Project Title:

QUalifying and Implementing a user-centric designed and EfficienT electric vehicle

Project Acronym: QUIET

GA: **769826**

Topic:	**Electric vehicle user-centric design for optimised energy efficiency**
Topic identifier:	**GV-05-2017**
Type of action:	**RIA Research and Innovation action**

Deliverable No.	QUIET D3.1	
Deliverable Title	Hybrid foam material and demonstrator seat with weight and thermal improved parts	
Deliverable Date	2019-03	
Deliverable Type	Report	
Dissemination level	Public	
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Approved by	WP Leader (ECON) Coordinator (AIT) Quality Coordinator (HRE-G)	2019-04-03 2019-04-04 2019-04-02
Status	Draft 1.5	2019-04-04

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Publishable Executive Summary

One aim of the work described here was the development of various types of a hybrid foam material consisting of advanced pore morphology aluminium foam spheres and a polymer or a polymer foam and to provide samples for determination of relevant properties like mechanical strength or thermal conductivity. Depending on the results regarding strength, energy absorption and thermal conductivity the best suited type of material should be selected.

With the cold curing hybrid advanced pore morphology aluminium foams and the warm curing advanced pore morphology foams with higher PA12 coating thickness two foam materials are available which fulfilled the requirements.

For the further work the material with higher PA12 coating thickness was selected based on the general properties and requirements.

A further aim was to create a demonstrator seat with improved parts concerning weight and thermal properties. At the beginning the current seat structure was analysed by 3D laser scanning due to missing CAD data and the components were positioned as a group in CAD. A parts list was compiled containing dimension and weight of each component of the seat structure followed by an ABC-weight analysis. These preparatory results form the basis for the design of the QUIET lightweight seat structure. The substitution of several steel parts through aluminium and the usage of expanded polypropylene inserts in foam enables an expected weight reduction of about 16.9%_for the whole seat. A virtual test of strength of the lightweight seat structure was performed by finite elements method and taking in account load cases for the European and the American regulation. The resulting maximum Von Mises stress and the corresponding equivalent plastic strain for the loading case support the application of the new seat structure design. The aluminium prototype parts were manufactured by low-pressure die-casting including preparatory works such as casting compatible design, mould filling and solidification simulations, and manufacturing of the sand moulds. Simultaneously, sheet metal seat parts from the original Honda-seat are adapted and will be assembled with the cast-parts resulting in an aluminium-steel lightweight seat structure. At the actual date the process step to build up the improved seat is still work in progress. For economic upscaling, the profitability of several manufacturing techniques over varying seat quantities was analysed. In detail, the low pressure die casting and the high pressure die casting processes were compared for manufacturing aluminium cast parts for the QUIET seat structure. From an economic point of view, the former process is chosen for smaller quantities (below 20,000 seat structures).

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Abbreviations and Nomenclature

Table 1: List of Abbreviations and Nomenclature.

Symbol or Shortname	Description
EV	Electric Vehicle
WP	Work Package
HAPM	Hybrid Advanced Pore Morphology
APM	Advanced Pore Morphology
CAD	Computer Aided Design
FEM	Finite Element Method
EPP	Expanded PolyPropylene
LPDC	Low Pressure Die Casting
HPDC	High Pressure Die Casting
PA12	PolyAmide 12

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1. Introduction

QUIET aims at developing an improved and energy efficient electric vehicle (EV) with increased driving range under real-world driving conditions. This is achieved by exploiting the synergies of a technology portfolio in the areas of: user centric design with enhanced passenger comfort and safety, lightweight materials with enhanced thermal insulation properties, and optimised vehicle energy management.

The developed technologies will be integrated and qualified in a Honda B-segment electric vehicle validator. Among these, a novel refrigerant for cooling, combined with an energy-saving heat pump operation for heating, advanced thermal storages based on phase change materials, power films for infrared radiative heating, and materials for enhanced thermal insulation of the cabin will be investigated. Further focus is put on lightweight glazing for windows, as well as light metals like aluminium or magnesium for seat components. Optimized energy management strategies, such as pre-conditioning and zonal cooling/heating the passenger cabin as well as user-centric designed cooling/heating modules will further enhance the thermal performance of the vehicle. WP3 involves developing new lightweight vehicle components with improved thermal performance in order to reduce the entire vehicle weight and to guarantee improved passenger-compartment insulation. For the windshield, different technologies and structures based on innovative approaches will be investigated. Further, vehicle components like lightweight doors will be developed and realised by combining novel materials for enhanced thermal insulation with lightweight composites. Additionally, lightweight materials such as aluminium or magnesium will be used for realising seat-structure components for optimising the weight of the reference vehicle. All developed lightweight components (windshield, doors and seats) with improved thermal performance will be ready for integration into the reference vehicle at the end of WP3.

1.1. Description of the deliverable – Goals

One goal is to develop various types of a hybrid foam material consisting of APM aluminium foam spheres and a polymer or a polymer foam and to provide samples for determination of relevant properties like mechanical strength or thermal conductivity. Depending on the results regarding strength, energy absorption and thermal conductivity the best suited type of material will be selected.

A further goal is the implementation of a demonstrator seat with improved parts concerning weight and thermal properties. The existing steel design by Honda is the starting point for the new improved design. Target is to substitute steel with aluminium structures.

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2. Materials investigated and methods

In order to find and select the best suited type of APM material 3 different material variants were investigated:

- Hybrid APM aluminium foam
- APM aluminium foam with lower polymer coating thickness
- APM aluminium foam with higher polymer coating thickness

For the preparation of the required APM aluminium foam spheres the equipment shown in Figure 1 was used. Foamable aluminium wire with a diameter of 3 mm was cut into small granules which then ran through a conveyor belt furnace to foam them up. Behind the furnace the uncoated aluminium foam spheres were collected for manufacturing hybrid APM aluminium foam samples. For APM foam with polymer coating the warm spheres were dropped into a fluidized bed of adhesive powder.

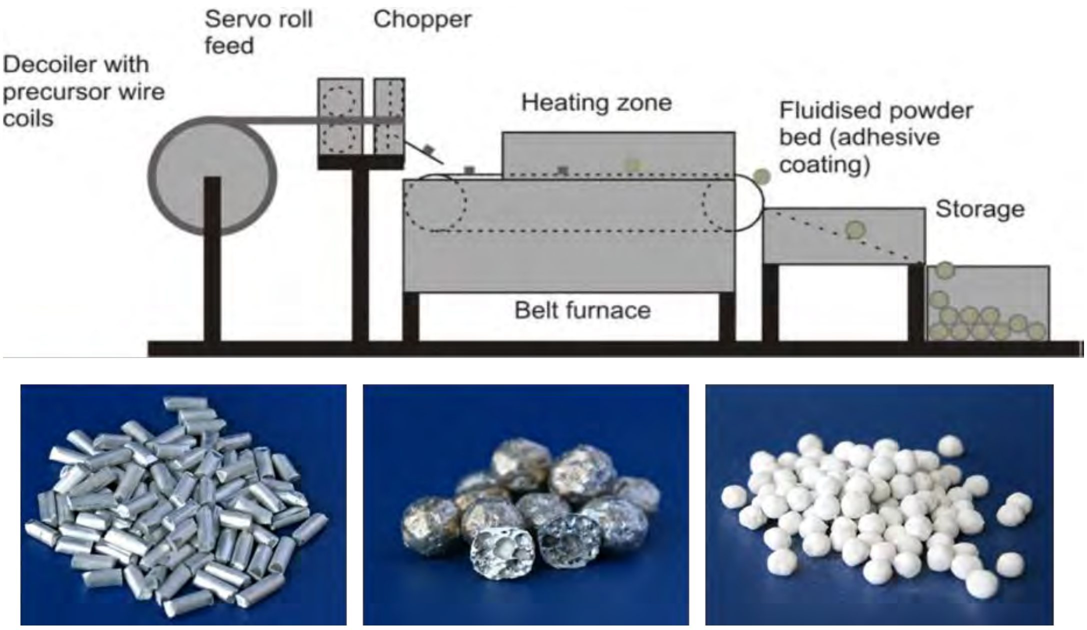

Figure 1: Preparation of uncoated and coated APM aluminium foam spheres

For the preparation of test samples of each material variant a steel mould with dimensions of about 300 x 300 x 35 mm was used. The mould was lined with Teflon film to avoid adhesion between the sample and the mould. The open mould is shown in Figure 2.

