

DESIGN OF LIGHTWEIGHT ELECTRIC VEHICLE AND APPLICATION FOR EFFICIENCY CHALLENGE MARATHON COMPETITION

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ABSTRACT

Many vehicle manufacturers have started up the development and production of electric vehicles reducing in response to climate change, increasing air pollution and exhaust emission problems. In addition, the most important of the difficult problems associated with electric vehicles is the high cost caused by the use of a large number of batteries and the use of a limited number of batteries negatively affects the driving distance of the car. The limitations caused by the battery problems are not only to increase the cost but also increase vehicle load because it takes up too much space and limits the usage area of the vehicle. In order to address these problems, electric vehicle manufacturers have tried to find a way to reduce the weight of the vehicle body. Therefore, to reduce weight, it would be more accurate to use light metal alloys that could get better results than using polymer composites in this study 6063 series aluminum alloy box and tube profiles were used as chassis materials, and birdcage chassis production was carried out by combining these profiles with MIG welding. After production is completed, the steering system, brake system, suspension system and other moving parts are installed on the chassis. As a result, the final weight of the vehicle was 210 kg and the negativity that may occur was prevented.

Keywords: Composite Material, Sandwich Structure, Electric Vehicle, Lightweight Chassis Design

1. INTRODUCTION

Electric vehicles convert electrical energy in a chemical form stored in the battery into kinetic energy by transmitting it to the electric motor. In recent years, these vehicles have become preferred as an environmentally friendly and economical alternative due to air pollution caused by high exhaust emission results and increasing fuel costs. One of the reasons for their affordability is that they do not require maintenance. But it should be known that the foundations of the development of these electric vehicles are based on internal combustion engines [Agrawal and Razik \(2013\)](#), [Hirsch \(2011\)](#). The first electric vehicle was produced by the British inventor Robert Anderson in 1832 and became quite common at the end

of the 19th century. at the beginning of the twentieth century, as a result of reduced fuel prices and the demand of the public for longer driving distances, internal combustion engines became more in demand. With the mass production of Henry FORD's internal combustion engine Model T in 1908, the price of internal combustion engine vehicles dropped dramatically. In 1912, electric vehicles were sold for \$ 1,750, while an internal combustion engine vehicle was sold for \$ 650. For such reasons, the era of electric vehicles was closed in the early 20th century. However, it reopened at the end of the same century as a result of changing needs. But electric vehicle manufacturers began to face the same problems again. Although battery technologies have improved in recent years compared to past technologies, batteries are still expensive and very heavy. Because of the reasons mentioned here, the battery capacity of an electric vehicle is very low and the range is not long enough. But instead of loading more batteries to make long distances, reducing the weight of the car is an alternative way that we also prefer. Especially the chassis formed by using 6063 series aluminium alloy box and tube profiles and the body made of composite material provides a significant weight reduction.

In most tests conducted in passenger vehicles today, it has been noticed that 90% of fuel or energy consumption depends on the weight of the vehicle. As a material, 6063 series aluminium is 34% lighter than steel in general and can provide the required strength. In addition, while it is similar to steel in terms of strength feature in the body made of composite material, it is generally 60% lighter than steel in weight. In short, in an electric vehicle operation, a chassis made of 6063 series aluminium with the same amount of battery and a car with a body made of composite material can go longer or use fewer batteries for the same range. The aluminium body was first introduced in 1899. At the International Motor Vehicle fair in Berlin on this date, an aluminium body was used for the first time in sports cars. Earlier, cast aluminium parts were used more often, while in the following years they were also used in doors, sides, and body. Aluminium was also used in the Ford 'Model T' vehicle produced in the 1930s. The body and other parts designed using aluminium in the car caused a 40% decrease in the overall weight of the car. Aluminium bodywork and materials were often used in luxury cars. The reason is that it reduces fuel consumption and increases the lifespan of the vehicle by increasing safety. Currently, the Model S produced by TESLA is known as an aluminium electric vehicle. Because 97% of the vehicle consists of aluminium. Much lighter and more durable than traditionally used metal alloys, aluminium's replacement of steel in the industry has created lightweight and good corrosion resistance in the vehicle. The use of light aluminium instead of cast iron and steel in vehicles can be used in parts or for all large surface area parts.

