Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 31(2), ss. 243-255, Aralık 2016
Çukurova University Journal of the Faculty of Engineering and Architecture,31(2), pp. 243-255, December 2016

Weight Reduction of Intercity Bus by Different Seat Construction Design in Compliance with APTA and FMVSS Standards

Gonca DEDE[*1], **Mustafa ÖZCANLI**[2]

[1]*Amasya University, Technology Faculty, Automotive Engineering Department, Amasya*
[2]*Çukurova University, Faculty of Engineering and Architecture, Automotive Engineering Department, Adana*

Geliş tarihi: 07.06.2016   Kabul tarihi: 23.11.2016

Abstract

In this study, weight reduction potential of different seat construction designs has been evaluated for intercity bus. The passenger seats were designed as CAD model. Finite element method was used to simulate the tests of FMVSS and APTA standards. Total deformation and maximum stress parameters, which were obtained by test simulations in FEA software, were analyzed to verify seat designs. This study results show that using aluminum alloy for seat design instead of St-37 steel provide 50% weight reductions for seat design. This weight reduction can reduce CO_2 emissions and also provide fuel efficiency over the vehicle's operating life.

Keywords: Vehicle efficiency, Emission, Aluminum alloy, Seat

Şehirlerarası Otobüslerde APTA ve FMVSS Standartları'na Uygun Farklı Koltuk Yapısı Dizaynları ile Ağırlık Azaltılması

Öz

Bu çalışmada, şehirlerarası otobüslerde farklı koltuk yapı dizaynlarının ağırlık azaltma potansiyeli değerlendirilmiştir. Yolcu koltukları bilgisayar destekli yazılım modeli olarak tasarlanmıştır. FMVSS ve APTA standartları testlerini simüle etmek için sonlu elemanlar yöntemi kullanılmıştır. Koltuk dizaynlarını doğrulamak için, sonlu elemanlar analiz metodu ile yapılan test simülasyonları sonucunda elde edilen toplam deformasyon ve maksimum stres değerleri incelenmiştir. Çalışma sonuçları koltuklarda çelik yerine alüminyum alaşım kullanmanın %50 ağırlık azalışı sağlayacağını göstermiştir. Bu ağırlık azalışı araç ömrü süresince CO_2 emisyonlarını azaltabilir ve yakıt verimliliği de sağlayabilir.

Anahtar Kelimeler: Araç verimliliği, Emisyon, Alüminyum alaşımı, Koltuk

---

[*] Sorumlu yazar (Corresponding author): Gonca DEDE, *gonca.dede@amasya.edu.tr*

1. INTRODUCTION

Vehicles are one of the most important parts of daily life. They provide comfort and mobility for people. In the same time, they affect significantly the environment during their life time. Greenhouse gas emissions and energy consumption are important effects of vehicles.

Previous studies show that approximately 15% of overall greenhouse gas emissions is occurred due to transportation sector. Globally, the transportation sector's CO_2 emissions represent 23% of overall CO_2 emissions from fossil fuel combustion [1]. In addition to greenhouse gas emissions, transportation sector accounts for 63% of the total growth in world consumption of petroleum and other liquid fuels from 2010 to 2040 in the reference case of International Energy Outlook 2013 issued by U.S. Department of Energy [2]. Due to the increments of energy consumption and greenhouse gas emission, there is aim for reducing emissions and improving fuel efficiency in transportation sector.

Weight reduction of vehicles is one of the most effective means to reduce fuel consumption and greenhouse gases for vehicle. It has been estimated that for every 10% of weight eliminated from a vehicle's total weight, fuel economy improves by 7%. This also means that for every kilogram of weight reduced in a vehicle, there is about 20 kg of carbon dioxide reduction over the vehicle's operating life [3].

In 1995, Stodolsky et al. performed a study which estimates total life-cycle energy savings over time as aluminum-intensive vehicles (AIVs). Their study showed that 19-31% weight reduction (270-460 kg) is possible with the intensive use of aluminum in passenger cars and light trucks, resulting in a fuel economy improvement of 12.5-20% for AIVs over conventional steel vehicles. They defined in that at least three ways to decrease the empty weight of a vehicle in their study. These three ways are; reducing vehicles' size, optimizing its design to minimize weight, and replacing the materials used in its construction with lighter mass equivalents. According to the Stodolsky et al. the third alternative, use of lightweight materials could provide greater gains [4].

It can be understood from ratio of overall vehicle weight; passenger seats have an important energy saving potential. Approximately, 8% of unloaded vehicle weight is seat weight [5]. Previous studies show that using lightweight material can provide a reduction of weight in between 8, 6% and 30% [4-8].

In this study weight reduction potential of intercity bus by different seat construction designs in compliance with APTA & FMVSS standards has been investigated theoretically. Analyses were conducted with final element analysis software.

2. MATERIAL AND METHOD

2.1. Material

Lightweight materials include magnesium, aluminum, advanced high-strength steels, titanium as well as polymer-matrix composites reinforced with glass and carbon fibers. Aluminum material and its potential for weight reduction are shown in Table 1 [9].