Each material variant was characterized regarding mechanical strength (ECON) and thermal conductivity (IFAM). The samples for measuring the mechanical properties and thermal conductivity had dimensions of about 35 x 35 x 35 mm. In some cases, the thermal conductivity was also measured on cylindrical specimen with a diameter of 47 mm and a height of 30 mm.

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Figure 2: Steel mould for preparing samples of dimensions ca. 300 x 300 x 35 mm

For measurement of the thermal conductivity IFAM's divided bar apparatus was used which is shown in Figure 3 (top left: real equipment; top right: schematic sketch). The specimen is placed between 2 quadratic aluminium plates of dimensions 50 mm x 50 mm. By applying slight pressure and by utilization of thermal conducting pastes or foils a good thermal contact between the sample and the aluminium plates is obtained. To generate a heat current through the sample the upper aluminium plate is electrically heated to a constant temperature of about 30 °C and the lower plate is cooled to a constant temperature of about 20 °C. The temperature difference ΔT is measured using two Pt-100-thermocouples which are integrated into the aluminium plates. From the electrical power and the temperature difference ΔT the thermal conductivity can be calculated.

Mechanical tests of 35 mm x 35 mm x 35 mm cubes were performed in uniaxial compressing mode with two different loading velocity (5 and 100 mm/min). Tested samples and the test apparatus are shown in Figure 3 (bottom right and left, respectively) where H is the initial sample height and u is the controlled displacement of the compression plate.

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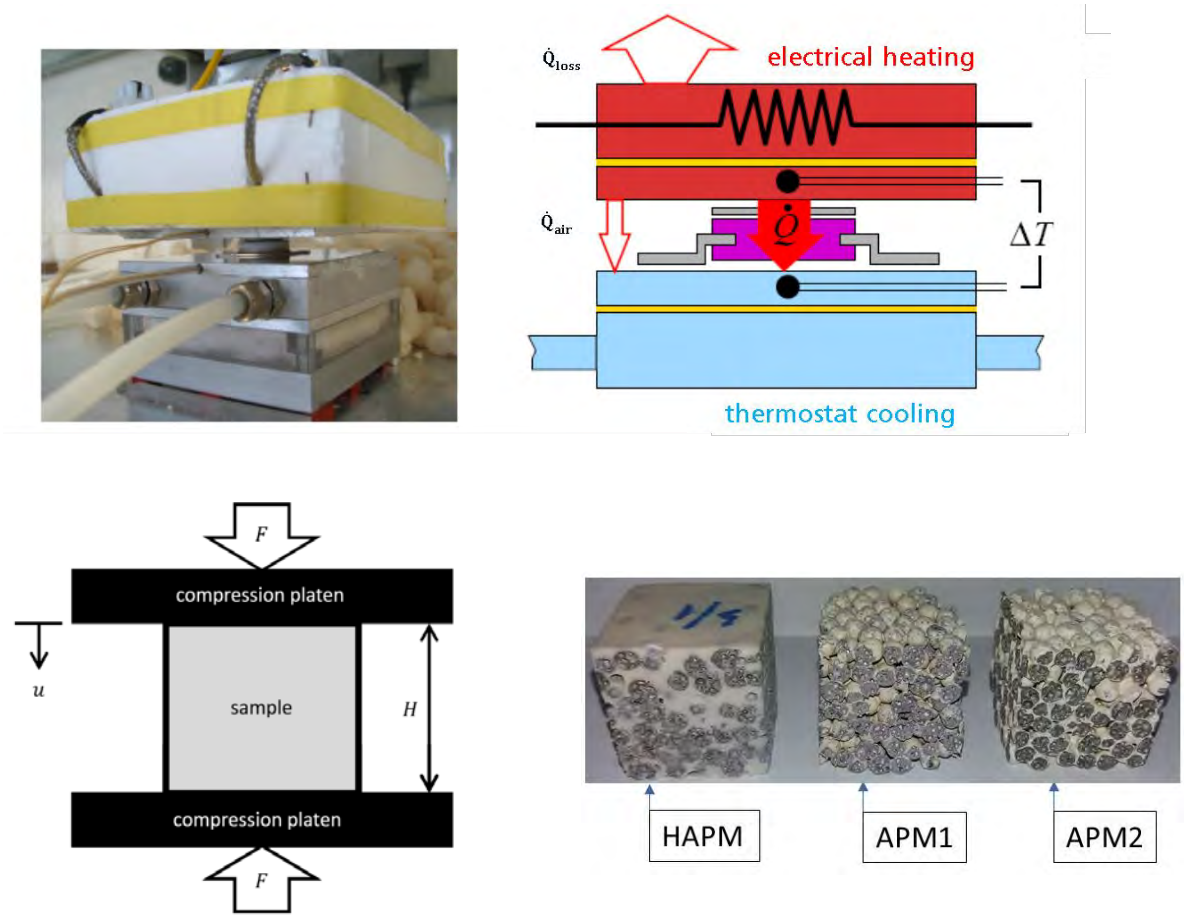

Figure 3: Divided bar apparatus for measurement of the thermal conductivity (top left) and schematic sketch (top right). Adjustment of compressive mechanical properties (bottom left) and investigated cubes (bottom right)

2.1. Hybrid advanced pore morphology aluminium foam

For the preparation of the Hybrid Advanced Pore Morphology (HAPM) aluminium foam uncoated aluminium foam spheres and a cold curing foaming epoxy adhesive system were used. First the resin RenCast CW 2215 was mixed with the hardener Ren HY 5160 and with the foaming agent DY 5054. Then the uncoated aluminium foam spheres were added, and the mixing continued until a homogeneous mixture was obtained. The mixture was filled into the mould, see Figure 4, and afterwards the mould was closed. After 2 days of curing the sample was removed from the mould. The sample had an integral density of 0.66 g/cm³ and was given to project partner ECON, which conducted the mechanical testing.

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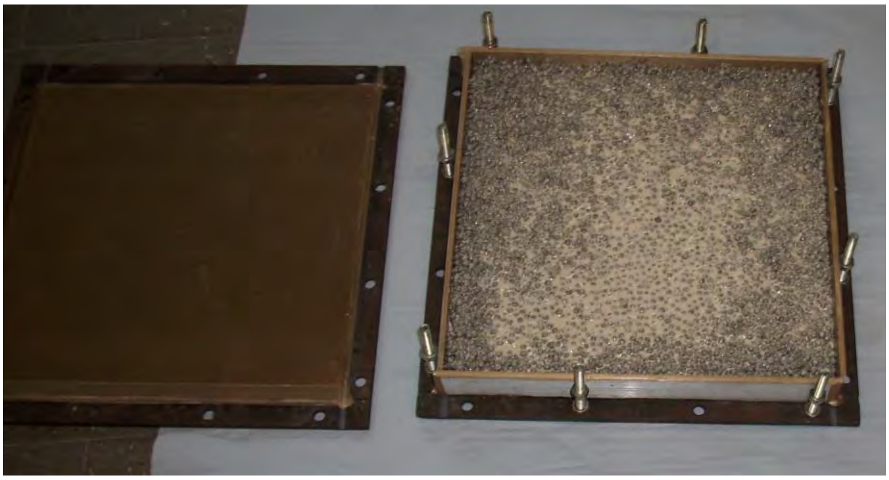

Figure 4: Mixture of APM aluminium foam spheres and epoxy system, filled into the mould

Typical stress-strain curves of HAPM are displayed in Figure 5. With the sample density of 0.65 g/cm³ the compressive strength is found to be around 8-9 MPa. The thermal conductivity was measured to be 0.73 W/m/K.