BMW, one of the leading companies in the automotive industry has developed the aluminium/steel hybrid series (E60). This improvement has been implemented in the form of an aluminium front area, steel passenger cabin and rear aluminium area. In this way, the half steel and half aluminium weight balance was achieved. Today, aluminium is the most used material in the upper part and body. The use of aluminium in automobiles has gradually increased over the last 40 years. The approximate amount, which was 39 kg (3%) in 1976, increased to 89 kg (7%) in the 1990s. While 110 kg of aluminium was used per vehicle in 1996, today it has approached 250-340 kg. Aluminium is most commonly used in engine blocks, drivetrains (transfer mechanisms) and wheels. These parts are parts produced by casting, forging and extrusion. Forged aluminium is used in A/C units and covering panels. Aluminium is also used extensively in moving parts and heat exchangers. Beams, body, and body parts are the developing areas of aluminium in the automotive sector. This is followed by pistons, suspension, brake parts and airbags.

An average welded body makes up 27% of the car and these are the main areas where aluminium can be used.

New designs were required for optimum use of aluminium in the body. In the designing process, there were two options: the birdcage system and the complete body design. As a result of the studies conducted to choose between these two options, it was decided that the birdcage system would make more sense, so this method was used. This body system is combined with a body created with composite material. Bodywork made of composite materials was first used in luxury brands in the 1980s. Today, the BMW i3, one of the most familiar electric cars, uses this bodywork method. The purpose of using composite material in these vehicles is to reduce weight and to be durable materials similar to the metal alloys traditionally used. [Matulka \(2014\)](#), [Riley and George \(2002\)](#), [Lovatt \(2008\)](#), [Chan \(2013\)](#).

The Efficiency Challenge Electric competition of the Scientific and Technological Research Council of Turkey (TUBITAK) is an efficiency-oriented competition in which the first car to complete a certain distance with minimum electricity consumption within a certain period is the winner of the race. One of the most important goals of this competition is to ensure that the car is as light as possible. Based on this situation, a birdcage chassis was used as a chassis, some mechanical parts and the body were made of 6063 series aluminium to achieve minimum weight, while the bodywork was made of composite material. Thus, the vehicle was reduced to 210 kg in total.

2. MATERYAL AND METHOD

2.1. PRODUCTION OF BIRDCAGE CHASSIS

The chassis is the main structural frame of an electric vehicle. The chassis connects all important components (including suspension and drivetrain). In addition, the main functions of the chassis are to provide space for passengers and baggage and to create a rigid frame that connects the entire assembly. A 3D solid model of the chassis has been created using Solidworks software. For the calculation of the chassis height, width, length, axle and axle distances; roll bar and chassis profiles, wall thickness, battery box, design and safety of other electronic components, seating areas for two people, etc. criteria have been taken into account. There are different chassis types, but as a result of this review, it was decided that the suitable chassis for this electric car would be a birdcage system. At the design stage, the seat and models, the moving parts of the vehicle was completely modelled in real dimensions and assembled. 4 different models of roll cage were designed and compared after the analyses were made. As a result of the crash analysis, it was determined that the cross profiles added to the chassis from the side contributed to the strength, and the designed chassis model is given [Figure 1](#).

The model uses 3 mm wall thickness 30 * 30 mm box profiles and 2 mm thick and 20 mm diameter tube profiles. It is designed to be lightweight and has an advantage by using aluminium. Continuous improvements have been made depending on the changes in the analysis and production stages in the design process. The technical specifications of this vehicle are given [Table 1](#).