Table 1. Potential Vehicle Materials Substitution [9]

Lightweight Material	**Material Replaced**	**Mass Reduction**	**Relative Cost (per part)**
Aluminum	Steel, Cast Iron	40-60	1.3-2
Aluminum Metal Matrix Composite	Steel or Cast Iron	50-65	1.5-3+

In automotive industry, high strength steel, aluminum alloys, magnesium alloy, composites are used to reduce weight. These materials must have the performance requirements (strong, durable, easily formed and joined into assemblies and components, sufficiently well-characterized) to use for vehicle design [10].

2.1.1. Aluminum Alloys

Aluminum is a light metal and the use of aluminum offers considerable potential to reduce the weight of an automobile body. Aluminum is a soft metal, but high strength-weight ratios can be achieved in certain alloys.

An aluminum alloy has a chemical composition where other elements are added to pure aluminum in order to enhance its properties, primarily to increase its strength. These other elements include iron, silicon, copper, magnesium, manganese and zinc. These alloy are divided several groups according to alloying elements. One of these groups is 6xxx series. The 6xxx series are versatile, heat treatable, highly formable, weldable and have moderately high strength coupled with excellent corrosion resistance. Alloys in these series contain silicon and magnesium in order to form magnesium silicide within the alloy. Extrusion products from the 6xxx series are the first choice for architectural and structural applications. Alloy 6061 is the most widely used alloy in this series and is often used in truck and marine frames [11].

The properties of aluminum alloy are given in Table 2. Material properties were taken from MatWeb for Al-6061 [12].

Table 2. Material properties [12]

Material	Elastic Modulus (GPa)	Poisson's Ratio	Tensile Strength	
			Yield (MPa)	Ultimate (MPa)
Al-6061 T6	68.9	0.33	276	310

2.2. Computer Software

CAD and FEM software were used for the decision of the design. A reference seat frame design was made to determine the weight reductions in this study.

2.3. Seat Dimensions' Constraints

A CAD-model of seat frame was built based on reference dimensions of "Standard Bus Procurement Guidelines RFP". Reference dimensions are shown in Figure 1 [13].

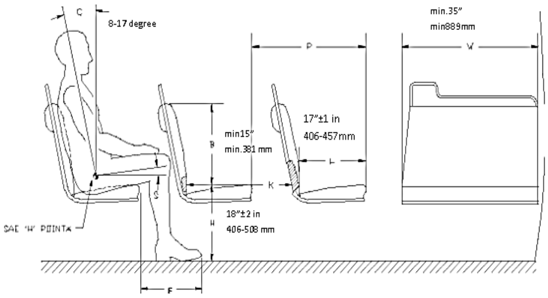

Figure 1. Seating dimensions &standard configuration [13]

2.4. Seat Reference Point

The seat reference point was specified by using 95th percentile man manikin. The H-point of the manikin was specified as design reference point as it is described in SAE J1100 Motor Vehicle Dimension document. In Figure 2 the manikin, reference seat structure and H-point of the manikin are shown [14].

Figure 2. SRP of seat design with 95 percentile manikin [14]

In automotive sector there are several regulations which specify the minimum requirements of seats. According to these regulations, the seats must be designed to meet various loading conditions like forward, reward dynamic loads and other static loads. There are different standards for seats in Europe and United States. In United States, American Public Transportation Association (APTA) Standards (Standard Bus Procurement Guidelines) is used as a reference by seat designers. In Table 3 and 4 show an overview of seat standards. The load cases that are shown in tables were used in this study. In Figs 3-6, the force applications of APTA and FMVSS are shown.

Table 3. Overview of APTA standards (United States) [15]

Load Case	**Experimental Conditions**	**Area of Application**	**Max. Deformation (mm)**
Deceleration	10 G Duration: 10 msec	Entire Seat	<355 (upper part of seat)
Vertical Force	2.23 kN	Cushion	6.5
Horizontal Force	2.23 kN	Seatback (force equally distributed over the seatback)	6.5

Table 4. Overview of FMVSS 207 [16]

Load Case	**Experimental Conditions**	**Area of Application**
Rearward Force	F=20*9.81*ms Duration: Apply-5secs Hold-5secs Release-5secs	Center of Gravity
Moment Force	M=373 Nm F=373/D (distance between SRP and upper cross member) Duration: Apply-5secs Hold-5secs Release-5secs	Uppermost Cross Member

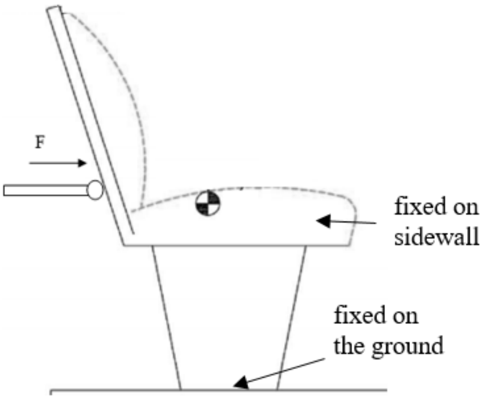

Figure 3. APTA seat tests photos-APTA horizontal seatback load application [15]