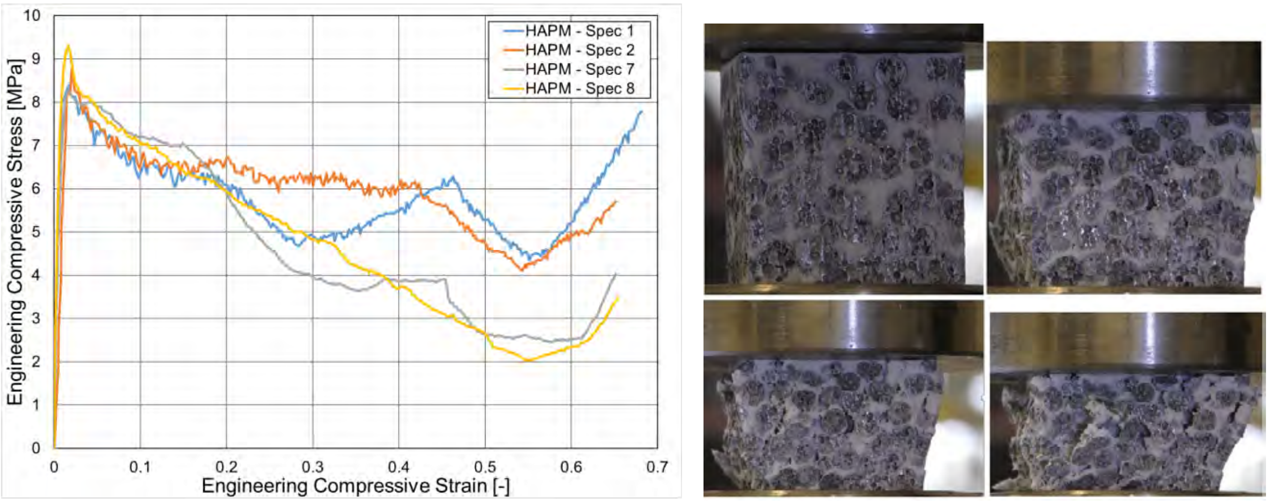

Figure 5: Typical stress-strain curves (left) and typical failure (right) of HAPM samples (ECON)

2.2. APM aluminium foam with low polymer coating thickness (APM1)

For the APM aluminium foam the polymer polyamide 12 (PA12) was selected as adhesive coating. The foamed aluminium spheres left the last heating zone of the belt furnace, see Figure 1, with a temperature of 450 °C and dropped into a fluidized bed of PA12-powder. Due to the heat stored in each sphere the PA12 powder melts and coats the aluminium foam sphere with low thickness (indicated by the acronym APM1), i.e. the ratio of PA12 to metal was measured to be around 10 % by weight of polymer.

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The PA12-coated APM spheres were filled into the mould shown in Figure 2 in a vertical position. The filled mould was put into a furnace for 2 hours at 200 °C to activate (melt) the PA12 adhesive. After cooling to room temperature, the sample was removed from the mould. The sample had an integral density of 0.50 g/cm³ and was handed over to project partner ECON, which conducted the mechanical testing.

Typical stress-strain curves of APM1 are displayed in Figure 6. With a sample density of 0.51 g/cm³ the compressive strength was found to be around 0.5-0.6 MPa (ECON). The thermal conductivity was measured to be 0.78 W/m/K (IFAM).

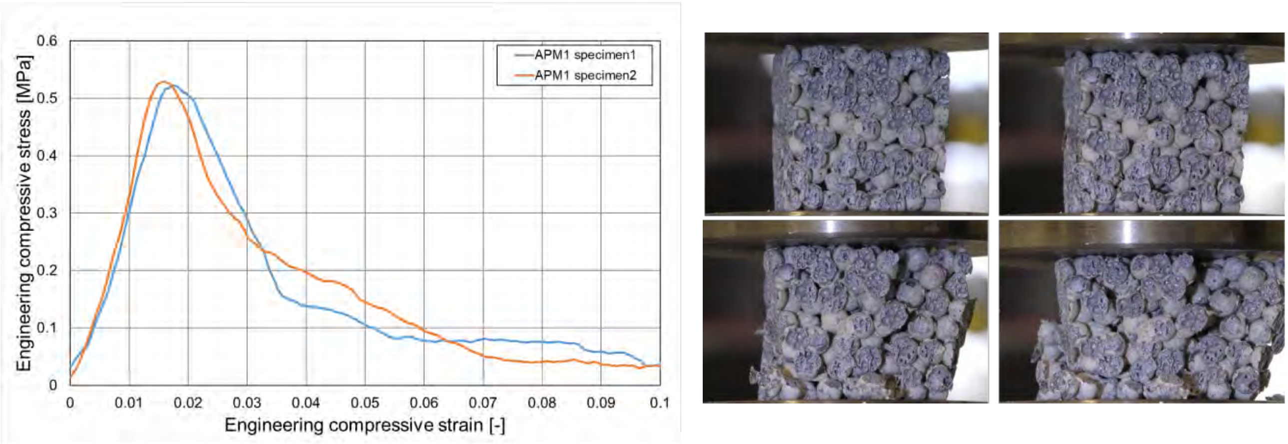

Figure 6: Typical stress-strain curves (left) and typical failure (right) of APM1 samples (ECON)

2.3. APM aluminium foam with high polymer coating thickness (APM2)

It was not possible to obtain a higher coating thickness of PA12 on the aluminium foam spheres with the equipment shown in Figure 1. Therefore, another furnace had to be used. The spheres were filled into a steel can and heated in a convection furnace to a temperature of 500°C. The warm spheres were then dropped into a fluidized bed of the PA12 adhesive powder. Due to the higher amount of heat stored in each sphere the coating thickness on the aluminium foam sphere increased (indicated by the acronym APM2). The ratio of PA12 to metal was measured to be around 26 % by weight of polymer.

The PA12-coated APM spheres were filled into the mould shown in Figure 2 in a vertical position. The filled mould was put into a furnace for 2 hours at 200 °C to activate (melt) the PA12 adhesive. After cooling to room temperature, the sample was removed from the mould. The sample had an integral density of 0.61 g/cm³ and was transferred to project partner ECON, which conducted the mechanical testing.

Typical stress-strain curves of APM2 are displayed in Figure 7. With the sample density of 0.61 g/cm³ the compressive strength was found to be around 6-7 MPa (ECON). The thermal conductivity was measured to be 1.09 W/m/K (IFAM).

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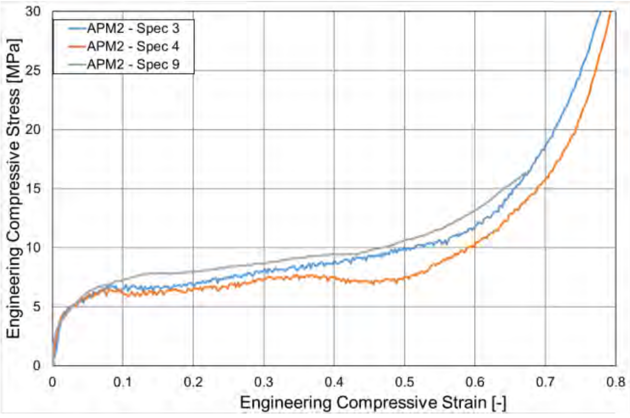

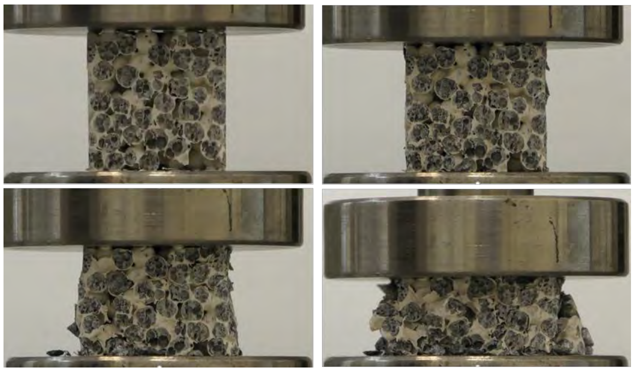

Figure 7: Typical stress-strain curves (left) and typical failure (right) of APM2 samples (ECON)

Comparing results, it can be concluded that thermal conductivity and structural density of all tested materials were in the targeted level. From viewpoint of mechanical properties e.g. the decision was simpler. The ductility and energy absorbing ability of HAPM, and both strength and energy absorbing of APM1 have not reached the required level. Mentioned materials behaved relatively rigid which is not acceptable for the targeted application as structural part of closures. APM2 had significantly better ductility than others with relatively high compressive strength so-called foam-like behaviour which makes it the best choice out of tested APM materials.

