Comfort and structural (FEA) analysis on light weighted car seat design optimized with EPP material

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Abstract: In this paper, comfort and strength performance of conventional and lightweight seat design which is developed by using EPP (expanded poly propylene) material is investigated by using FEA (finite elements analysis) method. The main goal is to contribute to reducing CO_2 emissions on passenger cars by providing weight reduction on car seats. To accomplish that, a special designed part made of EPP material, which has lower density and higher strength performance in compliance with PU (Polyurethane), is embedded in original car seats made of PU material, and the resulting composite material reinforces the structure and gives the similar performance compared to PU design, and in the meantime supporting metal frame's weight inside car seats is also reduced. In parallel with design optimization, a comparative analysis of strength and comfort performances between conventional seat design and lightweight seat design is studied correspondingly. Highly nonlinear contact analyses are performed with the dummy named "Manikin" (human model) to analyze comfort performance by looking at the pressure distribution on surface of seats. The results indicate that after design optimization by using new material technology, nearly same comfort and strength performance are achieved and weight of the car seats can be reduced remarkably.

Key words: Weight reduction on car seats, EPP material, Comparative comfort and strength analyses, FEA method

Introduction

Reducing fuel consumption and CO_2 emissions on passenger cars is a subject of intensive research in automobile industry for better environment. One way of achieving this goal is to provide weight reduction on car bodies. Because the heaviest interior element among all others is car seat sets, ongoing research on weight reduction usually starts with car seats by using new engineering materials and optimization techniques. However, utilizing new engineering materials in designs is in need of verifications in terms of passengers' comfort and strength performance. In industry, these are usually done by series of tests after the prototypes are produced.

In 2012, the total global sales in the sector of automotive became 86.5 million by increasing 5%. In the same year, the most of total sales happened to be 68.3 million in automobile market (Reports,2012). Due to the intense use of automobiles, total consumption of fuel and CO_2 emission increased dramatically. Therefore, automobile industry seeks alternative energy sources due to devastating greenhouse gas effect for the environment, and starts decreasing the use of fossil fuel energy with standardization in fuel consumption because of new rules and regulations. According to the CAFÉ reports, the target fuel CO_2 emission complied by passenger car and vans manufactured in 2025 is shown in Figure 1. (NHTSA, 2012).

