

Research Article

Optimum Material Selection for Battery Carrier System in Electric Buses

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(First received October 12, 2023 and in final form December 23, 2023)

Reference: Özlü, Ö., İmren, R., Kılınç, S., Şimşir, Ö. Optimum Material Selection for Battery Carrier System in Electric Buses. The European Journal of Research and Development, 3(4), 205-217.

Abstract

In countries around the world, with the increase in human population, the number of vehicles used in traffic has also increased at this rate. Within the scope of the Green Deal, the European Union has started to encourage countries to use public transportation in order to reduce air pollution and carbon emissions. Decreasing fossil fuel reserves make energy supply difficult. Vehicle exhaust emissions increase air pollution day by day. In this period when global warming is increasing in the global world, the transition to zero-emission electric vehicle production in public transportation has begun. Electric buses provide a clean, efficient and sustainable transportation alternative to diesel vehicles. One of the most important issues to consider in electric buses is the SoC (State of Charge) value of the battery, which is the range it will get from 0 to 100 when fully charged. Reducing weight in electric buses is one of the factors that increases the range value. For this reason, in the study, finite element analysis was carried out on the currently used battery carrier frame material EN10025 S355JR, alternatively aluminium 6061-T6, aluminium 7075-T6 and carbon fiber reinforced PEEK materials to lighten the vehicle weight. As a result of the analysis, 65.54% and 73.07% lightness were achieved with aluminium 6061-T6 and carbon fiber reinforced PEEK materials, respectively. When the analysis results were compared in terms of cost, manufacturability and lifetime, the most suitability for mass production was evaluated.

Keywords: Battery carrier system, Electric bus, Lightweighting, Carbon emissions, Material selection

1. Introduction

In the history of human being, with the beginning of automotive technology and the increasing civilization, bus technology has also become a part of world history. As urban populations increase, making transportation a basic necessity, calls for the promotion of public transportation have emerged due to the deterioration of air quality in response to the growing demand for motor vehicle usage. According to a research by the European Commission, Turkey is the country with the highest usage of public transportation vehicles (Steer Davies Gleave 2009). In times when fuel prices are rising, fuel savings in all types of vehicles will primarily result in positive outcomes for the environment in terms of cost.

The European Union has designated the fight against climate change as one of the UN Sustainable Development Goals. Targets for 2030 include a 55% reduction in greenhouse gas emissions, a 32% increase in energy efficiency, and a net zero carbon emissions target for 2050 [1]. Electric vehicles (EVs) have become the top priority among leading automotive manufacturers worldwide due to their efficiency, cleanliness, and sustainability compared to traditional fossil fuel vehicles [2]. Carbon emissions are a priority for bus manufacturers to achieve the net zero emission target. Efforts continue to address unexpected long charging times, low passenger thermal comfort resulting from energy savings, and uncertainties and cost reduction related to operational features and optimization challenges of mixed bus fleets.

Therefore, when purchasing new vehicles, it has become crucial to have prior information about the battery pack size and specifications, vehicle weight (including passengers), and operational features of passenger comfort components of auxiliary systems [3]. Battery systems account for 20% of the total weight of electric vehicles produced to protect the environment and reduce carbon emissions [4]. Weight reductions resulting from technological advancements provide a 10% fuel savings [5]. Throughout the operational life of passenger vehicles, approximately 86% of the energy they consume is for carrying their own weight and passengers [6]. Every kilogram reduced from the vehicle means an additional 3 kilometers of travel on a single charge [7]. Therefore, the selection of materials for use in electric vehicles is crucial. Nandhakumar and colleagues analyzed the electric bus chassis frame, currently made of steel for lightweighting, by replacing it

with aluminum 6061-T6 and aluminum 7075-T6 materials. As a result, they achieved lightness of 65.61% and 64.33%, respectively [8].

Taking into account the areas of use, based on FEA analysis results, they observed that the aluminum 7075-T6 frame exhibited less stress and deformation, and they determined it as the most suitable material [8]. The selected materials should be environmentally friendly, durable, and suitable for mass production. The use of lightweight materials has been observed to contribute to the improvement of acceleration and driving performance of the vehicle, as well as the reduction of problems such as vibration and noise [9].