3. Demonstrator seat with weight and thermal improved parts

This section summarizes research and development work on the demonstrator seat with the objectives of improving weight and thermal properties of the components. The work is structured as follows and summarized in subsequent sections:

- Analysis of current seat structure
- Design of lightweight seat structure based on the analysis results
- Manufacturing of prototype parts including preparatory work and building up the improved seat
- Considering thermal properties of the seat to reduce thermal inertia

In order to achieve the goal of reducing the weight and thermal inertia, the current seat structure is analysed to create a starting point for the lightweight design.

3.1. Analysis of current seat structure

The analysis of the technical properties and the current seat structure (SotA Honda seat) were performed after establishing the evaluation criteria. Due to the missing CAD data 3D-Laser scanning of the structural seat parts (cp. Figure 8) were performed and the components where positioned as a group in CAD. The result from the 3D Laser scan is not a full-featured CAD data. It contains only surface data of the scanned components. The surface data is considered as a hull geometry for the design space. Due to the lack of volumetric data, it is not possible to create a FEM model of the original seat.

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Figure 8: Current seat structure in steel (left) and positioning of components as a group in CAD (right).

As a starting point for the weight reduction a list was compiled containing dimension and weight of each component of the seat structure followed by an ABC-weight analysis, i.e. distinguishing three categories in decreasing order of impact (cp. Figure 9).

part	weight [g]	Share in total weight in %	
Frame seat plate and back complete	10100	50	A 80% Weight fraktion
Complete rails	4260	21,1	
Foam part backrest	1430	7	
Foam part seat surface	1055	5,3	
headrest	750	3,7	B 15% Weight fraktion
fabric cover backrest	700	3,4	
fabric cover seat surface	400	2	
MAL driver seat	368	1,8	
Cover outside left	318	1,6	
seat belt buckle	247	1,2	
lumbar support	165	0,8	C 5% Weight fraktion
Fasteners MAL	140	0,7	
Cover outside right	74	0,4	
Cover inside left	73	0,4	
Cover inside right	41	0,2	
Cover handle	31	0,1	
Cover backrest adjustment	21	0,1	
Guide headrest left	17,6	0,1	
Guide headrest right	17,5	0,1	
Weight total	20 208	100	

Figure 9: Parts list and ABC weight analysis of the current Honda seat structure.

One insight of the weight analysis was, that around 83 % of the seat weight are shared by only four parts: the “frame seat plate and back complete” (~ 50 %), the “complete rails” (~ 21.1 %), the “foam part backrest”

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(7 %) and the “foam part seat surface” (5.3 %). The task partners STS und AIT-LKR agreed not to modify the complete rails. So, the component “frame seat plate and back complete“ was selected for the potentially first weight reduction with the goal to reduce the weight from 10 kg to about 8.5 kg (~15 %) through substitution of steel with aluminium alloy structure.

3.2. Design of lightweight seat structure

The corresponding design space was evaluated to develop concepts with lower weight and enhanced properties. To get a benchmark for the mechanical properties, simulations of the original Honda seat were performed and compared with simulations of developmentally, design iteration-based seat concepts. The first design iteration was finalised within 3 months (cp. Figure 10, left picture).

Figure 10: Stages during design phase. Left: 1st iteration (aluminium parts in blue, steel parts in grey colour), Right: final aluminium steel seat structure.

The final result for an aluminium steel lightweight seat is depicted in the design structure in Figure 10 on the right side. The concept of the new lightweight seat structure was designed and structurally analysed by the CAD-tool CATIA. Already in the design phase the test of strength was performed by applying a static load of 3000N in horizontal direction normal to the headrest mounting support by using the CAD-program with a finite element model for calculating the Von Mises stress (which allows to predict deformation of materials under complex loading e.g. in the nodal values). As expected and also observed early during design phase, the highest stress values are in the region were the frame seat plate and the back complete are connected (cp. Figure 11).

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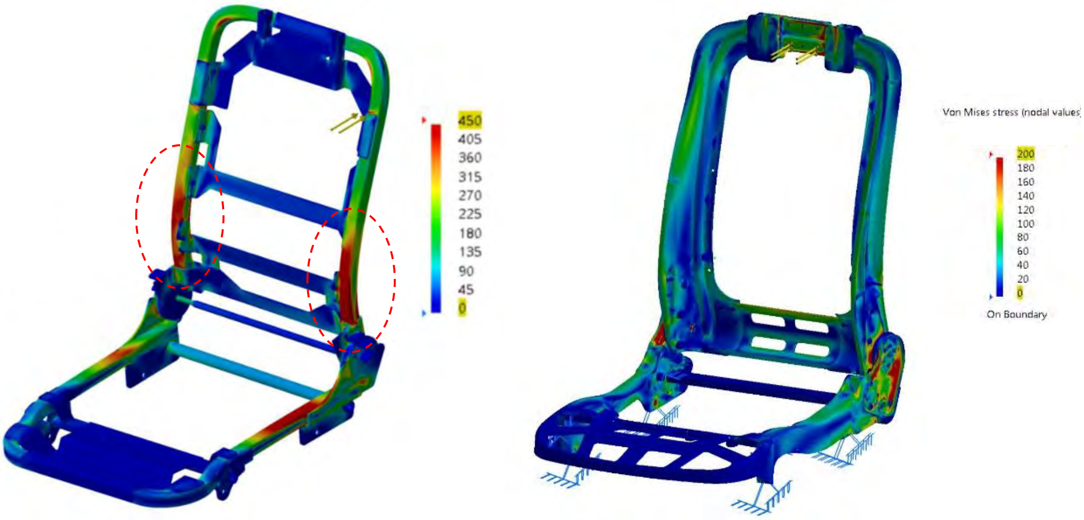

Figure 11: Test of strength results during CAD-design phase for 1st design iteration (left) and final lightweight aluminium steel seat structure (right).

Through lightweight design the stress could be minimised so that its maximum value is below 250 MPa as can be seen in the Von Mises stress distribution in Figure 11 (image on the right side). A detailed test of strength study considering two load cases according to UN ECE R17 (6.2) and FMVSS 571.207 (S4.2. d) are discussed in section 3.3 (Virtual test of strength of the seat structure by finite elements method).

In addition to the structural parts of the seat, the foam material of the seat can also be substituted. The foam material mentioned in the ABC-weight analysis among the 80 % weight fraction.
Figure 12 depicts the determined new QUIET aluminium / steel seat structure and the proposed expanded polypropylene (EPP) inserts are enabling an expected total weight reduction of about 16.9 %_for the whole seat.

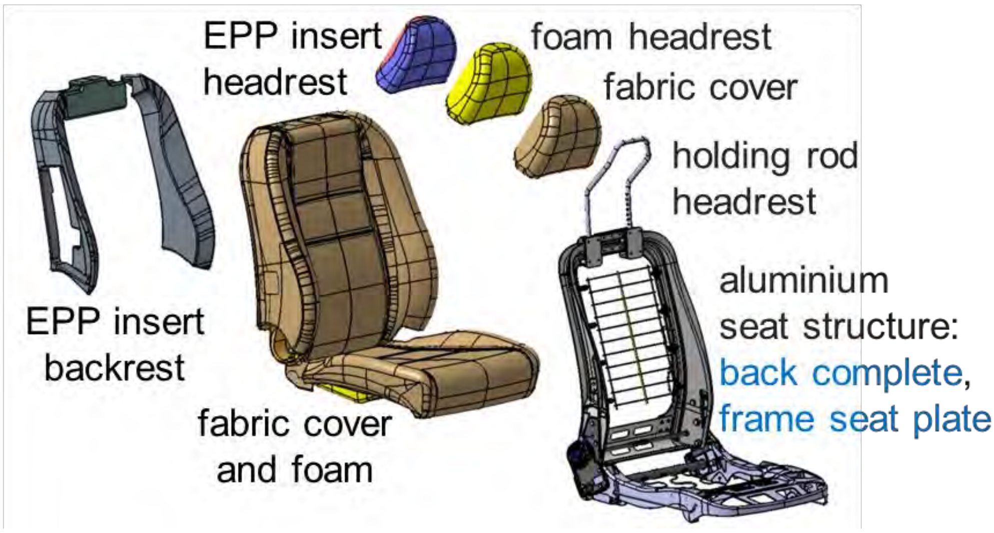

Figure 12: New aluminium / steel seat structure with Expanded Polypropylene (EPP) insert in foam

The results of the weight analysis for the new QUIET aluminium / steel seat structure are listed in Table 2, clearly showing a weight reduction from approx. 20 to below 17 kg due to lightweight design.