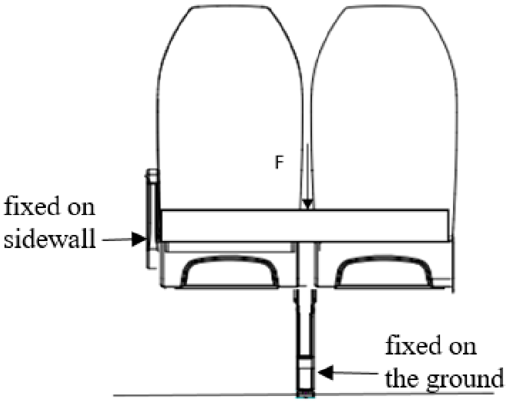

Figure 4. APTA seat tests photos-APTA vertical force application [15]

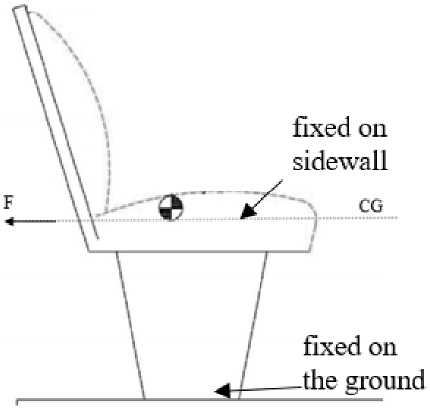

Figure 5. FMVSS 207 seat tests photos-FMVSS rearward force application [16]

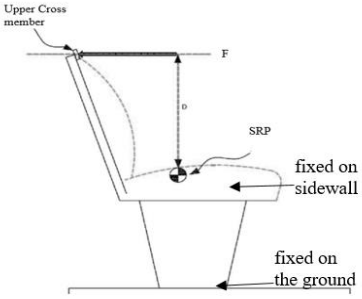

Figure 6. FMVSS 207 seat tests photos-FMVSS rearward moment load application [16]

3. RESULT AND DISCUSSION

3.1. Analysis Results of Load Cases for Reference Seat Design

A reference seat design was built in CAD program. Reference seat material was selected as St-37. A finite element model was formed in FEM software.

This final element model consists a seat structure. Most of seat structures were made of sheet and tube. In FEM analysis three type of elements are used; 3D elements, 2D (2D solids, plates and shells) elements, and 1D (truss and beam) elements. Usually, 2D elements should be used for areas/parts that have a plate- or shell-like geometry [17]. Therefore, in geometry modeling for the seat parts where 2D elements are to be used, the geometrical mid surfaces were created. Shell element type is used for the seat parts [18].

The mesh only needs to be finer in areas of importance, such as areas of interest, and expected zones of stress concentration, such as at re-entrant corners, holes; slots; notches; or cracks. For seat FEM model, the areas of holes and attachment points were meshed finer. Regularly shaped elements are not possible for every geometry, thus element distortions are possible in meshing. Mesh quality can be controlled by these element distortions limitations. Element quality, aspect ratio, jacobian ratio, wrapping factor, parallel deviation, maximum corner deviation, skewness are used to control mesh quality. The finite element model mesh quality was control criteria. Weld connections were simulated as bonded contact. Bolt connections were modeled by using line elements. The surface of sidewall and floor were defined as fixed support [19].

The reference seat was analyzed according to the APTA and FMVSS. The reference seat passed all tests.

3.2. Seat Design for Al-6061 T6

3.2.1. Design Step 1

Aluminum 6061 T6 was used instead of St-37 with same design. When the seat was analyzed for the APTA horizontal force load case and FMVSS rearward moment test, the maximum stress of the frame was above the ultimate tensile strength of material (Figure 7).

3.2.2. Design Step 2

Seat and floor attachment part dimensions were changed. The design passed the FMVSS rearward moment test. However, the design didn’t pass the APTA horizontal force application test. The maximum deflection was above the requirement (Figure 7).

3.2.3. Design Step 3

The seatback deformation was above the regulation; therefore, the gaps on seatbacks were removed (Figure 8).

3.2.4. Design Step 4

The total deformation was above the regulation; therefore, the gaps on upper seat frame parts were removed. (Figure 8).

3.2.5. Design Step 5

The total deformation was above the regulation; therefore, the seat frame wall thickness was increased (Figure 9).

3.2.6. Design Step 6

Seat and floor attachment part location was changed to reduce the total deformation. It was relocated to the near the sidewall (Figure 9).

3.2.7. Design Step 7

The parts on the seat frame profile were relocated to the front (Figure 10).

3.2.8. Design Step 8

The side profile width of the seatback was increased (Figure 10).

3.2.9. Design Step 9

The height of upper cross member of seat was reduced (Figure 11).

