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Design and Analysis of Thermoplastic Prepreg Based Heavy Commercial Vehicle Seat

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Abstract: Combining two or more reinforcing elements into the matrix to compose a new material with enhanced properties is called hybrid composite. By favor of related method; prime advantages such as lightening the vehicles and reducing the process steps are obtained and it is aimed to bring the parts production costs to a competitive point depending on the appropriate part selection and design optimizations. In this regard, it is essential to integrate hybrid composite and advanced molding technologies and to produce certain structural components associated with using this technology. Within the scope of this study, the metal part (S420 MC) used in the truck seat structure was modelled along with the finite element method of the continuous glass fiber reinforced composite material that will be used to produce with composite technology. Part design studies and ECE R14 regulation analysis applied to composite production of the relevant seat part have been realized. In this work, heavy commercial vehicle passenger seat backrest was chosen as the study product. The backrest of the existing weight is 3200 gr and the related backrest was welded from S420 MC tube. Based on this, weight reduced to 1700 gr by performing over-molding method under favor of using polypropylene / GF 40 (P40B01) raw material on Epoxy Resin based (OM10) prepreg material and weight reduction have successfully substantiated. Mechanical properties of the materials used as the acceptance criteria of the models were determined as the relevant acceptance ranges. Within the scope of the analysis studies, design that encounters the mechanical limits of the material for all the scenarios was determined as the accepted design. There is a static loading condition for ECE-R14 analysis. In the designs, ribs were added to the areas above the mechanical limits of the material, revisions were made in the thickness of the material.

Keywords: Thermoplastic Composite, Over-Molding, Composite Design, Finite element analysis

Introduction

Composite materials which have gained rapid development over the last 50 years, widely used in aeronautical, marine, subsea, automotive and artificial legs and arms, due to their excellent mechanical properties, low density, unique mechanical characteristics, light weight, corrosion resistance and ease of manufacture (Gaikwad, 2018). Especially in the automotive sector, the trend is towards weight reduction due to the new regulations

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created to reduce CO_2 emissions. This has led the automobile industry to develop new technology for lighter parts (Schijve and Kulkarni, 2016). In addition, many automotive manufacturers stated that they will be on the market with lighter vehicles after 2021 (Schijve and Kulkarni, 2016). For this reason, it has gained importance to use polymer-based materials instead of metal parts that make up about 90% of the vehicles by weight. However, meeting the current regulation requirements of these polymer-based materials, which are intended to be used instead of metals, stands out as one of the most important issues to be considered. Due to this reasons, composite technologies are one of the most important fields of study when it comes to using polymer-based materials instead of metals. On the other hand, the composite technology must meet the competitive conditions in the automotive industry and must be designed to be suitable for mass production of parts. From this point of view, the technologies such as chopped glass fiber reinforced thermoplastic composites (GMT, Glass Mat Thermoplastics) and hybrid thermoplastic composite parts production with injection molding are shown as the most up-to-date composite part production methods, which are suitable for mass production and meet regulation requirements. Thermoplastic composites are very popular today, especially in high-volume production industries, due to the fast and environmentally friendly production processes. As an intermediate product in the production of thermoplastic composites, thermoplastic prepregs with continuous fiber additive are expected to be used more in the upcoming periods due to their lack of a special storage condition, recyclability and unlimited shelf life (European Environment Agency, 2014).