In this study, in addition to the studies in the literature, lightweighting has been aimed to increase the range of the battery from 0 to 100% State of Charge (SoC) value in electric buses. FEA analysis was performed using the traditional ST52 steel, currently used as the battery carrier frame material on the vehicle roof, as well as aluminum 6061-T6, aluminum 7075-T6, and carbon fiber-reinforced PEEK materials. The obtained results were compared in terms of the bus's cost, manufacturability, and service life, and their manufacturability in mass production was evaluated.

2. Materials and Methods

2.1. Structure of Bus Frame and Battery

In studies investigating the impact of battery placement on driving comfort within a vehicle, some have highlighted the importance of positioning the battery at the center of the vehicle to enhance ride quality in passive suspension systems [10]. Conversely, a different study has suggested that, in the case of active suspension systems, it is appropriate to consider the weight center for optimal battery placement [11]. Another study supporting the validity of these findings has argued that, when determining battery placements, the road profile that the vehicle is expected to traverse should also be taken into account [12].

In electric vehicles, the typical locations for battery placement are generally the rear section and the roof. Due to the presence of the motor in the rear part of buses, suitable space is often not available, making roofs a preferred choice for battery systems. Another reason for choosing the roof for the battery system is the ease of operation due to the spacious working area. Since batteries are heavy equipment, the profiles supporting this system are expected to withstand the stresses associated with its weight.

In conclusion, the positioning of batteries in electric buses requires considerations of factors such as suspension system type, weight distribution, and ease of operation. Roofs are often preferred for battery systems in buses due to both structural and operational considerations, with the spacious working area and the need for accommodating the motor in the rear part of the bus being key factors.

2.2. Finite Element Model

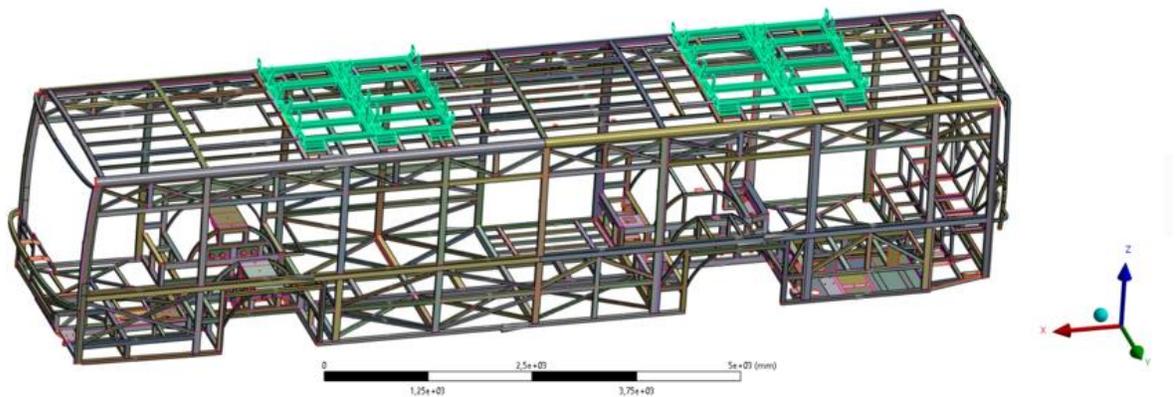


Figure 1: Location of battery carriers on bus structure

Finite Element Analysis (FEA) was performed using the Ansys 2023 R1 program. As shown in Figure 1, the battery carrier systems were defined and positioned on the vehicle roof. The mesh structure was created using 10 mm hexa elements. Due to geometrical conditions, tetra mesh with 6 elements was utilized. The aspect ratio determining the mesh quality was calculated as 1.26. The mesh consisted of 849,330 elements, and the number of nodes was determined as 768,340. Details and elements that could complicate the analysis without significantly affecting the results were simplified to facilitate the solution in the analysis program. The solution was based on the Von Mises yield criterion. Figure 2 illustrates the loads on the vehicle (Battery, battery cooler, air conditioning, Power Distribution Unit (PDU) defined for the analysis.