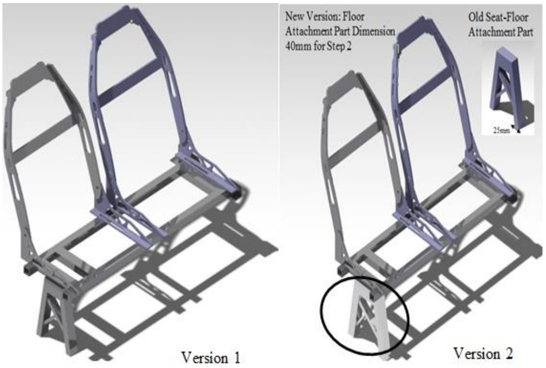

Figure 7. Seat design version 1&2

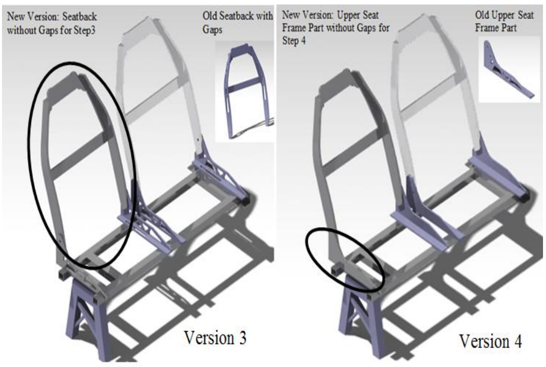

Figure 8. Seat design version 3&4

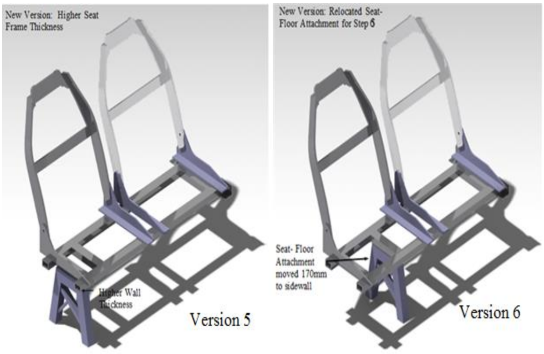

Figure 9. Seat design version 5&6

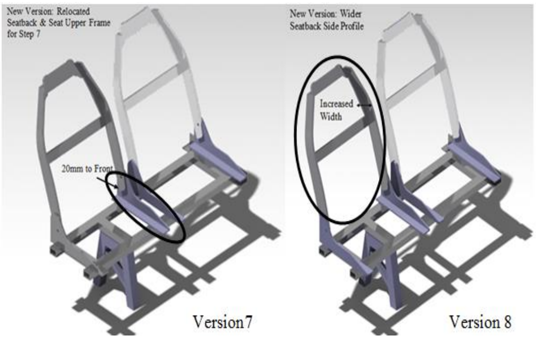

Figure 10. Seat design version 7&8

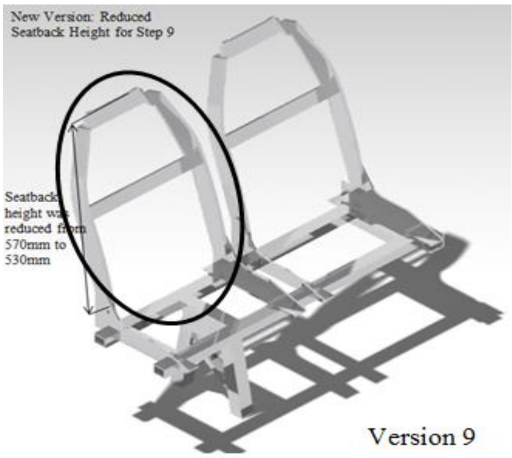

Figure 11. Seat design version 9

3.3. Seat Test Results for Al-6061 T6

After the final step of development, the seat design was passed all the tests. Test results are shown in Table 5-7 and Figs 12-17 in below.

Table 5. Wall thickness and weights for reference design and al-6061 design

Part Name	Reference	Al- 6061	Reference Seat Weight (kg)	Al-6061 Seat Weight(kg)
	Wall Thickness(mm)			
Seat-Floor Attachment	4	4	2.133	0.90
Seat Frame	2	4	4.398	3.14
Seat Upper Frame	6	6	0.918	0.46
Sidewall Attachment	5	5	0.874	0.22
Seatback	10	10	5.414	2.42
Total Weight			21.927	10.93

Table 6. Al-6061 seat analysis results for same design with reference design

Standards	Load Case	Requirement Max. Deformation (mm)	Max. Deformation (mm)	Max. Stress (MPa)
APTA Load Cases	Deceleration	<355 (upper part of seat)	7.1	49.7
	Vertical Force	6.5	0.37	84.2
	Horizontal Force	6.5	17.2	312
FMVSS	Rearward Force Application Test Simulation	-	5.6	82.6
	Rearward Moment Application Test Simulation	-	64	337

Table 7. Wall thickness and weights for reference design and al-6061 final design