Hybrid thermoplastic composite production technology; Multiple molding finds place in the world automotive industry as an important method that enables continuous fiber reinforced composites to replace parts formed by injection molding and metal components used in vehicles (European Environment Agency, 2014). For instance this technology, battery carrier, oil tank, air conditioner carrier, bumper carrier system, seat chassis parts and so on. Many structural parts are produced with composite materials and find a place in the sector. Examples of these studies are the oil tank project produced in cooperation with NIFCO and Dupont, the composite seat study produced by Faurecia and CETIM companies, and the seat project developed by Faurecia and ZF, which was introduced in 2018 (Tian Tuo Machinery, 2018). The most important point that stands out is that the relevant composite parts are designed correctly to ensure the specified regulation. At this point, designing composite parts with computer support and verifying the regulatory requirements of the part with computer aided analysis (CAE) is one of the first and most important stages of the composite part design and production process as in other design studies. In this direction, an important step was taken about the analysis of a part that is aimed to be produced by injection method with the method of finite element analysis, and a significant contribution was made to the literature in terms of the gradual realization of the composite part design (Carello et al, 2017). As an example of studies conducted with these methods, Karpat et al. (Karpat et al, 2014) focused on the design and analysis results of the seats used in buses for weight reduction and they achieved 20% weight reduction in this study. In another study Ning et al. (Ning, Pillay, Vaidya, 2009) focused an air conditioning cover roof door. They changed material aluminum to composite and they achieved %39 weight savings and reduction of free-standing deflection of 42% (Ning, Pillay, Vaidya, 2009). Within the scope of the study, it was mentioned that composite materials can be an alternative to traditional materials.

Finite element analysis is used for progressive damage characterization in composite material analysis. In the relevant analysis method, the material properties are assigned to the mesh that forms the composite structure when the model is created. With this method, the stress and strain values calculated in the element due to the load applied to any finite element network are calculated at the integration points of the relevant element. Therefore, it is assumed that the material properties are assigned to these integration points with this method. The elements created on the model represent composite plates formed by the combination of layers (Guney, 2019; Banerjee, Sankar, 2014). In addition to this, Hypermesh program is utilized in related analysis and supports wide variety of CAD and solver interfaces making it a perfect solution for most industry verticals and domains. With its advanced geometry and meshing capabilities Hypermesh provides an environment for rapid model generation (Ferruh, 2017). Overmolding is the injection molding process where one material (usually TPE) is molded into a second material (typically a rigid plastic). Regarding overmolding, process conditions permit high mechanical properties along with good stiffness for complex parts. During the related process; one of both materials is in molten condition with low viscosity. Besides, overmolding process have many advantages such as high level of function integration and large series in production cycle and that's why it has become popular in recent years (Akkerman, Bouwman, Wijskamp, 2020). The literature studies carried out so far have been examined and it’s determined that a product at the level required by the driver's seat regulation for heavy commercial vehicles has not been observed. With this study, it is aimed to meet the ECE R14 regulation conditions required for the heavy commercial driver's seat. Based on this, the materials have been modeled using Catia V5 program, then the appropriate design is produced by using innovative overmolding technology. In addition, it is aimed to weight gain by using composite material and to shorten the part production time with the use of over-molding technology.

Materials

In this study, twill 2/2 balanced glass fiber reinforced polypropylene (PP) matrix prepreg material (OM10) was supplied from Kordsa. The technical properties of the OM10 are given in Table 1.

Table 1. Technical properties of prepreg material

Polymer type	High crystalline polypropylene (PP)
Fiber type	PP compatible 1200 tex roving glass
Fiber volume	45% by volume
Density	1,6 g/cm^3
Fabric areal weight	600 gsm
Fabric type	Twill 2/2 balanced
Melt temperature	167°C
Glass Transition Temperature	-7°C
Processing Temperature	195-215°C
Tensile strength (ISO 527-4)	385 MPa
Tensile modulus (ISO 527-4)	18,5 GPa
Thickness	3mm

During the plastic injection; Polytron P40B001 which had 40 vol.% long glass fiber reinforced PP, was used as raw material. Technical properties of related raw material are given in Table 2.

