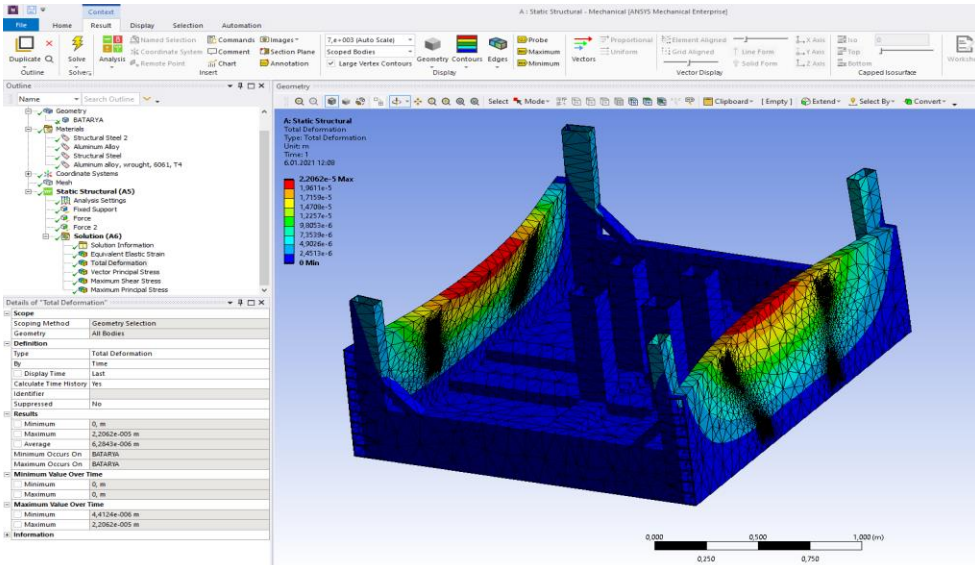

Figure 10. Battery pool total deformation analysis.

4. CONCLUSION and RECOMMENDATIONS

The biggest problems for electric vehicles are limited range and long charging times. Today, there are vehicles that can reach a range of 600 km on a single charge. However, these vehicles have large battery packs such as 90-100kWh capacity. Large battery capacity means high vehicle weight. The battery weights of these vehicles can reach 600kg. Compared to conventional vehicles, electric vehicles weigh much more. In order to compensate for this situation, the materials to be used in the vehicle chassis must be carefully selected.

In this study, the effect of the material used on the vehicle weight is revealed in a striking way. When aluminium alloy materials are used in the electric vehicle chassis design, it is seen that the extra weight from the battery can be significantly compensated.

As a result, it is seen that one of the most suitable raw materials to be used in the chassis is 7079 aluminium alloy material. Most of the chassis is made of this alloy. Considering the literature and prototypes, it is seen that the most suitable chassis model for electric vehicles is the tub-type chassis. It is seen that this chassis type is more protected against possible collision situations and is advantageous because it pulls the vehicle's center of gravity down.

Some analyses were made about the material selection and the accuracy of the designed chassis model. The static analysis module of the ANSYS program was used for these analyses. Among the results obtained, there are many data such as total deformation value, vector basic elastic stress value, equivalent elastic stress value, maximum principal stress and vector stress value. In static analysis, a force of 1500 Newtons is applied to each part surface to examine the total deformations of the parts one by one. As a result, no significant deformation occurred on the parts. It can be said that the results are quite good. It is seen that the chassis design and the aluminium 7079 material used make the electric vehicle quite light. In addition, it has been determined that the durability values are almost equal to those of steel chassis vehicles.

In the static analysis; it is seen that the chassis parts are deformed by a maximum of 9 mm against the 1500 Newton force applied to the front bumper. It has been calculated that when the same force is applied to the same type of chassis structure made of steel raw materials commonly used in conventional vehicles, a maximum deformation of 6.9 mm occurs in the chassis. There is no significant difference in the deformation values detected in two different materials under the same loads. However, when the chassis weights are compared, the weight of the chassis designed from Aluminum 7079 alloy material for the same type of structure is 408 kg, and the steel chassis weight is 1.136 kg. The difference is quite large for a vehicle. The intended design within the scope of this study has been successfully achieved.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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