Table 1

Table 1 The Technical Specifications of the Vehicle	
Type	Electric Vehicle
Dimensions(mm)	3000*1390*1175
Weight (kg)	210

Nominal Engine Power(w)	2000W-96V
Driver Rate	1
Wheel Specifications	Ø262x L59mm
Maximum speed (km/s)	84
Wheelbase	197
Width front/rear (mm)	1230/1210

Figure 1



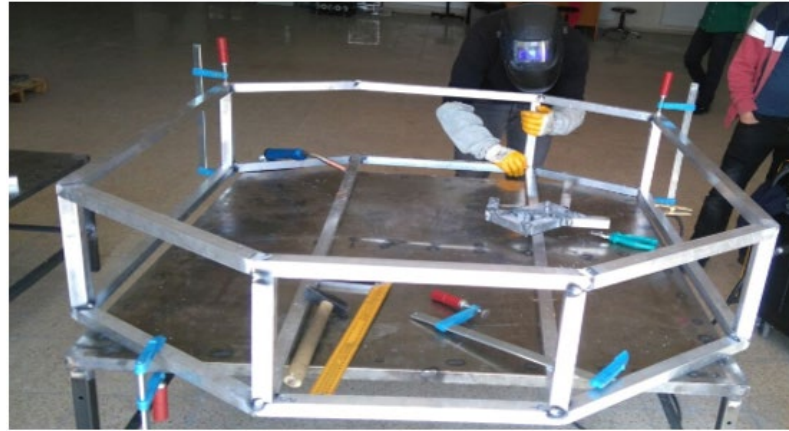
Figure 1 Design of Birdcage Chassis of the Electric Vehicle

The latest designed chassis dimensions are given in Table 2.

Table 2

Table 2 Designed Chassis Dimensions	
Spec.	Value
Weight (kg)	32,4
Length (mm)	2330
Width (mm)	1350
Height (mm)	1030
Axle Length (mm)	1361
Wheelbase (mm)	1862

6 m long 6063-T6 material profiles are cut to appropriate sizes and combined with MIG welding and 3mm thick square profile with 30x30 size was selected because of the easy installation of parts and shell and the high torsional rigidity compared to the tube profile with the same wall thickness. The production of chassis is given in [Figure 2](#).

Figure 2**Figure 2** Production of Birdcage Chassis

The sectors where AA 6063 alloy and extruded profiles are most commonly used are construction / architectural facade cladding, windows, doors, decoration, furniture, automotive, electrical/electronic and machinery manufacturing sectors. The anodic oxidation coating ability of AA 6063 aluminium alloy is also extremely good. The chemical composition of AA 6063 alloy is shown below (by weight %):

Table 3

Table 3			
Si:	0.20-0.60 %	Cr:	0.10 % max.
Mg:	0.45-0.90 %	Cu:	0.10 % max.
Fe	0.35 % max.	Mn:	0.10 % max.
Ti:	0.10 % max.		
Others: Each 0.05%, total 0.15% max.			

Mg and Si are the basic alloying elements and Fe is an impurity that needs to be controlled. Other elements such as Cr, Zn are more minor impurities. Mg and Si in aluminium form the compound Mg_2Si . The Mg_2Si compound consists of 63.4% magnesium and 36.5% silisium by weight and weight ratio is 1.73 / 1.

For extrusion manufacturers, AA 6063 alloy is of particular importance. The Mg_2Si measure in AA 6063 sets limits. Solvus, on the other hand, defines the melting limits of Mg_2Si in the aluminum solid melt. The solid solubility of the Mg_2Si compound in alloy 6063 ranges from 0.71% at 274°C to 1.42% at 552°C. 6063 alloy with Nominal composition contains 1.0% Mg_2Si , which melts in aluminium at 500°C. Mg_2Si , which is higher than this ratio, reduces its solubility due to the excess magnesium. The amount of silicon in excess of Mg_2Si and the classical level of iron slightly reduce the solubility of Mg_2Si

A typical 6063-T6 Aluminum extrusion product consists of microscopic amounts of aluminium solid solution matrix an $AlFeSi$ and Mg_2Si precipitate particles. In micrography, it seems that the two phases are important. Aluminium solid solution white background and an $AlFeSi$ gray particles. The $AlFeSi$ particles are sorted according to the direction of extrusion. Most of these particles are round-cornered. However, some are dispersed during the extrusion process. Sparse, Mg_2Si

black, circled particles can be seen in the ordinary structure. Especially in compounds with high Mg and Si. Elmarakbi (2013), Gibson (2012), Daniel et al (2002), Carlsson and Kardomateas (2011), Diabgroup (2012), Baştürk and Tanoğlu (2013).