Table 2. Technical properties of polytron P40B01 material

Density	1.22 g/cm^3
Flexural Modulus (ISO 178)	9000 MPa
Flexural Strength (ISO 178)	190 MPa
Tensile Modulus (ISO 527-2/1A)	10000 MPa
Tensile Strength (ISO 527-2/1A)	125 MPa
Notched Charpy Impact @-40°C Edgewise (ISO 179-1/1eA)	18 kJ/m^2
Notched Charpy Impact Edgewise (ISO 179-1/1eA)	20 kJ/m^2
Un Notched Charpy Impact @-40°C Edgewise (ISO 179-1/1eA)	45 kJ/m^2
Un Notched Charpy Impact Edgewise (ISO 179-1/1eA)	55 kJ/m^2

Over Molding Process

Before the over molding, epoxy resin based (OM10) prepreg material was reheated at 180^{o}C for 30 seconds at industrial type infrared furnaces. After the OM10 prepreg material was activated, material was inserted to the industrial type mold with robotic arm. There after mold was closed and PP GF40 (P40B001) material was injected onto the prepreg material between 15-30 seconds. Injection process parameters are given in Table 3.

Table 3: Injection process parameters

Insert Raw Material	Epoxy Resin based (OM10) prepreg
Injection Raw Material	Polytron P40B001 PP GF40
Injection Pressure	1000 TON
Mold Temperature	60 ^{o}C
Injection Speed	50 mm/sn
Holding Pressure	80 bar
Holding Time	7 sn

Finite Element Modelling

In this study, Catia V5 program was used as design program for the vehicle seat backrest and the Hypermesh program was used for finite element analysis (FEA). The reference methodology was given in Fig.1. In order to perform FEA of overmolded thermoplastic matrix based composite material, coupon samples were prepared from the relevant materials in accordance with ISO 517-4 standards. Instron 5982 model tensile test machine was used at a speed of 2 mm/min. Tensile tests were carried out on test samples in order to create a material database and to obtain the material data required for simulations at the desired scale.