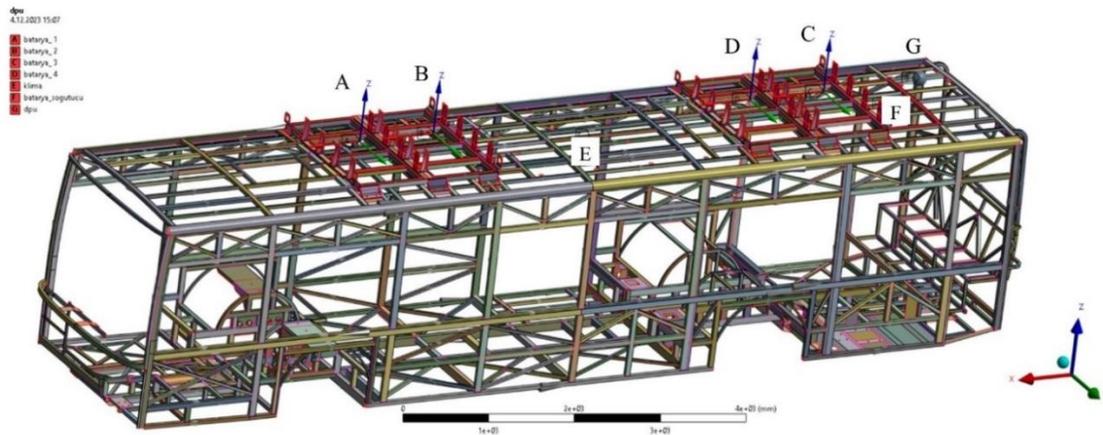


Figure 2: Defining of loads on the bus structure

As indicated in the figure, four battery loads (A, B, C, D) have been placed on the vehicle roof. E represents the load of the air conditioning unit, and F represents the load of the battery cooler. G shows the loads as the Power Distribution Unit (PDU). The weight of each battery (1 unit) is 750 kg. The weight of the air conditioning unit is 250 kg, the battery cooler weights 140 kg, and the Power Distribution Unit has been defined with a weight of 20 kg.

2.3. Material Selection

Four different material choices have been made for the finite element analysis of the battery carrier system. The materials were selected from the most commonly used materials in the automotive sector. For the analysis, St 52 was chosen as the material currently used in bus chassis, and 6061-T6 and 7075-T6 (heat-treated) high-strength-to-weight ratio aluminum alloys were selected. Additionally, a material with a high impact on vehicle lightweighting, namely 30% carbon fiber-reinforced PEEK (Polyether Ether Ketone), was included. Table 1 provides the chemical analyses for St 52, Al 6061-T6, and Al 7075-T6.

Table 1: Chemical Analysis of Materials [8][12]

Material	C	P	S	Mn	Si	Cu	Al	Al	
St 52	0,20	1,035	0,035	1,60	0,55	0,25-0,40	0,020	0,020	
Material	Zn	Mn	Si	Mg	Ti	Cr	Cu	Fe	Al
6061-T6	0,42	0,28	0,70	0,86	0,14	0,069	0,27	0,209	97,8
7075-T6	5,70	0,07	0,11	2,40	0,05	0,190	1,50	0,210	89,7

PEEK (Polyether Ether Ketone) polymer is a thermoplastic material characterized by its semi-crystalline structure and high stability. It retains its properties in temperatures ranging from -60 °C to 260 °C, exhibiting excellent thermal characteristics [13]. A composite material has been created by incorporating 30% carbon fiber into 70% PEEK, enhancing its overall properties with the addition of reinforcing fibers. This composite configuration is expected to provide improved strength and stiffness, making it a favorable choice for applications where both high-performance and thermal stability are essential considerations.

Table 2: Mechanical Properties of Materials

Material Properties	St 52 (S355JR)	Aluminium 6061-T6 [15]	Aluminium 7075-T6 [15]	Carbon fiber Reinforced PEEK [16]
Yield Strength (MPa)	355-500	276	503	-
Tensile Strength (MPa)	500-650	310	560	144
Young Modulus (GPa)	210	68.9	71.7	9.2
Hardness	200-220-Brinell	95-Brinell	150-Brinell	102 – Rocwell B
Melting Temperature (°C)	1420-1460	582-652	477-635	340
Density (g/cm ³)	7.85	2.70	2.81	1.40

3. Results

In finite element analysis, total weight values of batteries have also been calculated for lightweighting studies in buses. The total weight of two battery carriers created with St52 material is 406.23 kg. When produced with Aluminum 6061-T6, the weight of the battery carrier is 140.4 kg, and with aluminum 7075-T6, it is 146.12 kg. When the battery carrier material is defined as Carbon Fiber Reinforced PEEK, the weight is observed to be 109.4 kg. Weight reduction has been achieved in the bus roof in the specified proportions with the change of material.