Standards	Load Case	Requirement Max. Deformation (mm)	Max. Deformation (mm)	Max. Stress (MPa)
APTA Load Cases	Deceleration	<355 (upper part of seat)	3.99	16.73
	Vertical Force	6.5	0.29	17.8
	Horizontal Force	6.5	6.44	130.13
FMVSS	Rearward Force Application Test Simulation	-	2.72	74.4
	Rearward Moment Application Test Simulation	-	36.28	175.61

3.3.1. APTA Regulation 80 Deceleration Load Case Analysis

The seat design was analyzed according to the APTA; 10G deceleration was applied to the seat during 10 milliseconds. The maximum total deformation of the entire seat is 3.99 mm. This value is below the requirement of the APTA standard. The maximum stress of the seat design is 16.73 MPa, this values is below the tensile strength of Al-6061.

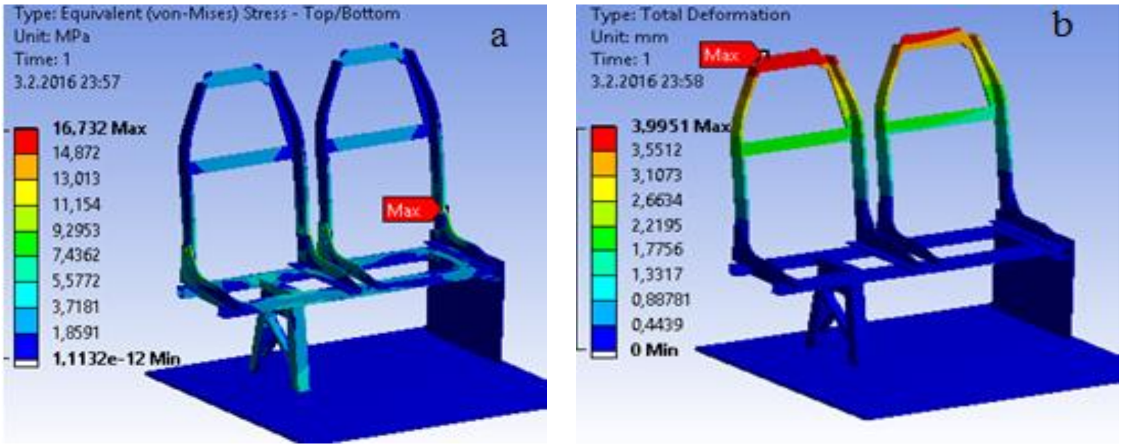

Figure 12. APTA& ECE R80 deceleration load case analysis results a) Total deformation b) Maximum equivalent stress

3.3.2. APTA Horizontal Force to Seatback Load Case Analysis

The seat design was analyzed according to the APTA, 2.23 kN load was applied to the upper cross member of seatback through the loading bar. The maximum total deformation of the entire seat is 6.44 mm. This value is below the requirement of the APTA standard.

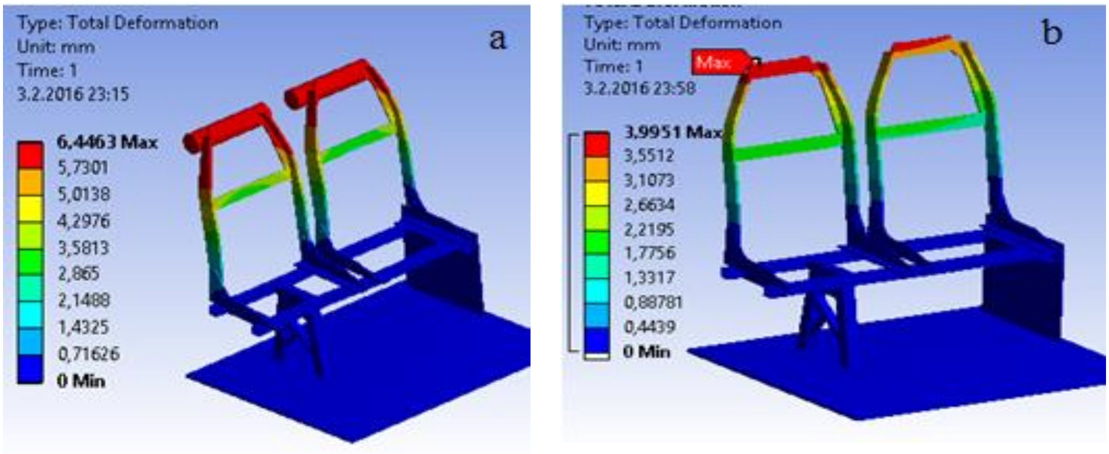

Figure 13. APTA horizontal force to seatback load case analysis a) Total deformation b) Maximum equivalent stress

3.3.3. APTA Vertical Force to Seat Cushion Part Load Case Analysis

The seat design was analyzed according to the APTA, 2.23 kN load was applied to the upper cross member of seatback through the loading bar. The maximum total deformation of the entire seat is below 1 mm. This value is below the requirement of the APTA standard.