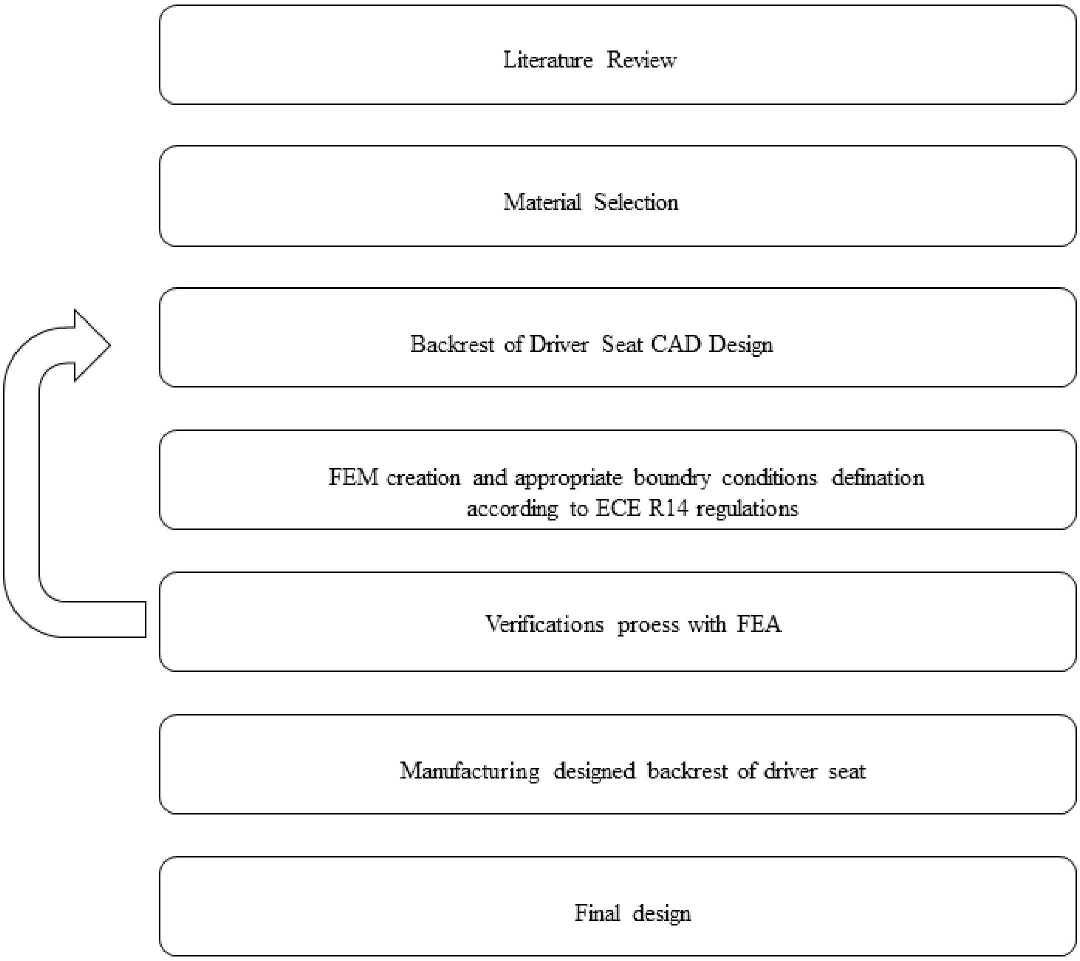

Figure 1. Flowchart of the backrest of driver seat design and analysis

As a result of the mechanical tests, various mechanical properties were obtained such as young's modulus, ultimate tensile strength and poisson ratio values. The obtained data were modelled in the Hypermesh program and solved in Radioss. Composite material's data was supported by the FEA, and a material card was created in the analysis program of the composite material. Finite element model test sample is shown in Fig. 2. Where h is the thickness of the composite material (2 mm), L_3 is the total length of the material (250 mm), L is unclamp total length (150 mm), b_1 is the width of the composite material (25 mm), L_0 is test length zone (approximately 50 mm), D is optional centering holes (5 mm).

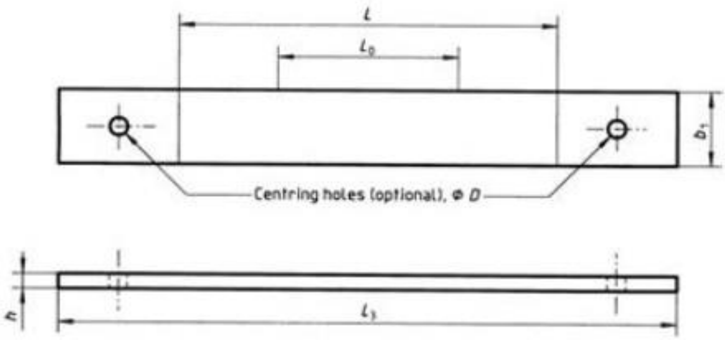

Figure 2. Finite element model test sample

After creating the material card, the model setup was done in the Hypermesh program. After removing middle surfaces of the entire structure, it was modelled using the shell element option. The element size was determined as 5 mm considering the time and model flatness. The element properties were determined by using P1_shell and QEPH24, and the number of integration points was determined as 5. All components in the seat structure were modelled with this method. OM10 and Polytron P40B001 materials in the structure were combined using the node to node merge feature. The connection between the designed composite seat back and the body was provided with mechanical joints as bolts. Defined spring element modeling was used to model the used bolts.

Composite seat-backrest part design studies were carried out in 3 revisions (code of revisions rev1, rev2, rev3) in a computer-aided environment using the Catia V5 program. According to the ECE R14 regulation requirement, the applied load was shown in Fig. 3. According to this regulation, seat belt anchorage points and seat vehicle anchorage points should maintain their structural integrity, should not exceed the maximum displacement amount given in the regulation. There should not be any sharp corners on the seat that may cause injury.

