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CHARACTERISATION OF THERMOPLASTIC FOAM CORE MATERIALS FOR SANDWICH APPLICATIONS UNDER CRASH LOAD

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1. ABSTRACT

Based on the requirements on the overall vehicle like driving dynamics, comfort, safety, ergonomics, costs, environmental safety and image the specific requirements on body-in-white components can be derivate. An important task of the material pre-selection is the mechanical properties and the structural requirements for each specific component. In the presented talk the developed method for material pre-selection is described for a firewall, which functions as a shear field. A firewall influences significantly the torsional stiffness of the body-in-white and as secondly protects the occupants during for all front crash load cases. Due to the main advantages of fiber reinforced thermoplastics, which have improved impact resistance compared to thermoset composites, a thermoplastic composite, consisting out of a PA6 skins and a homogeneous PA6 core is chosen as material.

In the presentation the characterization of the foam material and the subsequent development of the numerical description of PA6 sandwich core for dynamic loading conditions are shown.

2. INTRODUCTION

In the research project Next Generation Car (NGC) at the German Aerospace Center (DLR), three different novel vehicle concepts are being developed: Urban Modular Vehicle (UMV), Safe Light Regional Vehicle (SLRV) and Inter Urban Vehicle (IUV). The objective of this project is the cross-linking of different technologies, methods and tools for the holistic development of vehicles of the future in terms of vehicle design, vehicle structure, power and thermal management, vehicle intelligence and power train. The concept considered in this work is the Urban Modular Vehicle (Fig. 1) with a modular and multimaterial body-in-white.

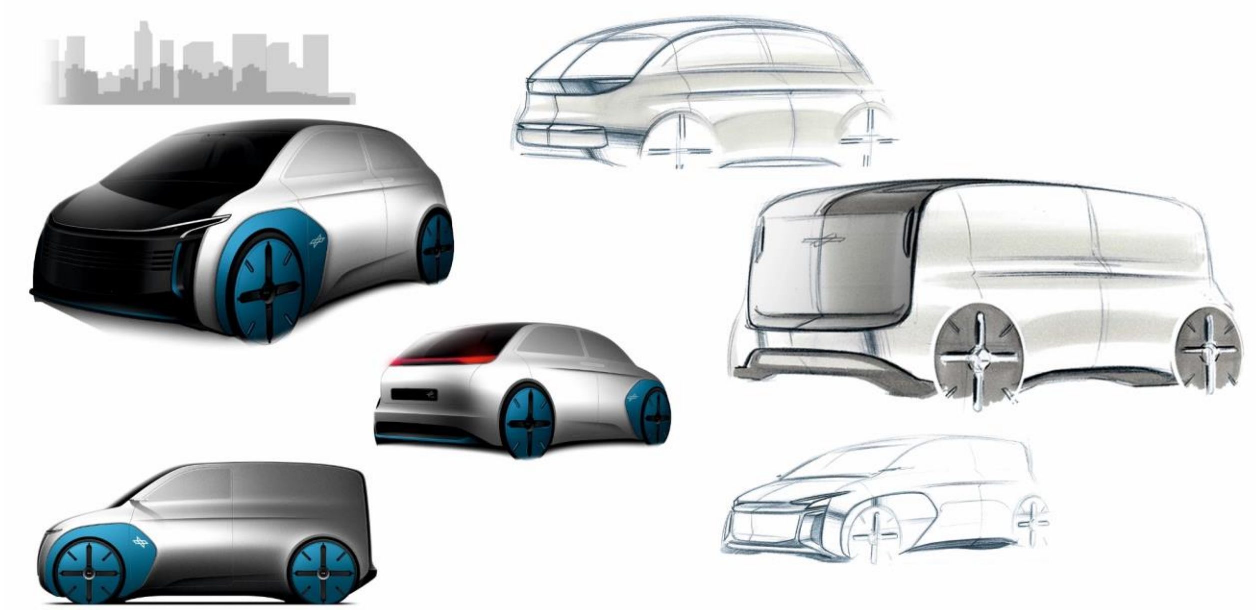

Fig. 1: Concept design of the Urban Modular Vehicle [1]

One starting point to reduce CO_2 emissions is to reduce vehicle mass and related driving resistances by using lightweight construction methods and new material combinations and manufacturing technologies. [2]

3. REQUIREMENTS FOR BODY-IN-WHITE PARTS UNDER CRASHLOAD

Based on the requirements on the overall vehicle like driving dynamics, comfort, safety, ergonomics, costs, environmental safety and image the specific requirements on body-in-white components can be derivate. An important issue of the pre-selection is the mechanical property objective (Fig. 2) of the specific component which will be investigated. The different body-in-white components can be divided into several groups. For example, a firewall is especially a shear field. It influences the torsional stiffness of the body-in-white and as a second objective it has to have low intrusions to protect the occupants during a front crash load case.