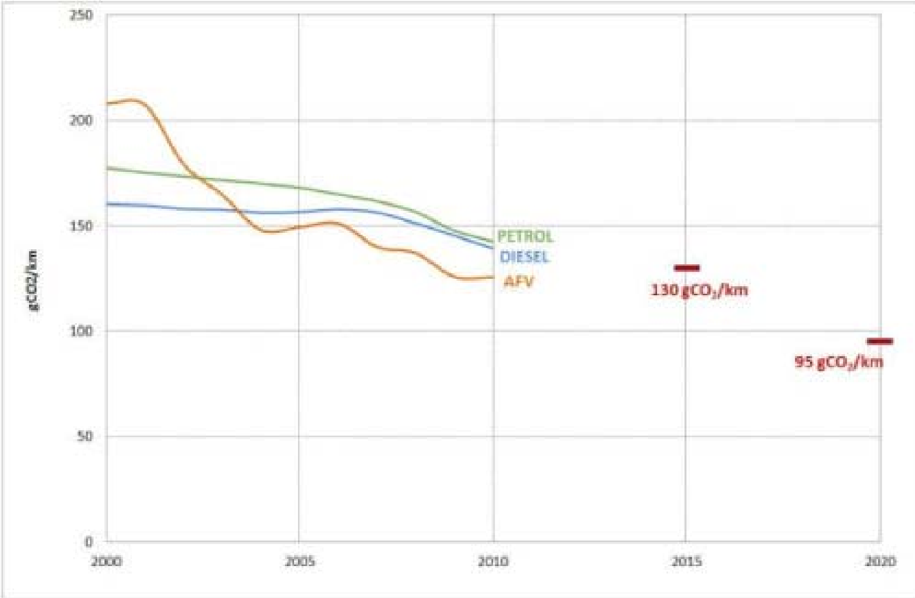


Figure 1: The target fuel CO2 emission by EU

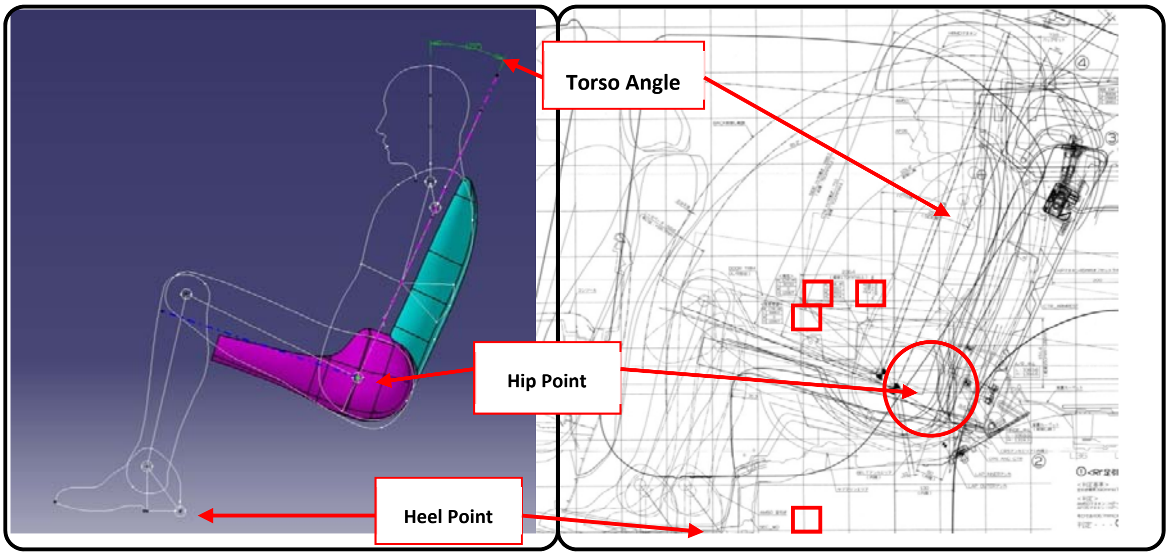
In EU, it is aimed to have at least 130gr CO_2/km emission in accordance with the new rules for passenger cars (European Parliament and of the Council Regulation, 2009). As a general rule, the modification to have 100kg weight reduction provides approximately 0.005lt/km fuel cut. It is also corresponds to 10gr/km CO_2 emission. 1kg weight reducing for cars, which the required emission rate cannot be complied, costs roughly 10€. Therefore, with the help of reducing weight, developing new engines and transmissions, alternative fuels and other advancements, engineers are optimistic to reach the expected CO2 emission goals (Eureka Project-Lightweight Seatbacks, 2013).

The work on reducing weight to decrease the CO2 emission is usually performed by replacing the traditional engineering materials with the high-tech materials that provide both lightness and strength, and analyzing the design to eliminate the unnecessary materials usage. When the literature is curiously searched, it is easily seen that there is little work comparative research between traditional and new seat designs with respect to comfort and strength performances. In one of them, Grujicic et al study finite element models of a passenger-vehicle occupant's seat and of a dummy and used in the investigation of human/seat interactions and seating comfort. On the other hand, Siefert et al, work on a seat model in which static and dynamic properties of the structure are defined. Authors evaluate static comfort which is mainly determined by the seat pressure distribution. However optimization type of research works cannot be found easily in literature. Therefore, in this research, it is aimed to reduce % 22 of weights on car back seats by replacing PU with EPP material. To achieve that goal, finite element method is extensively used in both comparative works and design optimizations.

Materials and Method

The procedure of weight reduction consists of three stages. In the first stage alternative material is selected and corresponding properties are determined. In our case, EPP is a material that fulfills most of the expectations. Meantime, in conventional seat design, PU foam and DIN 17223-B-type spiral high-carbon steel materials are widely used. On the other hand, selected EPP material has % 25 lower densities and better strength performance compared to PU material; therefore it is also expected to reduce steel wire material usage in the design optimization. In the second stage, various finite element analyses (FEA) are performed. In the modeling part of the FEA, AM50

(Adult Male 50) human model (manikin) is used to simulate the effect of passenger effect as a loading (SAE, Society of Automotive Engineers). Manikin is particularly placed on a car seat according to hip-point, heel-point and torso angle (Figure 2).