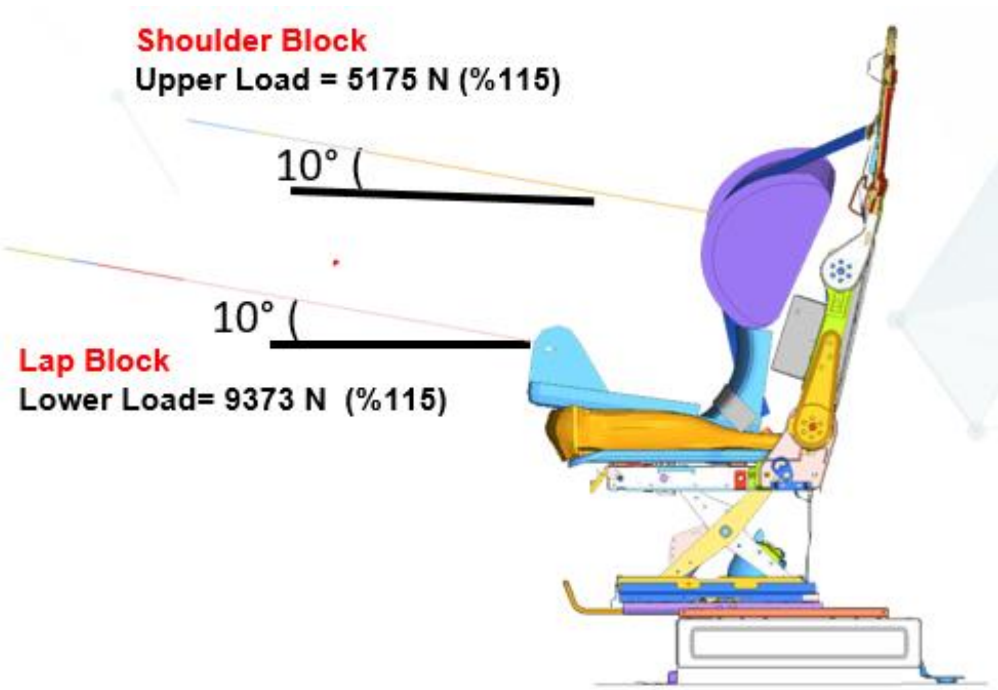

Figure 3. ECE R14 regulation virtual analysis model

Result and Discussion

The main purpose of performing virtual analysis modeling study on thermoplastic prepreg material is the finite element method modeling of (0°/90°) layered glass fiber reinforced PP matrix composite sample that mechanical properties are determined by the tensile tests and the use of this model in virtual analysis studies. In this direction, the material data used in the virtual analysis modeling studies of the relevant composite material and obtained from the tensile tests are given in Table 4

Table 4. Tensile test results of thermoplastic prepreg (OM10)

Pull Test - 0 °	Tensile Strength (MPa) - Xt	437,00
(ISO 527-4)	Young's Modulus (GPa) - E1	20,90
	Basic (Major) Poisson's Ratio	0,06
Pull Test - 90 ° (ISO 527-4)	Tensile Strength (MPa) - Xt	417,00
	Young's Modulus (GPa) – E2	19,90
	Basic (Major) Poisson's Ratio	0,08

Xt: X direction, E1:1. Module of Elasticity, E2: 2. Module of Elasticity

Stress-strain curve of tested thermoplastic prepreg sample was given in Fig.4 compared to the simulation curve data. As can be seen in Fig.4, both obtained stress-strain curves of the sample had similar characteristics. In the analysis studies, it was observed that the maximum tensile strength value was 15 % higher than the mechanical test result.