2.2. DESIGN LIMITATIONS FOR ELECTRIC CAR CHASSIS

The application of the aluminium 6063 series in urban concept electric vehicles and the space birdcage design produced in this study were used to form a vehicle chassis according to the technical drawings of the vehicle. Kahramanmaraş Sütçü İmam University designed and produced an urban concept vehicle in Kahramanmaraş, Turkey. The car has 32.4 kg chassis and two seats and participated in the Efficiency Challenge electric vehicle competition organized by TÜBİTAK (The Scientific and Technological Research Council of Turkey) in Kocaeli. The technical drawing of the vehicle is shown in the figure below. In the competition, teams competed to achieve minimum energy consumption at a certain distance.

Figure 3

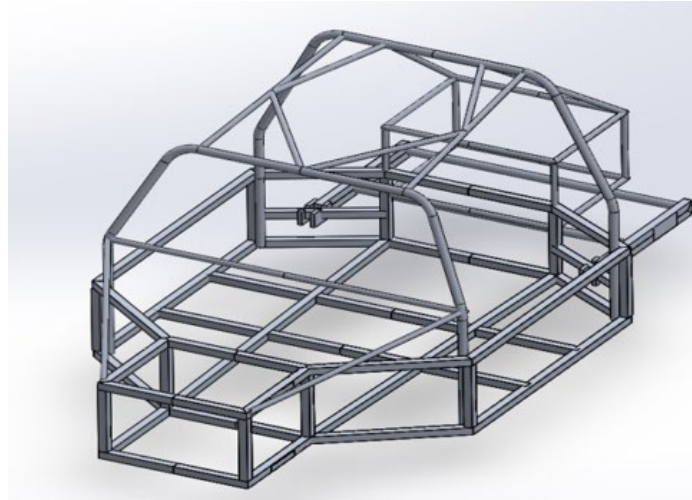
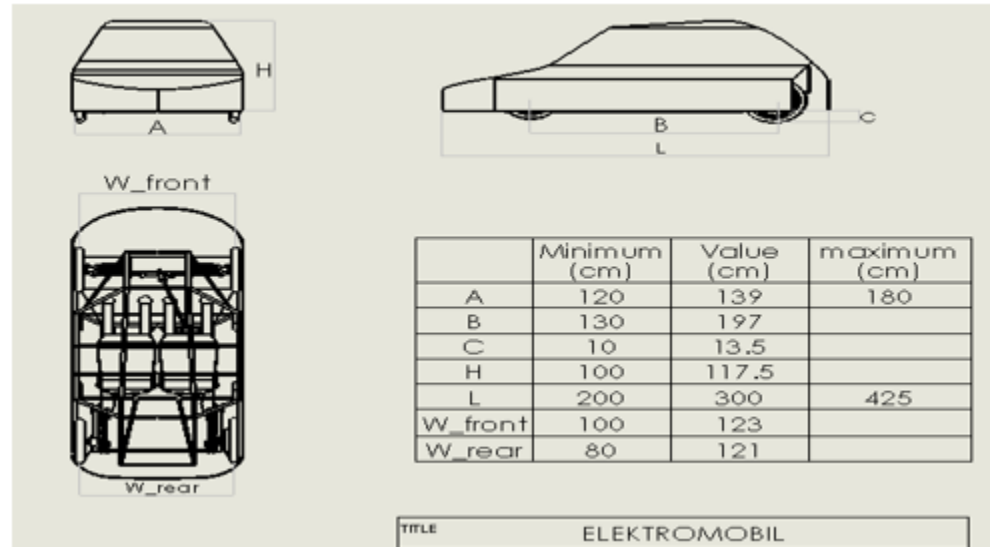