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Table 2: Weight analysis for the new aluminium-based seat

		Bauteil	Material	Dichte [g/cm³]	Volumen [cm³]	Gewicht [g]	Stückzahl	Gesamtgewicht [g]				ALT	Reduzierung [%]
Rahmenkonstruktion - komplett	Sitzschale	Grundrahmen	Aluminum/Guss	2,7	807,9	2181,3	1	2181,3	3570,5	7769,8	16793,6	20208,1	16,90
		Blech Versteller LI/RE	Stahl	7,85	28,7	225,5	2	450,9					
		Befestigung Versteller	Stahl	7,85	1,3	10,3	2	20,6					
		Verstärkung Rohr	Stahl	7,85	75,3	591,3	1	591,3					
		Federn	Stahl	7,85	7,0	54,7	4	218,7					
		Drähte Sitzrahmen	Aluminum	2,7	34,4	92,9	1	92,9					
		Befestigung Federn	Aluminum	2,7	1,4	3,7	4	14,8					
	Lehne	Grundrahmen (Seitenteil) li	Aluminum/Guss	2,7	396,8	1071,4	1	1071,4	2808,9				
		Grundrahmen (Seitenteil) re	Aluminum/Guss	2,7	390,8	1055,3	1	1055,3					
		Blech Versteller LI/RE	Stahl	7,85	13,6	106,9	2	213,8					
		Schweißmutter	Stahl	7,85	0,4	3,1	3	9,4					
		Verbindung Blech Unten	Aluminium	2,7	63,3	170,9	1	170,9					
		Bleche_KS	Aluminium	2,7	15,0	40,5	2	81,0					
		Rückengitter	verschieden			82,8	1	82,8					
		Federn	Stahl	7,85	1,4	10,8	8	86,5					
		Draht für Airbag	Aluminium	2,7	9,1	24,6	1	24,6					
		Befestigung Federn	Aluminum	2,7	0,6	1,6	8	13,2					
	Verstelleinheit	Drehachse	Stahl	7,85	28,1	220,8	1	220,8	1390,3				
		Rastbeschlag	Stahl	7,85	59,2	373,0	2	746,0					
		Drehfeder	Stahl	7,85	27,4	192,0	1	192,0					
		Mitnehmerscheibe	Stahl	7,85	5,1	39,9	1	39,9					
		Lehnenverstellung komplett (Bleche	Stahl	7,85	20,9	164,4	1	164,4					
		Mitnehmerzapfen	Stahl	7,85	3,5	27,2	1	27,2					
Polster	Kopfstütze	Tragstange	Stahl	7,85	53,2	417,8	1	417,8	598,4	3551,2			
		Kern (Zweiteilig)	EPP	0,04	1470,8	58,8	1	58,8					
		Schaum	PUR	0,055	1010,5	55,6	1	55,6					
		Bezug	Stoff	0,3	220,8	66,2	1	66,2					
	Sitz	Schaum Sitzfläche	PUR	0,055	16353,6	899,4	1	899,4	1299,4				
		Bezug Sitzfläche	Stoff			400,0	1	400,0					
	Rücken	Schaum Rückenpolster	PUR /geteilt	0,055	15160,9	833,9	1	833,9	1653,4				
		Einleger Rücken LI	EPP	0,04	1299,2	52,0	1	52,0					
		Einleger Rücken RE	EPP	0,04	1279,5	51,2	1	51,2					
		Einleger Rücken oben Mitte	EPP	0,04	409,2	16,4	1	16,4					
		Bezug Lehnenfläche	Stoff			700,0	1	700,0					
Übernahme	MAL	MAL	verschieden			368	1	368,0	480,4	4987,4			
		Befestigung MAL	Aluminium	2,7	41,64	112,428	1	112,4					
	Sonst.	Stellschiene	Stahl			4260	1	4260,0	4507,0				
		Gurtschloss	verschieden			247	1	247,0					
Kunststoffteile	Verkleidung	Abdeckung Griff	Kunststoff	0,9	37,63	33,9	1	33,9	485,2	485,2			
		Abdeckung aussen links	Kunststoff	0,9	331,34	298,2	1	298,2					
		Abdeckung aussen rechts	Kunststoff	0,9	81,13	73,0	1	73,0					
		Abdeckung innen links	Kunststoff	0,9	44,51	40,1	1	40,1					
		Abdeckung innen rechts	Kunststoff	0,9	44,51	40,1	1	40,1					

3.3. Virtual test of strength of the seat structure by finite elements method

The test of strength of the seat-back of a car seat has been performed virtually with the Finite Element Method (FEM). Two load cases were considered according to two regulations: UN ECE R17 (6.2) and FMVSS 571.207 (S4.2. d). The material properties of the actual aluminium alloy were not available at the time of simulation and hence, the material properties of a different but comparable aluminium alloy have been used. The backrest strength test has been simulated for different seating positions to investigate the worst-case scenario. The simulations will be repeated, by the time the material model of the actual used casting material is available. The material characterisation will be performed as part of the project and the results will be mentioned in a later report (i.e. D3.2).

Finite Element Model

A finite element model has been built based on the simplified geometry of the modified seat (cp. Figure 13). The geometry has been simplified based on engineering judgement, practical aspects, and the degree of details relevant to the finite element simulation.

The FE-model consists of 2D shell elements and 3D solid elements. The components are discretized with shell elements if their thicknesses are small enough to assume a state of plane stress. Since a 3D stress state is inevitable, 3D solid elements were used to model the components which consist of bulk material. The mechanical joints are modelled with special contact definitions without any failure criteria.

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Figure 13: CAD model of the seat geometry (left) and FE-model of the seat geometry (right)

Material Model

A non-linear elastic-plastic material model has been used to describe the material behaviour of the seat structure. The material model is based on the Von Mises constitutive law. This is the most commonly used material model in crashworthiness simulation. The flow curve of a comparable aluminium alloy has been used since the flow curve of the actual material was not available at the time of simulation.

Boundary Conditions

Appropriate boundary conditions were applied based on the seat mechanism and the requirements according to the regulations (UN ECE R17, and FMVSS 571.207). The boundary conditions were applied by nodal constraints.

Load Cases

Two load cases were considered from two regulations: (1) UN ECE R17 and (2) FMVSS 571.207. The UN ECE R17 is the European regulation concerning the approval of vehicles regarding the seats whereas FMVSS 571.207 is the American standard for vehicle seating systems.

According to the UN ECE R17 (section 6.2), a force producing a moment of 530 Nm should be applied on the seat-back frame whereas, according to FMVSS 571.207 (section S4.2 d), a force producing a moment of 373 Nm should be applied on the seat-back frame. Since UN ECE R17 is more conservative than FMVSS 571.207 for this specific load case, the moment magnitude of 530 Nm to stay on the safe side is applied.

According to both regulations, the force should be applied with respect to the seating reference point. Usually, the seating reference point for each seating position should be provided by the seat manufacturer and/or it should be determined with the help of a 3D H-point machine (Figure 14). 3-D H-point machine means the device used for the determination of "H" points. The detailed description of the H-point and the H-point machine can be found in [1].