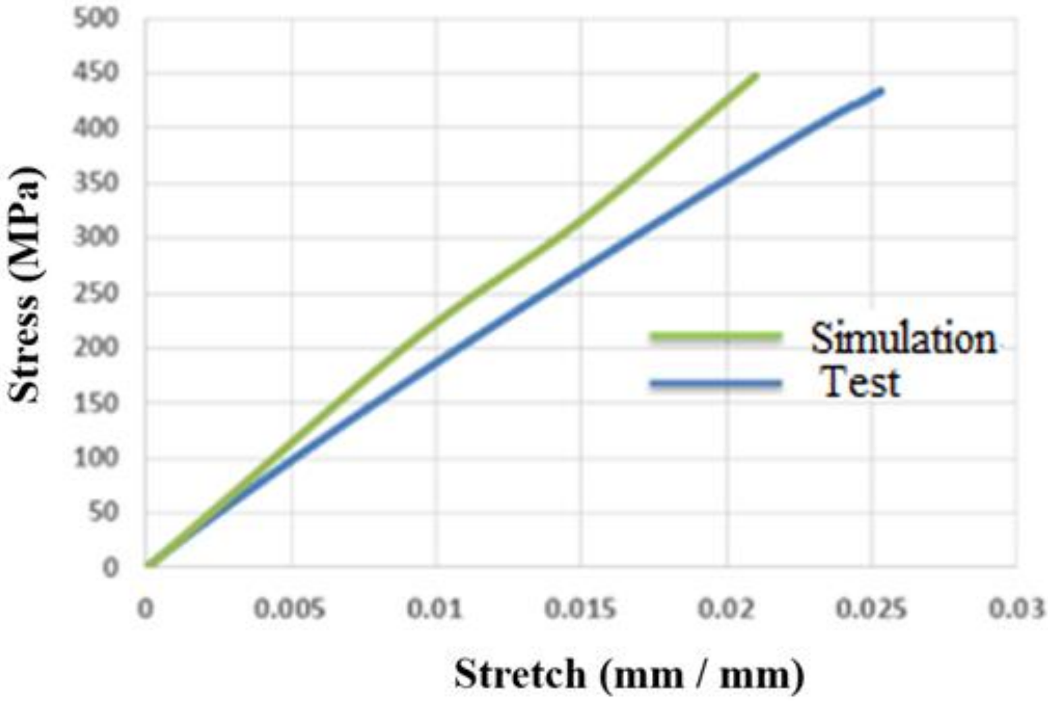

Figure 4. Stress-strain curve of tested thermoplastic prepreg sample compared to the simulation curve data

Technical information about the design studies is given in Table 5. In the Rev1 design, a U-shaped rib design was made and the effect of the stresses on the design during the ECE R14 simulation was analyzed. With the benchmark studies carried out in the Rev 2 design, the rib design in U form was canceled and a 45 ^{o} angle rib design was applied. ECE R 14 analysis results showed an improvement of approximately 13% according to Rev1. The Rev3 design, opposing 45 ^{o} angled rib designs were added to cross with previously designed 45 ^{o} angled ribs, and additional rib designs were added to the back of the seat. According to Rev 2 Approximately 45% improvement was observed in the ECE R 14 analysis results and the design studies were frozen.4

Table 5. Technical information about the design studies

Design of Rev1	
Main Material Thickness (Polytron P40B001)	3 mm
Type of Rib	U Type
Prepreg (OM10) Material Thickness	2 mm
Prepreg (OM10) Length / Width	300 mm / 100 mm
Design of Rev2	
Main Material Thickness (Polytron P40B001)	3 mm
Type of Rib / Rib Thickness	45 ^{o} angular / 1,5 mm
Prepreg (OM10) Material Thickness	2 mm
Prepreg (OM10) Length / Width	300 mm / 100 mm
Design of Rev3	
Main Material Thickness (Polytron P40B001)	3 mm
Type of Rib / Rib Thickness	45 ^{o} angular / 3 mm
Prepreg (OM10) Material Thickness	3 mm
Prepreg (OM10) Length / Width	300 mm / 100 mm

Various designs were realized depending on the examination of the metal structure in the reference seat and the research studies. Related designs are named as Rev 1-3. Criticalities were determined with the analysis made within the framework of the relevant designs, the sections in the design were changed according to these implications, and suitable load paths were created to transfer the load to other parts. In addition, design changes and improvements were made by taking the maximum stress and plastic elongation values as reference Fig. 5.