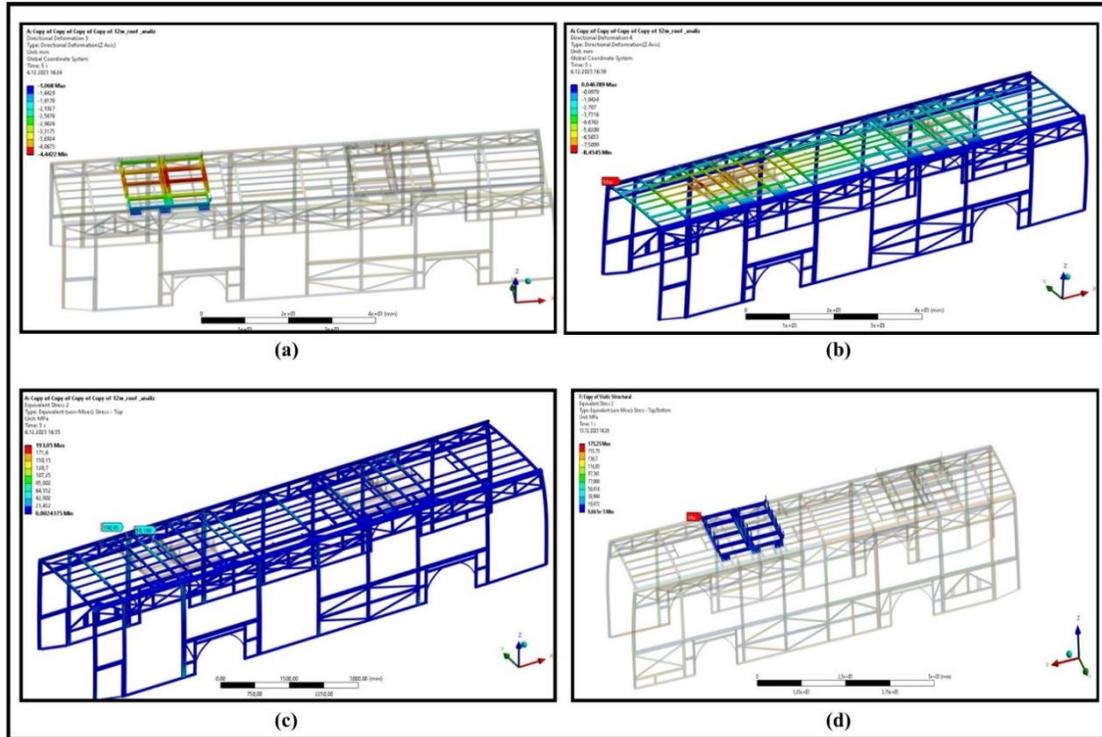


Figure 3: In FEA Analysis Performed with S355JR, (a) Directional Deformation on Battery Carrier, (b) Directional Deformation on Roof Structure of Bus, (c) Equivalent Stress on Roof Structure of Bus, (d) Equivalent Stress on Battery Carrier

The roof profile material used in manufacturing is defined as St52 (S355JR), and in the conducted analyses, changes have been made only to the materials of the battery carriers. The results of the finite element analysis are presented in Figure 3. In Figure 3.a, the deformation on the battery carrier is measured at 4.44 mm, and the deformation is concentrated in the central parts of the battery carrier skeleton. In Figure 3.b, the axial deformation on the geometry of a 12-meter electric bus roof is calculated as 8.454 mm, and it is observed to be concentrated in the region where the battery cooler, 2 batteries, and the air conditioner are located. In Figure 3.c, the maximum stress occurring on the bus roof is 193.05 MPa, and it is identified to occur on the corner bracket connecting the roof and side profiles. On the battery carrier (Figure 3.d), the maximum equivalent stress is 175.25 MPa, occurring at the points where the battery is connected to the bus skeleton.