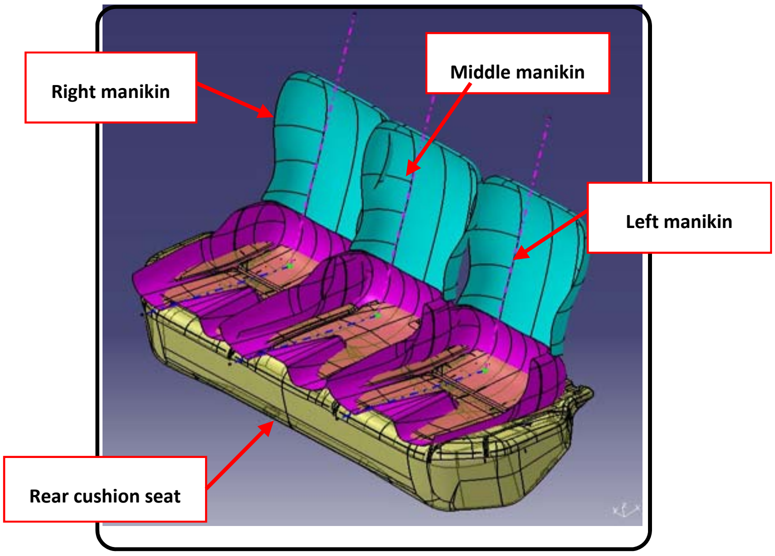


Figure 2: CAD model of AM50 dummies and their positions on the car back seat

Also new wire frame is design to be embedded in the EPP part (Figure 3). Therefore, the usage of steel wire can be reduced. Furthermore upper surface of the EPP part is designed by considering the manikin shape which directly affects the passenger comfort. Then, whole design of parts is completed in CATIA V5 CAD environment and transferred to finite element software (Figure 3).