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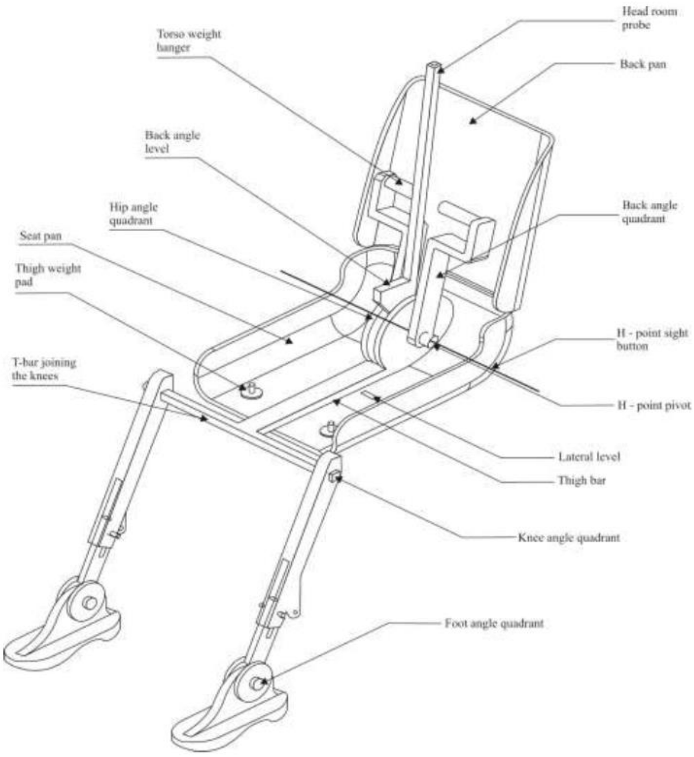

Figure 14: 3D H-point machine [1]

The 3D H-point machine should be placed on the seat to determine the location of the H-point. A detailed procedure of determining the seating reference point can be found in [1].

Figure 15: SAE J826 H-point manikin [2]

However, in this case, the seating reference point was not available from the manufacturer. In addition, determining the seating reference point with the help of a 3D H-point machine was out of the scope of this

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project. Therefore, the location of the seating reference point has been approximated based on Figure 14 and Figure 15 as shown in Figure 16.

Figure 16: Approximated H-point of the seat in the FE-model

According to the UN ECE R17, the force should be applied to the upper part of the seat back frame through a component representing the back of a manikin shown in Figure 14 or Figure 15. Furthermore, according to FMVSS 571.207, the force should be applied to the upper crossmember of the seat back as shown in Figure 17.

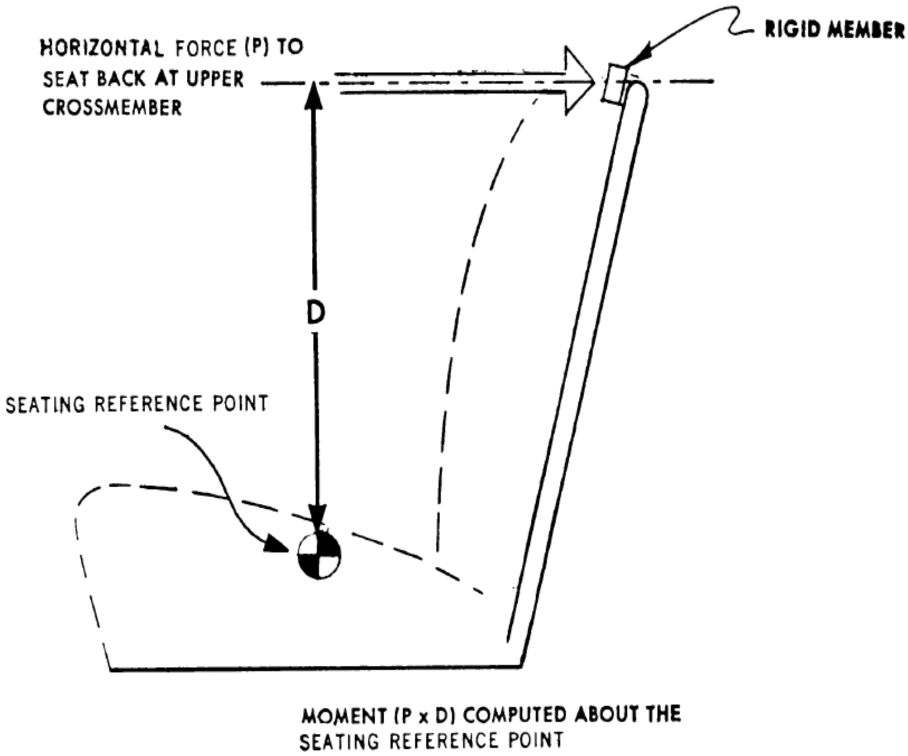

Figure 17: Loading scenario according to FMVSS 501.207 [3]

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The force according to UN ECE R17 (530 Nm) is higher than that in FMVSS (373 Nm). Hence, we have chosen the force from UN ECE R17 to be on the save side. However, the FMVSS describes the loading scenario more clearly, whereas the UN ECE R17 does not tell us how the load should exactly be applied. Hence the loading scenario from FMVSS is adopted with a slight simplification: uniformly distributed nodal forces have been applied over a small area instead of a single force. The reason is to avoid singularity problems and numerical instability consequently in the FE-simulation.

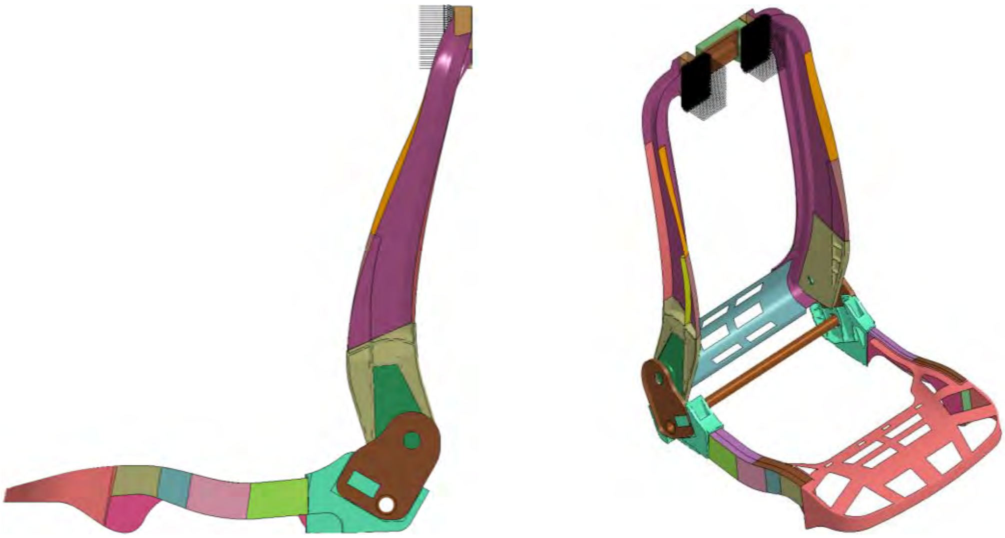

Figure 18: Uniformly distributed nodal forces in FE-model of the car seat. Unlike Figure 13 (right), the mesh cannot be seen because the mesh is turned off for a better visualization of the loading.

The seat-back of a car seat can be adjusted at various inclined positions. The structural response of the seat in different position will be different under the loading condition mentioned above. Hence, the backrest strength test has been simulated for seven different positions starting from the vertical position of the seat back until a maximum inclination of 30° as shown in Figure 19 (top and middle).