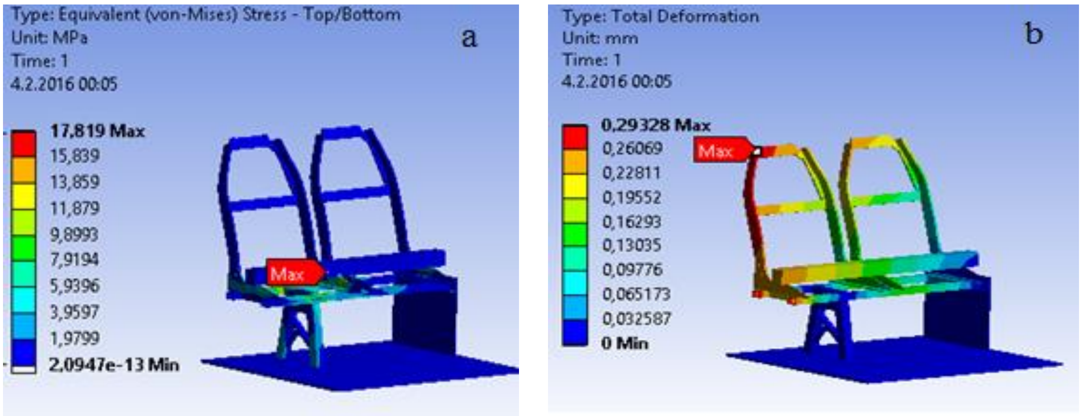

Figure 14. APTA vertical force to seat cushion part load case analysis a) Total deformation b) Maximum equivalent stress

3.3.4. Rearward Force Application Test Simulation

The force was applied through the center of gravity on a rigid member. The force, which was determined according to the FMVSS 207, was equal to the 20 times the mass of the seat in kilograms multiplied by 9.8. The force was applied in 5 seconds, hold for 5 seconds and released in 5 seconds.

The force is expressed as

$$F= 20\, g m_s \text{ (N)} \tag{1}$$

where g is gravity force and m_s is mass of the seat.

The force is determined as

$$F= 20 \times 10.93 \times 9.81 \text{ N} = 2145 \text{ N} \tag{2}$$

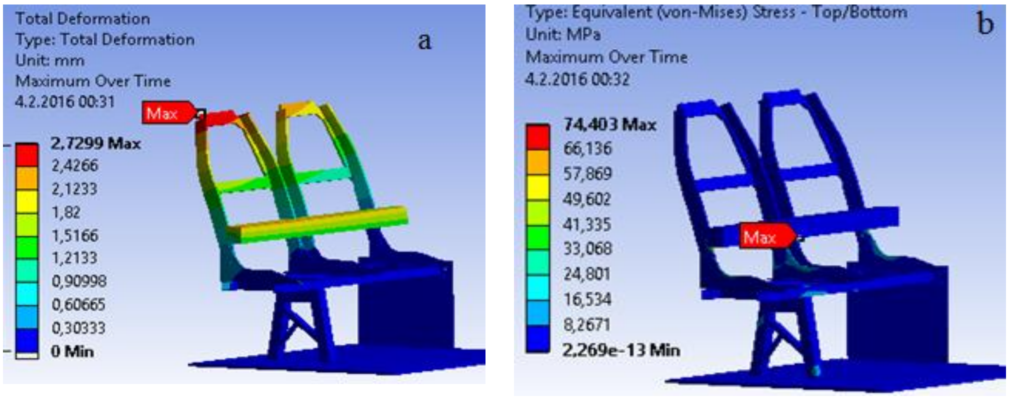

Figure 15. Rearward force application test simulation a) Total deformation b) Maximum equivalent stress

3.3.5. Moment applied in a Rearward Longitudinal Direction Test Simulation

The force was applied to the upper cross-member of the seat backs. All loads were applied in 5 seconds, hold for 5 seconds and released in 5 seconds.

The force is expressed as

$$F = M / D \tag{3}$$

where M= 373 Nm/occupant, D is the Vertical distance between SRP plane and upper cross member.