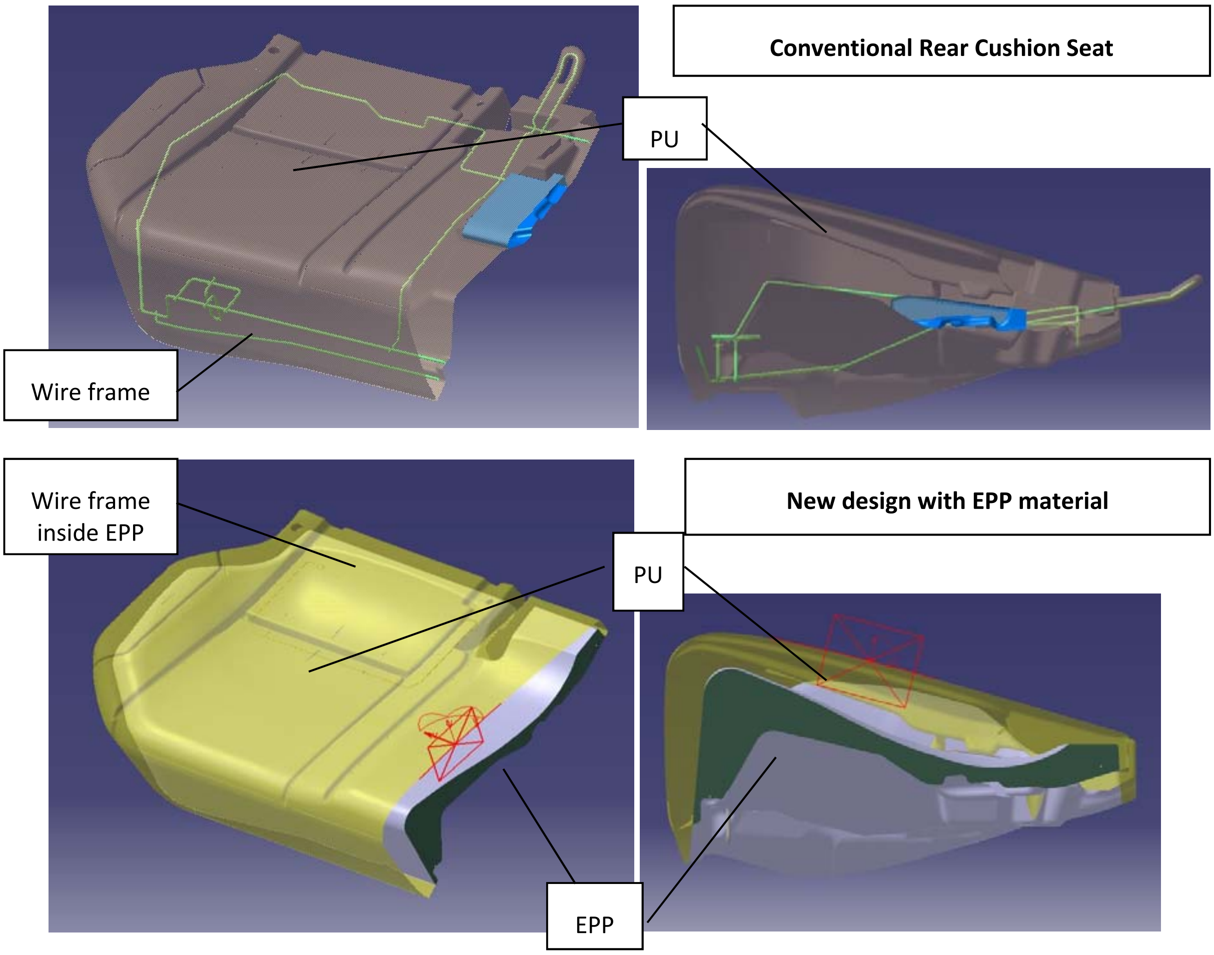
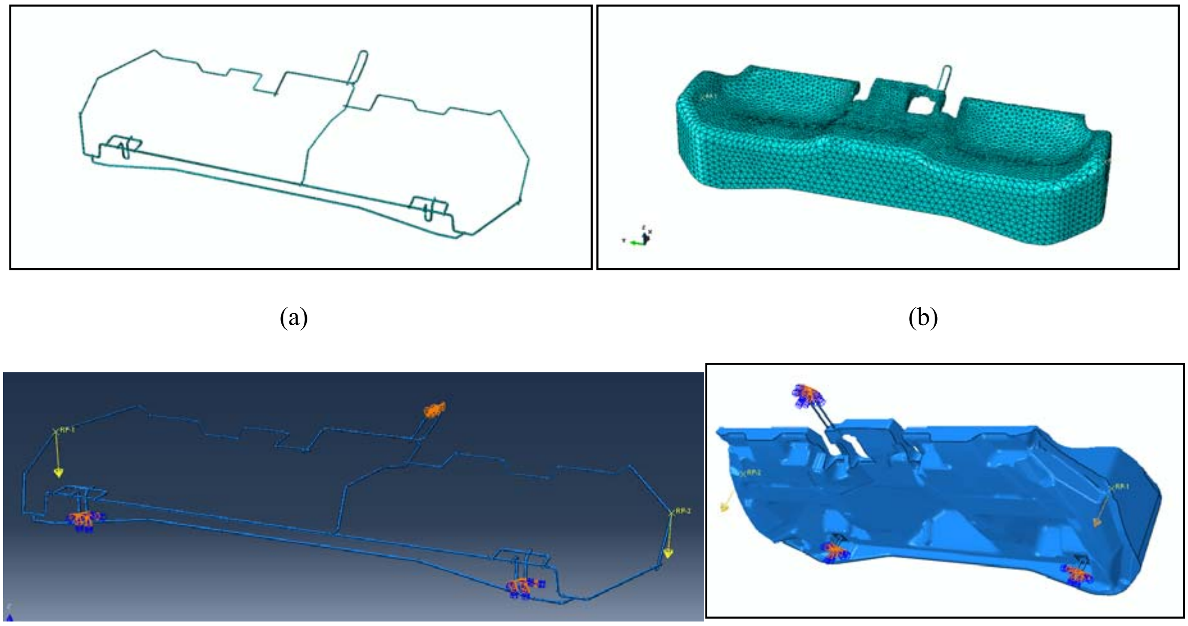


Figure 3: Current design and new design sections

After that, the models are meshed with tetrahedron elements due to the complex geometries. Meantime, tensile test results of EPP and PU materials are evaluated by finite element software, and hyper-elastic Marlow model is selected and assigned to EPP and PU parts. For the new composite design, embedded constraint between EPP and embedded wire frame, and non-linear contact between dummy and PU part are defined Both models are fixed from the same 3 fixation points of wire frame to car floor and corresponding boundary conditions are defined. Finally, loads are defined by applying 77 kg force (standard weight value of the AM50 Manikin) at the center of the gravity of dummy and body forces of the parts (Figure 4).