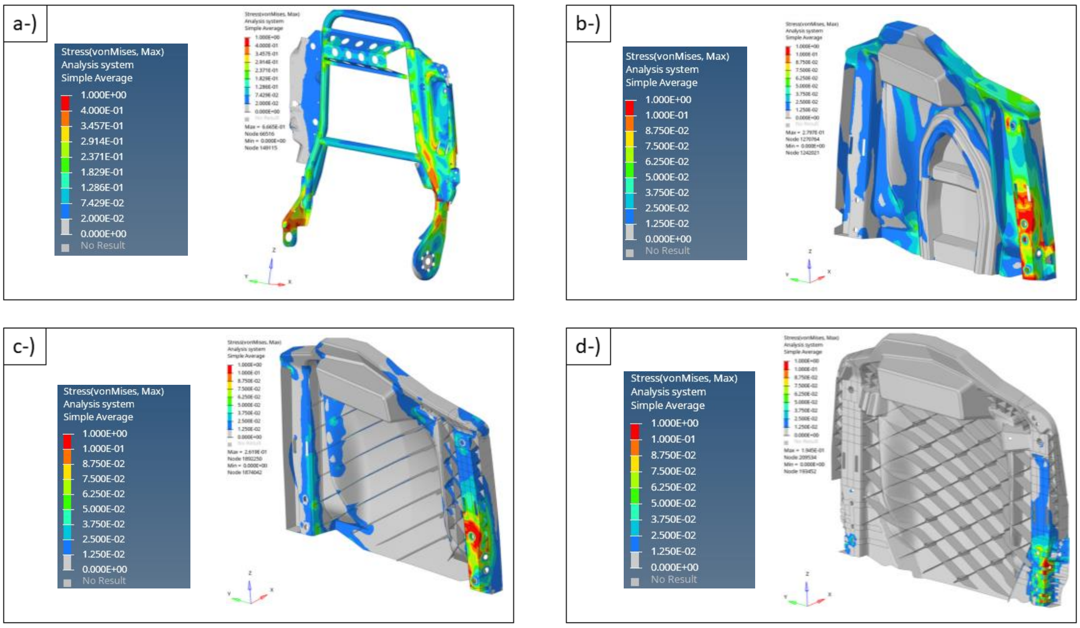

Figure 5. a-) Reference Seat Backrest(Metal), b-) Design of Rev1, c-) Design of Rev2, d-) Design of Rev3

Glass fiber reinforced polymer material was used as the material in the first phase of the design studies. Related studies were started with the reference model (metal backrest), which was carried out based on the investigation of the metal structure in the reference seat and the research studies. In this design, the structural tests applied on the metal seat frame were simulated in computer environment and the critical regions were determined by numerical analysis on a draft plastic body. ECE R14 loading results applied to various designs is given in Table 6.

Table 6. Results of maximum resultant stress on composite seat (axial and shear stress)

Reference Seat (Metal)	0,567 MPa
Design of Rev1	0,289 MPa
Design of Rev2	0,251 MPa
Design of Rev3	0,184 MPa

Conclusions

As a result of this study, sample modeling was made for finite element analysis of prepreg material with continuous glass fiber reinforced woven-based thermoplastic PP matrix, and the model correlation was achieved with the physical tests performed on the relevant sample. Then, using the material data, a finite element model was created and numerical analyzes were made on the seat.

Considering the analysis results, the design was developed and Rev3 design; It has been determined to be the best design within the scope of composite part optimization and analysis studies. Accordingly, the design phase was frozen in Rev3. The current version of the design is within the desired limit values within the ECE R14 regulation conditions

With the displacement of the metal and the composite structure, which is the main purpose of the study, a structure similar to metal in performance but lighter than metal was achieved. In this context, 1500 gr weight reduction has been achieved and success has been achieved regarding the related project target.

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