The force is determined as

$$F=373/0{,}329=1133\text{N} \tag{4}$$

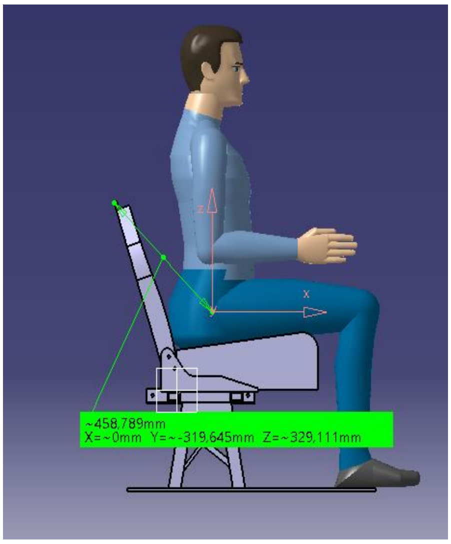

Figure 16. Vertical distance between SRP plane and upper cross member

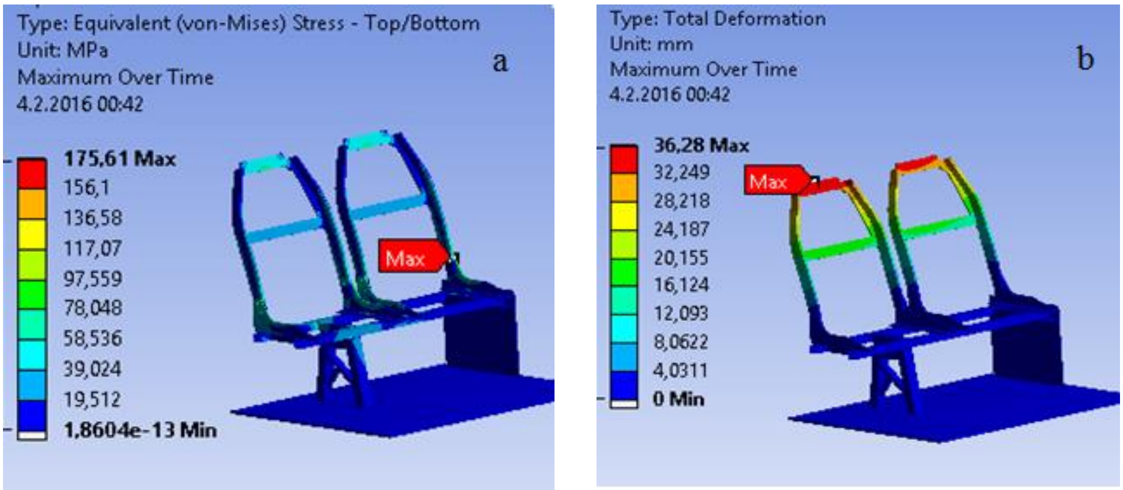

Figure 17. Rearward moment application test simulation a) Total deformation b) Maximum equivalent stress

3.4. Comparison of Seat Design

The main objective of this study is reducing the seat weight. Therefore, lightweight material was used to reduce the weight. An aluminum alloy was selected. The seat structures were tested safety standards that are set for bus seats. The seat designs are shown in Figure 18.

The aluminum alloy design has higher wall thickness for seat frame part. Table 8 represents the seat and floor attachment part of aluminum alloy design are closer to the sidewall.

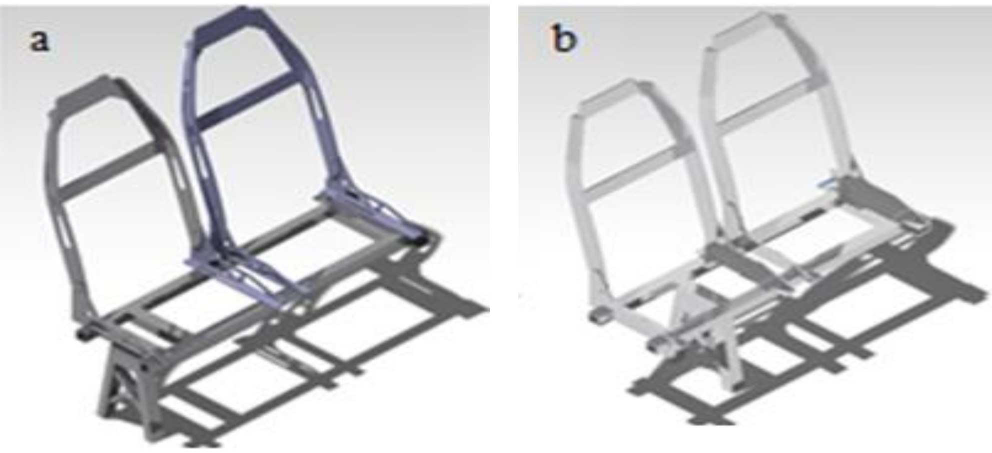

Figure 18. Seat designs a) Reference seat design b) Aluminum alloy seat design

Table 8. Comparison of seat designs

Part Name	Reference	Al-6061	Reference	Al-6061
	Wall Thickness(mm)		Seat Weight (kg)	
Seat-Floor Attachment	4	4	2.133	0.9
Seat Frame	2	4	4.398	3.14
Seat Upper Frame	6	6	0.918	0.46
Sidewall Attachment	5	5	0.83	0.22
Seatback	10	10	5.447	2.42
Total Weight			21.927	10.93

As seen in the Table 9, the aluminum alloy decreases the reference seat's total mass 21.92 to 10.99 kg (50% in mass).

Table 9. Weight comparison

	St-37	Al 6061
Total Weight (kg)	21.92	10.93
Weight Reduction (kg)	0	10.99
Weight Reduction (%)	0	50.14
Bus Weight Reduction* (%)	0	2.83

* This calculation is done for a bus with 40 seats

In addition to fact that the aluminum alloy provides weight reduction, when we calculate the factor safety for final design, it can be seen that its factor safety is about 1,6.