In the third stage, having finished the analyses for comparative strength and comfort analysis between current design and new design of rear seat cushion, comparative strength analysis is studied between composite structure of EPP + wire frame, which is developed in the new design, and the current wire frame, which reinforces whole strength in current design.

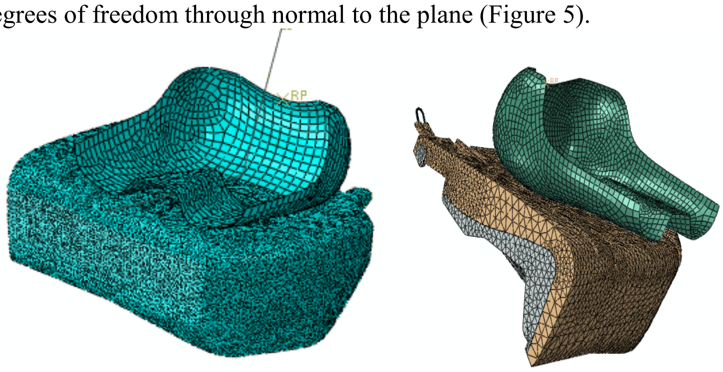


(a) (b)

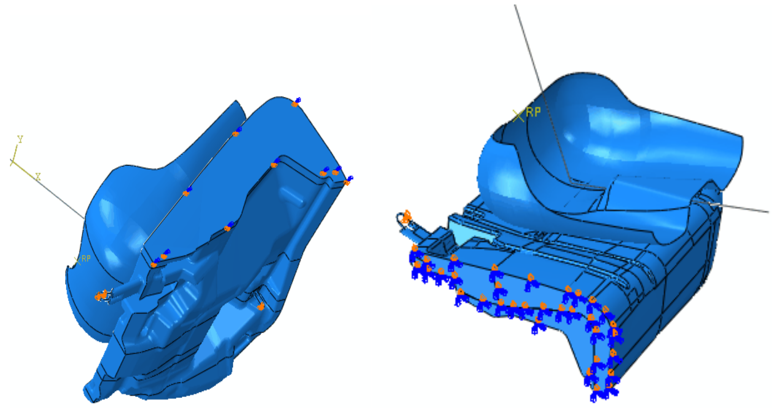
(c) (d)

Figure 4: (a). Mesh system of current design (b) Mesh system of new design (c) Boundary and loading conditions of current design (d) Boundary and loading conditions of new design

To simulate the seating condition of a human, comfort analysis is performed by applying contact condition between manikin and PU surface. But both models are almost symmetrical, for the sake of comparison, half of the rear cushion seat is used to avoid unnecessary calculation. As a result symmetrical plane is applied as boundary condition by limiting degrees of freedom through normal to the plane (Figure 5).



(a) (b)

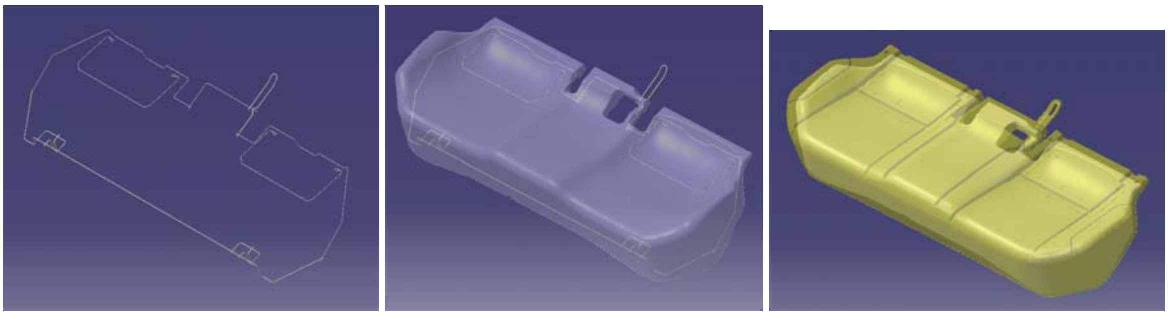


(c) (d)

Figure 5: (a). Mesh system of current design (b) Mesh system of new design
(c) Boundary and loading conditions of current design (d) Boundary and loading conditions of new design

Results

Before the changes take place, the weight of traditional rear seat cushion is 4320g. According to the results of analyses, it is seen that %40 volume of PU material is replaced by EPP material in the new design. Due to %25 density difference between these materials, 350g weight reduction is provided. In addition, usage of steel wire is reduced 65%. Therefore, total weight of the rear seat cushion is reduced about % 22 compared to current designs, and the weight obtained for the new design reaches to 3372g total. (Figure 6).