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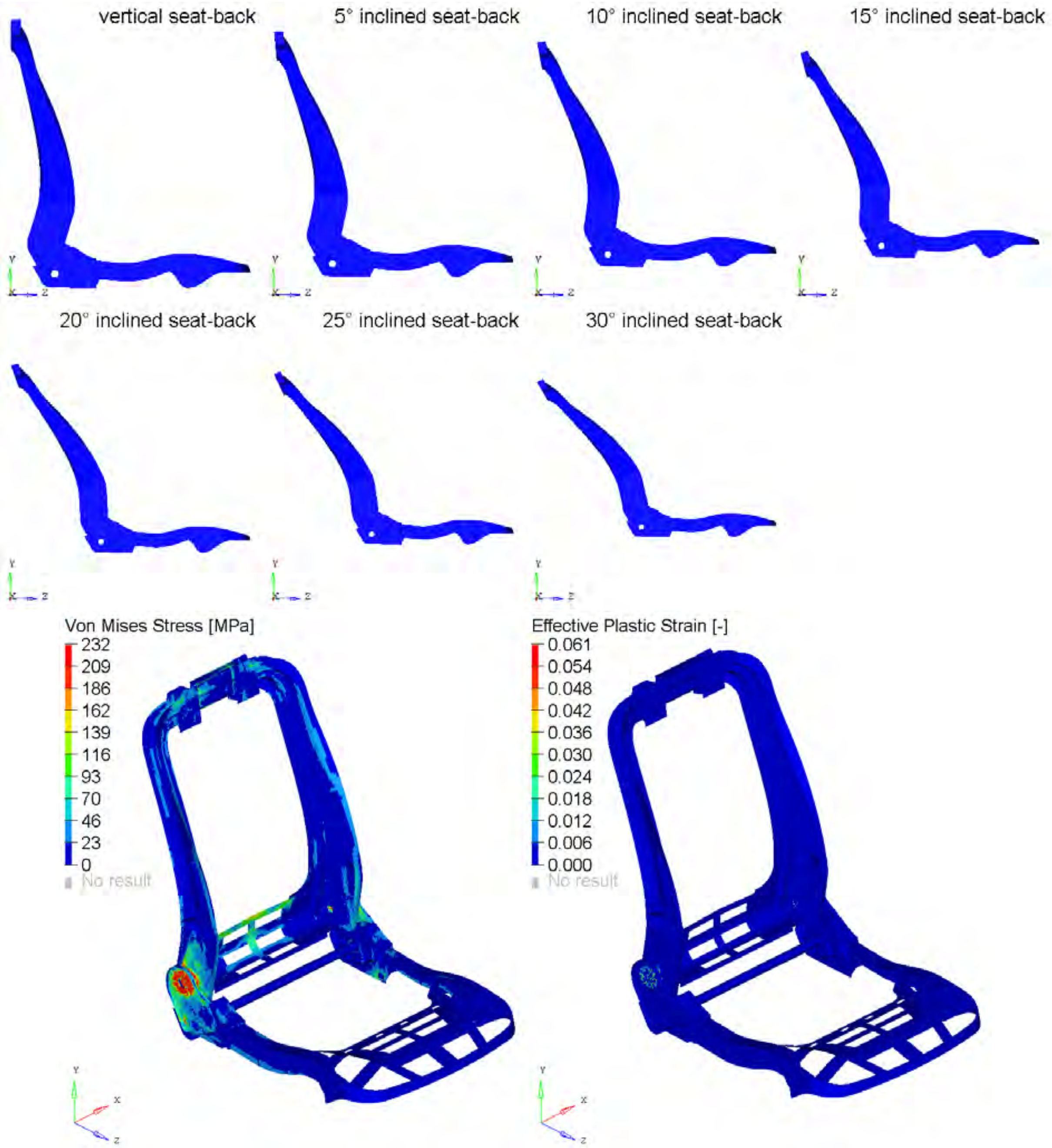

Figure 19: Different position of the seat-back (top and middle) and identified worst-case at 5° inclination (bottom left and right)

The seat-back at 5° inclination has been found to be the worst-case scenario. The maximum Von Mises stress and the corresponding equivalent plastic strain for this loading case has been found to be 232 MPa and 0.061, respectively (cp. Figure 19 bottom, left and right).

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3.4. Manufacturing of prototype parts, build-up of the improved seat

The lightweight (aluminium) prototype parts for the assembly of the QUIET seat structure were manufactured by means of low-pressure die casting (LPDC). Figure 20, left, depicts the applied LPDC-process exemplarily for the produced seat frame components (center). The casting sand mould halves (cp. Figure 20, right) were manufactured within preparatory works of the low-pressure die casting processes setup.

Figure 20: LPDC-process (left), pre-burred seat frame components (center) and the two assembled mould halves (right)

The preparatory work starts with the casting-compatible design of selected seat structure components and the creation of a casting concept for LPDC. This step contains:

- Design of sprue / feeder / core
- Cooling concept design (local iron chill), and
- Defining casting process parameters: filling curves / holding times.

In Figure 21 the necessary preparatory works are summarized: casting compatible design, mould-filling and solidification simulation, and designing and manufacturing of casting sand moulds. The design of sprue/feeder/core and the mould-filling and solidification simulation is an iterative process. The final mould-filling and solidification simulation of the design predicts cast parts without casting defects (e.g. shrinkage cavities). According to that specifications the casting sand mould was designed and manufactured.

Through LPDC three seat frame components of steel material were substituted with aluminium. Those components are one frame seat plate and two parts for the back complete. Consequently, the raw back complete frame is comprised of two vertically aligned aluminium cast parts which are connected by metal sheet parts (headrest holder on top and a formed metal sheet on bottom). For pursuing illustration purposes, the comparison with Figure 12 is mentioned here. The casted aluminium seat frame components are mechanically processed by milling at a third-party company followed by a heat treatment. For the components the T6 heat treatment is applied which consists of solution annealing followed by quenching and artificial ageing for precipitation hardening. Due to the treatment a considerable increase in strength is achieved by generating finely distributed, brittle precipitates.

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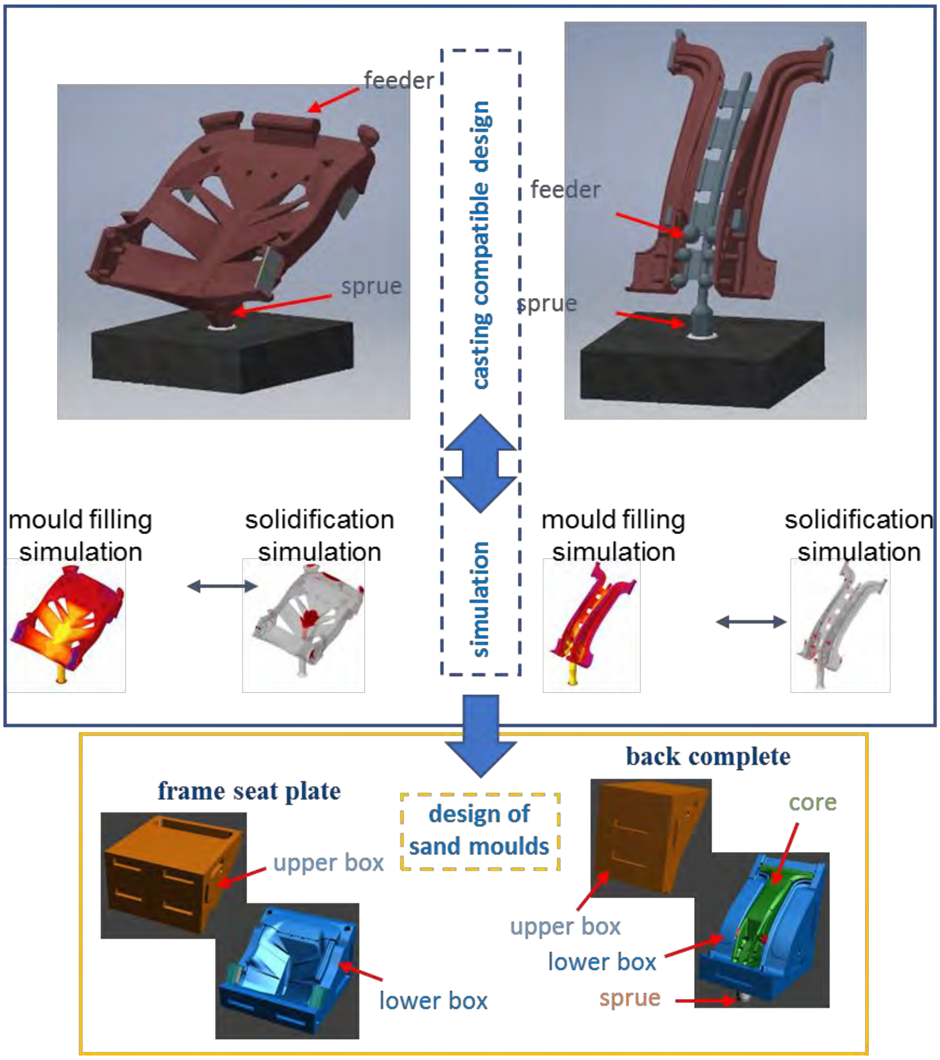

Figure 21: Summary of preparatory works: casting compatible design for the cast parts, mould-filling and solidification simulation and design of casting sand moulds.