The factor of safety expressed as

$$\text{factor of safety}=\frac{\text{material yield stress}}{\text{maximum design stress}} \tag{5}$$

for design with Al 6061 is determined as

$$\text{factor of safety} = \frac{276}{175} = 1{,}57 \tag{6}$$

where material yield stress is equal to 276 Mpa from Table 2 and maximum design stress is 175 Mpa from Table 7.

Reducing vehicle weight can help decrease energy and petroleum consumption by increasing efficiency. In addition, it decreases the greenhouse gas emissions. Ghassmieh estimated that for every 10% of weight eliminated from a vehicle's total weight, fuel economy improves by 7% and for every kilogram of weight reduced in a vehicle; there is about 20 kg of carbon dioxide reduction [3]. According to the Ghassmieh's estimations fuel economy and CO_2 reductions were calculated approximately for this study, calculation results are shown in Table 10.

Table 10. Fuel economy and CO_2 reduction calculation for Al-6061 seat design

Estimation		**Calculation for Al 6061**	
Vehicle Weight Reduction	**Fuel Economy**	**Vehicle Weight Reduction**	**Fuel Economy**
10% Weight Reduction	7% CO_2 Reduction	3% Weight Reduction *	2.1% CO_2 Reduction *
1 kg	20 kg	440 kg	8800 kg

* This calculation is done for a bus with 40 seats

4. CONCLUSION

The aim of this study was designing lightweight seat design for an intercity bus. Aluminum alloys material was used to reduce the weight of the seat design.

Conclusions based on the comparison of designs with reference seat design

- 50% weight reduction was obtained by using aluminum alloy as seat material.
- If aluminum alloy design used for a bus with 40 seat 2.1% fuel economy could be obtained and 8800 kg CO_2 emission could be prevented during lifetime in comparison with the reference design.

5. REFERENCES

1. International Transport Forum, Reducing Transport Greenhouse Gas Emissions-Trends & Data, 2010. 15.07.2015, 2010.
2. U.S. Energy Information Agency, International Energy Outlook, 2013. 15.07.15, 2013.
3. Ghassemieh, E., 2011. Materials in Automotive Application, State of the Art and Prospects, New Trends Developments in Automotive Industry, Chiaberge, M., 978-953-307-999-8
4. Stodolsky, F., Vyas, A., Cuenca, R., Gaines, L., 1995. Life-Cycle Energy Savings Potential from Aluminum-Intensive Vehicles, 1995. Total Life Cycle Conference & Exposition, Vienna, Austria.
5. Yuce, C., 2013. Yeni Nesil Ticari Araçlar için Hafifletilmiş Yolcu Koltuğu Tasarımı ve Prototip İmalatı, Master's Degree, Uludağ Univercity, Institute of Science and Technology.
6. Burman, R., 1997. 11-IBCAM Vehicle Technology '97, Automotive Engineer.
7. García Nieto, P.J., Vilan, J.V., Del Coz Diaz, J.J. Matias, J.M., 2009. Analysis and Study of an Automobile Rear Seat by FEM, International Journal of Computer Mathematics, 86;640–664.
8. Steinwall, J., Viippola, P., 2014. Concept Development of a Lightweight Driver's Seat Structure & Adjustment System, Master's Degree, Department of Product and Production Development, Chalmers University of Technology.
9. U.S. Department of Energy, Multi-Year Program Plan 2011 – 2015, 16.07.15, 2010.
10. Cheah, L.W., 2010. Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U.S., Doctor of Philosophy, Engineering Systems at The Massachusetts Institute of Technology.
11. The Aluminum Association, Aluminum Alloys 101, The Aluminum Association, 03.08.2015.
12. MatWeb,LLC.,http://www.matweb.com/search/DataSheet.aspx?MatGUID=90404a0c001c4016b2b359a6c19f9127, 03.08.2015.
13. American Public Transportation Association, APTA Bus Procurement Guidelines, 03.08.2013.
14. The Executive Director Office of the Federal Register Washington, 1984. D.C., SAE 1100: Motor Vehicle Dimensions, 4.08.2015.
15. Bergeron, F., Audet, J.F., 2004. Feasibility Study for the Development and Marketing of Magnesium Seats for Motor Coaches and other modes of Public Transit, Feasibility Report, TP 14275E, Transportation Development Centre, Canada.
16. U.S. Government Publishing Office, 2008. Federal Motor Vehicle and Safety Standard, Standard No. 207, Seating Systems, 4.08.2015.
17. Liu, S.S.Q.G.R., 2003. The Finite Element

Method: A Practical Course. Butterworth-Heinemann.

18. ANSYS, Inc., ANSYS Meshing User's Guide, Knowl. Creat. Diffus. Util., vol. 15317.

19. Ansys, 2014. An Overview of Methods for Modelling Bolts in ANSYS V15, in Ansys Regional Conference.