(a) (b) (c)

Figure 6: (a). Light weighted wire frame (b) EPP and embedded wire frame (c). New rear cushion design with EPP

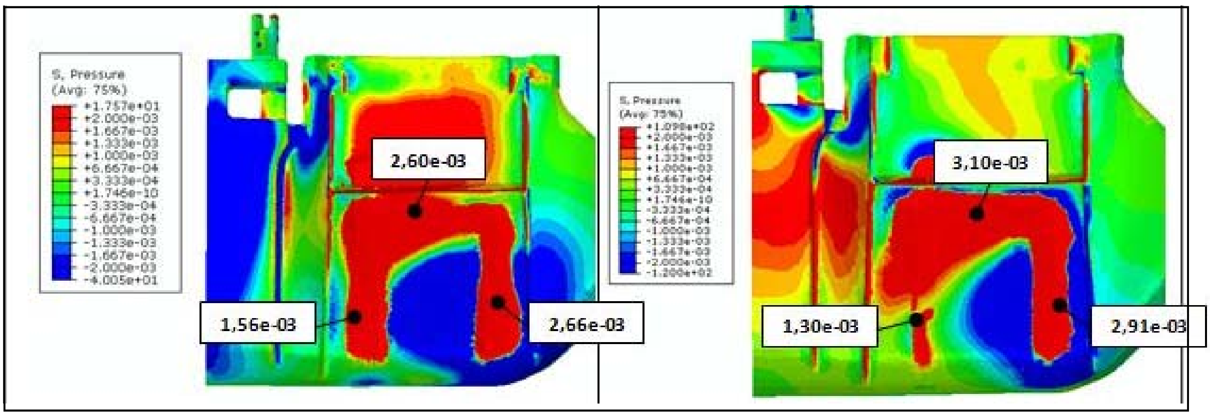
Based on results of the strength analysis, both maximum strength generated in the current wire frame and maximum stresses for the EPP + wire frame composite structure in the new design is elastic. Maximum displacements for both configurations are almost same (Figure 7).

(a) (b)

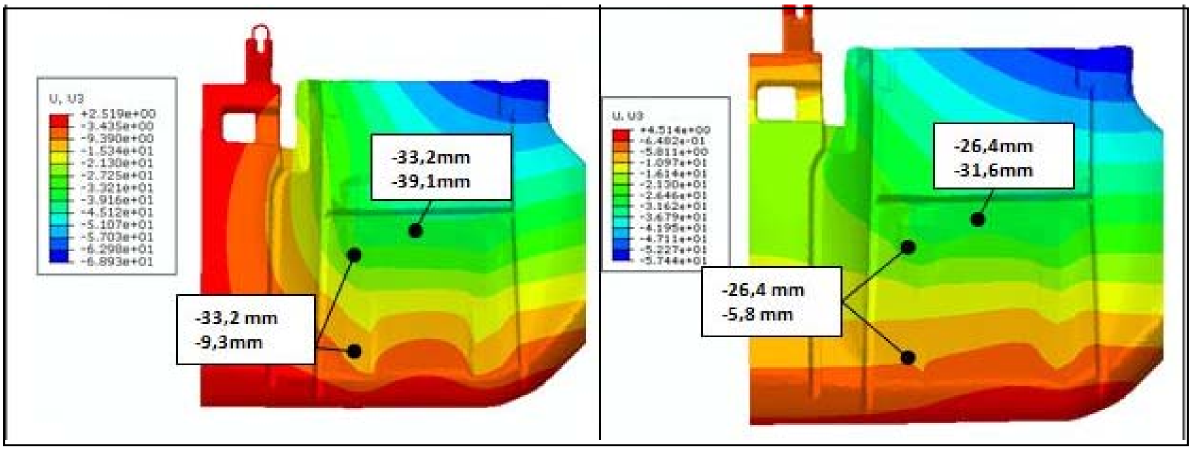
	Current wire frame	New wire frame embedded in EPP
Maximum Displacement [mm]	(c) -394	(d) -404