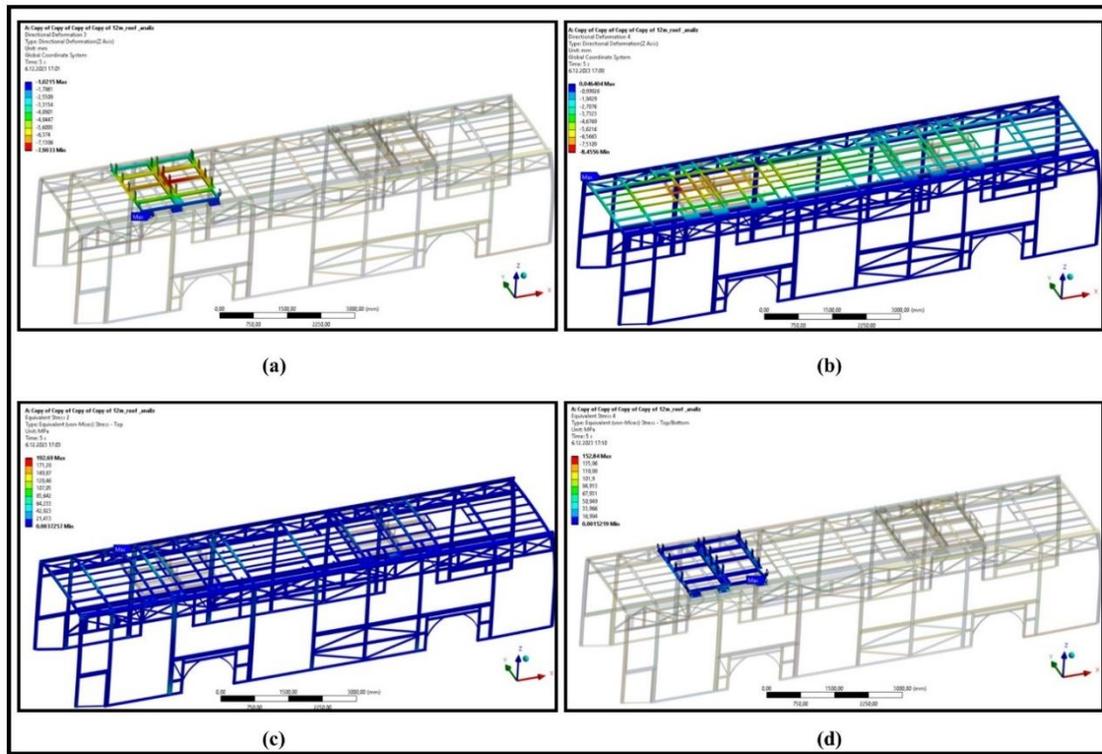


Figure 4: In FEA Analysis Performed with A6061-T6, (a) Directional Deformation on Battery Carrier, (b) Directional Deformation on Roof Structure of Bus, (c) Equivalent Stress on Roof Structure of Bus, (d) Equivalent Stress on Battery Carrier

The material of the battery carriers has been changed to aluminum 6061-T6, and an analysis has been conducted. The results of the finite element analysis are presented in Figure 4. In Figure 4.a, the deformation on the battery carrier is measured at 7.903 mm, and the deformation is concentrated in the middle and front parts of the battery carrier skeleton due to the positions of the loads. This concentration is caused by the close positioning of the battery cooler, two batteries, and the air conditioner. In Figure 4.b, the axial deformation on the roof geometry is calculated as 8.455 mm. In Figure 4.c, the maximum stress occurring on the bus roof is 192.69 MPa and is observed on the corner brackets connecting the roof with the side profiles where the battery is located. On the battery carrier (Figure 4.d), the maximum equivalent stress is 152.84 MPa, occurring at the points where the battery is connected to the bus skeleton.