Figure 3 A 3D Production Model of Birdcage Chassis of the Electric Vehicle

Almost most of the vehicles are equipped with commercially available electric motors and powertrains, but the weight of the vehicle depends on the research work of the teams and the choice of materials. Therefore, the aluminium structures of the 6063 series offer the best alternatives for weight loss. As can be seen, all parts are made of 6063 series aluminium structures and composite materials. It not only provides a remarkable amount of weight reduction but also provides high mechanical strength due to its very high flexural stiffness.

Figure 4**Figure 4** Final Dimensions of the Electric Vehicle

Grooves and holes in the side body were used to mount the wheel shaft, suspension system, steering system, and related metal alloy brackets. The vertically mounted panel, made from the main material, separates the driver's compartment from electrical devices such as the battery, engine driver and other electronic circuit boards placed at the rear of the vehicle, and acts as both a flame screen and a roll bar. In this way, it provides additional security. In [Figure 4](#), is shown final dimensions of the electric vehicle

Figure 5**Figure 5** The View of Composite Materials at the Bottom of Birdcage Chassis

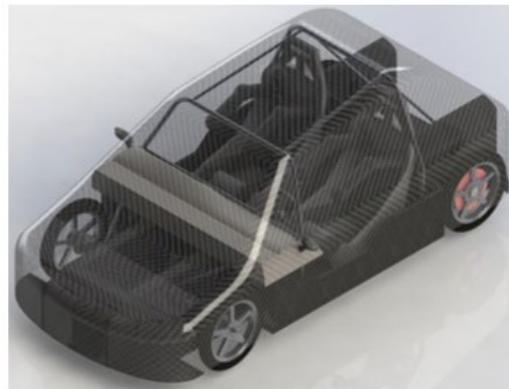
If the chassis were made of steel with old technology, it would be 95 kg, and it would be impossible to manufacture with satisfactory results with the rapid growth of material technology. Now using the birdcage chassis design and aluminium material, the weight of the chassis of the existing electric vehicle with two seats was achieved as just 32.4 kg. Therefore, the construction of the vehicle chassis using 6063 series aluminium has resulted in a significant weight reduction compared to

our previous experience. In [Figure 5](#). is shown the view of composite materials at the bottom of birdcage chassis.

3. RESULTS AND DISCUSSIONS

In this study, the vehicle chassis was designed using birdcage chassis and aluminium material structures. Many aluminium panels, pipes and ducts are manufactured. The parts were successfully assembled to build the chassis of the vehicle, resulting in a significant weight reduction. Because when the chassis is made of aluminium, a weight reduction of about 49% is achieved. Aluminium chassis can achieve an 82% weight drop compared to steel chassis. The reduction in the weight of the vehicles also made the cars environmentally friendly, providing higher performance and longer driving distance with less energy consumption under the same battery capacity. The produced two-seat vehicle participated in the Efficiency Challenge competition organized by TUBITAK in Kocaeli. The vehicle completed a 60 km track in 65 minutes with an energy consumption of 1445 kW at the 2021 TUBITAK race. In these competitions, we won the best technical design award and also received awards as the sixth vehicle in productivity in 2018, the 7th in the productivity field and the 3rd fastest vehicle in 2021. In [Figure 6](#). is shown the produced lightweight concept electric vehicles (a) Final 2-seated Design and (b) The electric Vehicle at The Efficiency Challenge Competition Organized by TUBITAK.

Figure 6



(a)



(b)

Figure 6 The produced lightweight Concept Electric Vehicles (a) Final 2-Seated Design and (b) The Electric Vehicle at the Efficiency Challenge Competition Organized by TUBITAK

CONFLICT OF INTERESTS

None.

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None.

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