Figure 7: Displacement distributions (a) on current wire frame (b) on EPP and embedded wire frame

For comfort analysis, pressure distributions on the upper surfaces of the both models are investigated. In the current model, average pressure values obtained as 2.66-03 MPa under the area of left leg, 2.60 MPa-03 on the hip area and 1.56-03 Mpa under the area of right leg. The average value of displacement on the legs are in the range of 33.2 to 9.3 mm and through (-) direction, for the hip area, displacement is obtained from 33.2 to 39.1 mm, also through (-) direction. In the new design, average value of pressure distribution is 2.91-03 Mpa on the left leg area, 3.10 MPa-03 on the hip area, 1,30-03 Mpa on the right leg area. The average value of displacement on the area of legs is through (-) direction and in the range of 26.4 to 5.8 mm, for the hip region it is through (-) direction and obtained between 26.4 - 31.6 mm (Figure 8).



(a) (b)



(c) (d)

	Manikin Contact Area	Current Design	New Design
Maximum Stress [Mpa]	Left leg	(a) 2,66e-03	(b) 2,91e-03
	Hip	(a) 2,60e-03	(b) 3,10e-03
	Right leg	(a) 1,56e-03	(b) 1,30e-03
Maximum Strain [mm]	Hip	(a) -33,2 -39,1	(b) -26,4 -31,6
	Legs	(a) -33,2 -9,3	(b) -26,4 -5,8

Figure 8: The average value of displacement on the area of legs

Discussion

It is obvious that any reduction attempt by reducing wire frame usage in seat design causes reduced strength performance accordingly. In this study, this situation is compensated by developing a new EPP + wire frame composite structure. EPP is a new engineering material and has 25% lower density in comparison with PU. In the optimization part of the solution, the weight of traditional rear cushion seat is reduced about % 22 from the value of 4320g to 3372g. The weight of steel wire frame is decreased by % 65 by supporting the seat structure with EPP material, and the intended target for weight reduction of % 22 is reached.

Results of the analysis shows that strain/stress values of the EPP + wire frame composite structure appears to be around +/- % 2.5 compared to the current wire frame strain/stress performance. Regarding to these results, the new design, EPP + wire frame structure, is as stiff as the current wire frame.

In the process, it is also aimed to achieve same comfort performances between current and optimized seat design in maximum level. As a result of comparative comfort performance analyses, pressure distributions on the upper surfaces of the models shows that comfort performance of the new seat appears to be around -%17 / +%19 compared to current seat design. Even these results are not so close to each other, a small reduction on comfort performance is expected because of usage of such a rigid EPP material. Since the primary objective of the study is to reduce weight by 22%, the convergence of comfort performance is in the acceptable level. Considering all these results of comparative analyses, EPP material usage is optimized and % 22 of weight reduction is provided on rear cushion seat (Table 1).

Table 1: A comparison table between targets and results of design optimization

	TARGET	**RESULT**
Design optimization	%22 Weight reduction	%22 Weight reduction
1. Comparative Strength Analysis	Current wire frame vs. EPP+wire frame	**Stress** Difference: +%2,5 **Strain** Difference: -%2,5
2. Comparative Comfort Analysis	Current seat vs. New seat	**Pressure Distribution** Difference: between -%17 / +%19 **Displacement** Difference: between -%19 / -%20

Conclusions

Weight reduction studies in cars are extremely important in terms of the reduction of CO2 emissions. Weight reduction on car seat sets is also an important part of these studies. But the challenge is to have a stabile comfort and strength performance of existing seat while weight is reduced, and do it at the design stage to avoid high prototype costs. Based on this study, the following recommendations and conclusions can be drawn;

1-Weight reduction studies are usually made for the front seat sets. In this study, weight reduction is studied for conventional rear cushion seat, and % 22 of weight reduction is obtained by using a new material which is EPP.

2- Pressure distributions based comfort analyses are usually studied for front seat sets. While reducing the weight highly nonlinear FEA analyses made for design optimization and strength/comfort performance is maintained.

3- Strength/comfort ratio of traditional seat is reached by that of optimized designs in strength/comfort performance analyses.

4- For further studies, finite element models can be detailed by applying car floor restrictions and vibration loads acting on the occupant while driving conditions.

Acknowledgements

The technical support of Sakarya University is gratefully acknowledged.

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