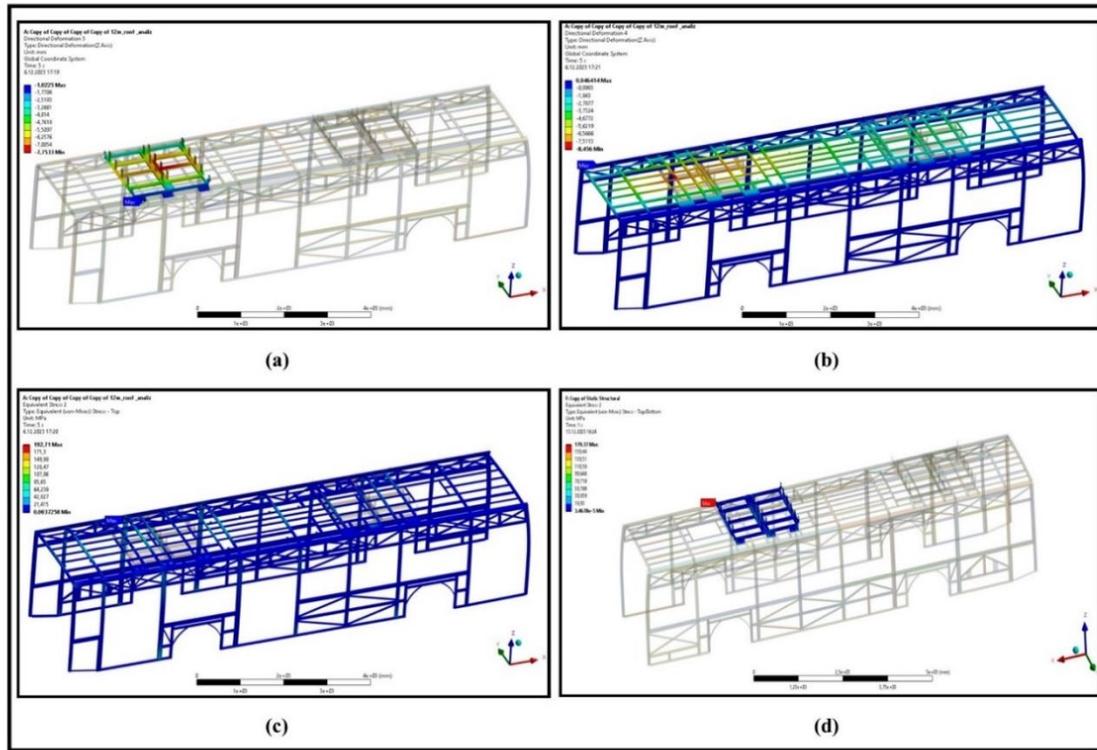


Figure 5: In FEA analysis performed with A7075-T6, (a) Directional deformation on battery carrier, (b) Directional deformation on roof structure of bus, (c) Equivalent stress on roof structure of bus, (d) Equivalent stress on battery carrier

The finite element analysis results for the battery carriers with the material specified as aluminum 7075-T6 are provided below. In Figure 5.a, the deformation on the battery carrier skeleton is measured at 7.753 mm. As previously mentioned, the areas where deformation is observed are regions with high load intensity. In Figure 5.b, the axial deformation on the roof geometry is found to be 8.456 mm. It is observed that the deformation occurs at points on the roof where the batteries, battery cooler, and air conditioner are located. In Figure 5.c, the maximum stress occurring on the bus roof is 192.71 MPa, and it is observed on the corner brackets connecting the roof with the side profiles where the battery is located. Lower stresses are observed on the profiles where the battery is positioned compared to the corner brackets. On the battery carrier (Figure 5.d), the maximum equivalent stress is 179.37 MPa, occurring at the points where the battery is connected to the bus skeleton.