Simultaneously, sheet metal seat parts from the original Honda-seat are adapted and will be assembled with the cast-parts resulting in an aluminium-steel lightweight seat structure. Figure 22 shows the head rest holder (left picture) and the metal sheet for bottom of back complete, both, combining the aluminium cast parts for one back complete structural component.

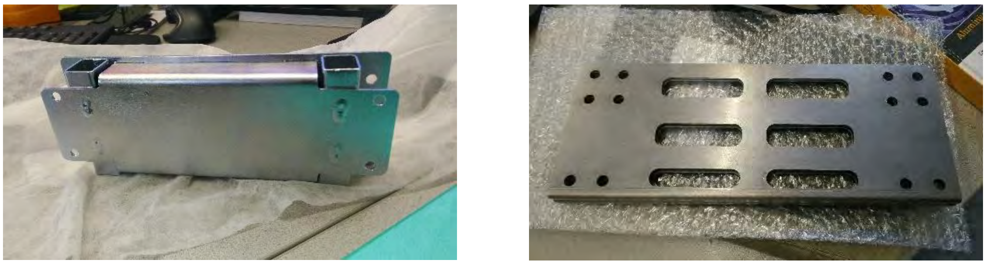

Figure 22: Forged sheet metal parts for assembling the back complete.

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After milling the foam and EPP parts, the prototype seat structure is assembled. Due to several necessary iteration loops in the design phase as well as extended delivery period for mechanical processing by milling the work is still in progress in the task T3.4.
For economic upscale, the analysis of the profitability for several manufacturing techniques over varying seat quantities is an important issue. For the casting parts of the seat structure low-pressure die-casting (LPDC) and high-pressure die-casting (HPDC) manufacturing technique were investigated over varying cast part quantities. Although those manufacturing technologies cannot be easily compared, the results for the actual cast parts clearly show that HPDC technique is preferable for higher seat structure volumes. Even if the acquisition costs and fixed costs for HPDC plant are higher, the investment amortizes due to significantly shorter cycle times. The productivity depends on the complexity of the cast parts. Assuming for the existing cast components the productivity of HPDC technique is three times higher as LPDC, the cost per casted seat (three cast components per seat in one production step) is lower as soon as more than 20,000 process cycles are performed. The cost of cast parts per seat in dependence on the amount of seat structures are shown in Figure 23.

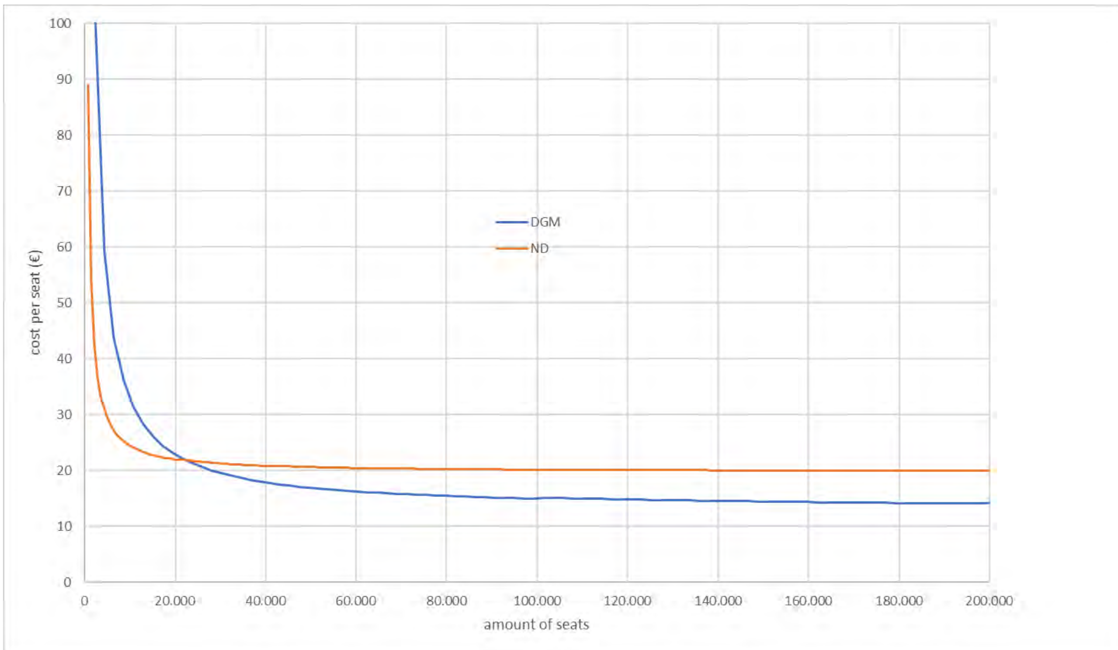

Figure 23: Cost of cast parts per seat vs. amount of seat structures, comparing LPDC (orange line) and HPDC (blue line) technique.

The figure clearly demonstrates that for lower amount of seat structures the LPDC is the process of choice due to lower fixed costs (less maintenance for plant and mould). Here in the calculation a mould of steel (permanent mould) is considered. With increasing amount of seat structures the HPDC rapidly amortizes due to much lower process cycle times and thus higher productivity.
The thermal properties of the prototype seat structure are considered with the aim to reduce the thermal inertia. For instance, the seats will heat up faster in colder seasons. However, this cannot be obtained by simply changing from steel-based alloys to light metals, as the steel has a lower heat capacity. In order to achieve the goal of improved thermal properties, the design of the structure and, even more important, the foam materials must be optimized, considering the thermal properties. For thermal improvements it is proposed to use a grid as support in the back (instead of plastic and EPP inserts in the headrest) and in the backrest as well. Practical approaches for thermal improvements in the entire seat structure are shown in Figure 12 and considered in task T3.5.

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4. Conclusions

With the cold curing hybrid aluminium foams (HAPM) and the warm curing APM foams with higher PA12 coating thickness (APM2) two foam materials are available for the further work based on the general properties and requirements.

Furthermore, a demonstrator seat with improved weight and thermal properties was investigated. At the beginning the current seat structure was analysed by 3D laser scanning due to missing CAD data and the components were positioned as a group in CAD. A parts list was compiled containing dimensions and weight of each component of the seat structure followed by an ABC-weight analysis. These preparatory results form the basis for the design of the QUIET lightweight seat structure. The substitution of several steel parts by aluminium and the usage of expanded polypropylene inserts in foam enables an expected weight reduction of about 16.9% for the whole seat. A virtual test of strength of the lightweight seat structure was performed using the finite elements method taking into account load cases for both, the European and the American regulation as well. The resulting maximum Von Mises stress and the corresponding equivalent plastic strain for the loading case support the application of the new seat structure design. The aluminium prototype parts were manufactured by low-pressure die-casting including preparatory works such as casting compatible design, mould filling and solidification simulations, and manufacturing of the sand moulds. Simultaneously, sheet metal seat parts from the original Honda-seat were adapted and will be assembled with the cast-parts resulting in an aluminium-steel lightweight seat structure. At the actual date the process step to build up the improved seat is still work in progress. For economic upscaling, the profitability of several manufacturing techniques over varying seat quantities was analysed. In detail, the LPDC and the HPDC processes were compared for manufacturing aluminium cast parts for the QUIET seat structure. From an economic point of view, the former process is chosen for smaller quantities (below 20,000 seat structures).

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6. Acknowledgment

European Union's Horizon 2020 research and innovation programme

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The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

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4	**QPD**	qpunkt Deutschland GmbH	Germany
5	**VEN**	VENTREX Automotive GmbH	Austria
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