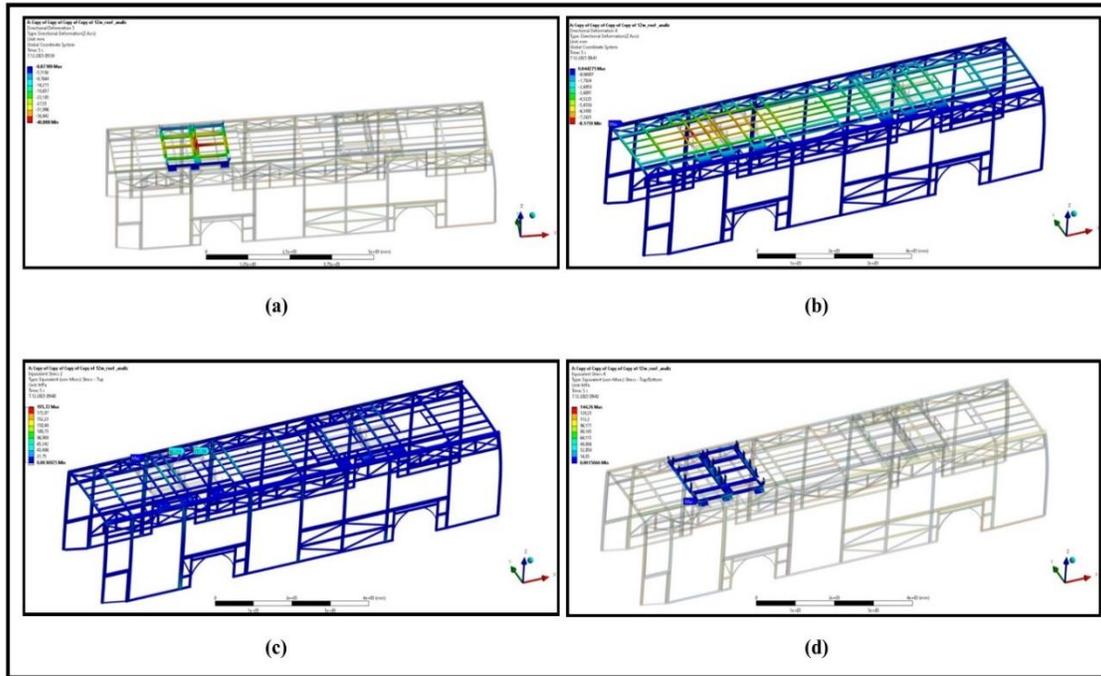


Figure 6: In FEA analysis performed with %30 Carbon fiber reinforced PEEK, (a) Directional deformation on battery carrier, (b) Directional deformation on roof structure of bus, (c) Equivalent stress on roof structure of bus, (d) Equivalent stress on battery carrier

The finite element analysis has been conducted using another alternative material we specified for the battery carriers, which is 30% carbon fiber-reinforced PEEK (Polyether Ether Ketone). As seen in Figure 6.a, the deformation on the battery carrier skeleton is measured at 40.88 mm. The areas where deformation is observed are regions with high load intensity, as mentioned before. In Figure 6.b, the axial deformation on the roof geometry is measured at 8.175 mm. The axial deformation on the roof is observed in the same regions as in other analyses, and this is because the loads remained constant in each analysis. In Figure 6.c, the maximum stress occurring on the bus roof is 195.72 MPa, and the maximum equivalent stress is observed on the corner brackets where the roof profiles connect to the side profiles. On the battery carrier (Figure 6.d), the maximum equivalent stress is 144.26 MPa, occurring at the points where the battery is connected to the bus frame. Analyses conducted based on a 5-hour duration have yielded the following results:

Tablo 3: Comparison of FEA Results

Material Properties	St 52 (S355JR)	Aluminium 6061-T6	Aluminium 7075-T6	Carbon fiber Reinforced PEEK
Directional Deformation on Battery Carrier Structure (mm)	4,44	7,903	7,753	40,88
Directional Deformation on Bus Structure (mm)	8,454	8,455	8,456	8,17
Maximum Stress (MPa)	193,05	192,69	192,71	195,75
Equivalent Stress on Battery Carrier Structure (MPa)	175,25	152,84	179,37	144,26

4. Discussion and Conclusion

The goal of achieving weight reduction in electric buses, thereby increasing the range of the vehicle's battery at full charge from 0 to 100% State of Charge (SoC), has been targeted. As a result of the study, weight reduction percentages were achieved in the battery carrier located on the electric bus roof: 65.54% when produced with aluminum 6061-T6, 64.03% when produced with aluminum 7075-T6, and 73.07% when produced with carbon fiber-reinforced PEEK materials.

While achieving weight reduction in electric buses, parameters such as cost, manufacturability, and service life must be taken into account for mass production. Keeping the bus skeleton material constant and changing the material of the battery carriers results in stress values on the roof that are very close to each other. While the deformation occurring in the battery carrier is acceptable in materials other than 30% carbon fiber-reinforced PEEK, the deformation and stress in PEEK composite material are much higher than the others. This affects the stress in the vehicle roof skeleton, reducing the vehicle's service life.

While achieving weight reduction in electric buses, parameters such as cost, manufacturability, and service life must be taken into account for mass production. Although the highest weight reduction ratio was achieved with 30% carbon fiber-reinforced PEEK material, it has been determined that it is not a suitable material in terms of manufacturability, cost, and resistance under load.

Weight reduction has been achieved with aluminum 6061-T6 and 7075-T6 materials compared to the currently used ST52 material. In the analysis with aluminum 6061-T6 material, a safety factor of 1.8 was calculated, and for aluminum 7075-T6, the safety factor

was calculated as 2.8. While these safety factors are acceptable, it is concluded that a material change could be made in the front and rear panels of the supporting structure, if not the entire structure, or certain design changes could be made to prefer aluminum 6061-T6 or 7075-T6 over the currently used ST52.

5. Acknowledge

We express our gratitude to the R&D Center staff and the management of Güteryüz Karoseri Otomotiv Sanayi ve Ticaret A.Ş. for their contributions to the emergence and continuation of this study.

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