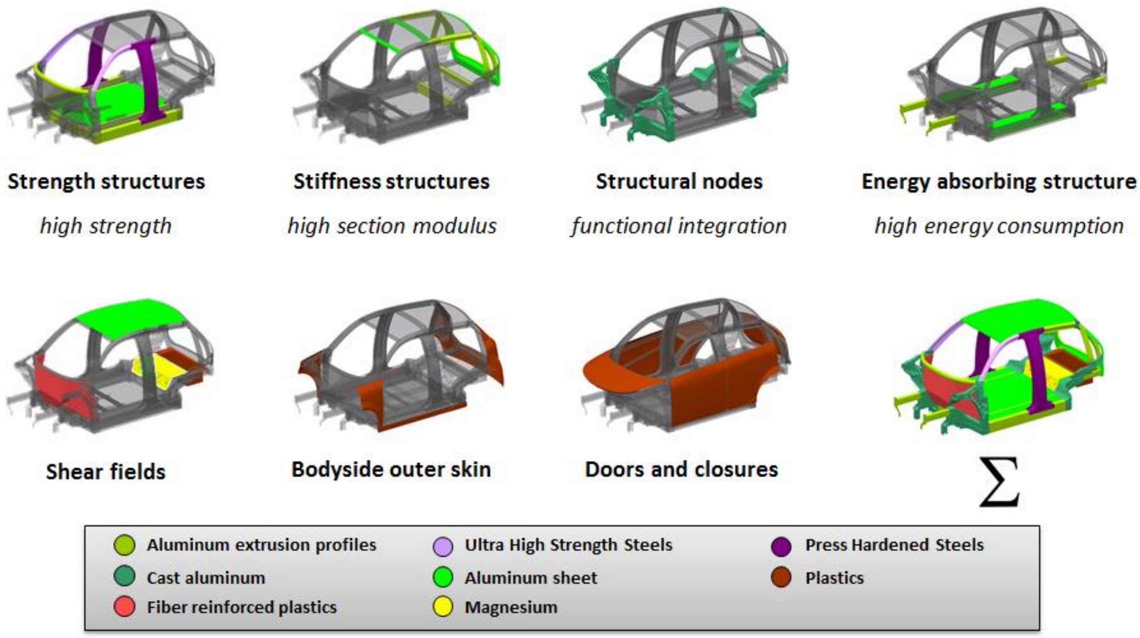

Fig. 2: Specific requirements of body-in-white components [3]

Taking into account the further requirements of the firewall (separation of front end and passenger compartment, low noise emissions, integration of attachment parts and etc.) the sandwich construction is preferred due to the offer of major potential for weight reduction, the possibility of the integration of different functions, high energy absorption capacity as well as the high thermal and acoustic isolation. [4]

Due to the variety of core geometries and the materials available, there is a wide range of cores that can be used for sandwich structures.

In terms of geometric design, sandwich can be distinguished at the macroscopic level between homogeneous and structured cores. If they are further classified according to the degree of support / stabilization to the face sheets, they can be derived into five core geometries [2, 5, 6, and 7]:

1. Cores with a homogeneous structure and therefore providing homogeneous support (e.g. balsa wood and various polymer foams)
2. Cores providing local support for the face sheets (e.g. textile and wire cores)
3. Cores providing partly local support (e.g. 'drilled out' foam and balsa cores, hump plates and hollow cone structures)
4. Cores providing unidirectional support (e.g. corrugated sheet, longitudinal bars or tubular structures)
5. Cores providing multidirectional support for the face sheets (e.g. core materials with a honeycombed structure)

Due to the major advantages of thermoplastics a thermoplastic PA6 composite with a homogeneous PA6 core and PA6 composite skin was selected for this application. The main advantages of thermoplastic resins are its less brittle which results in a higher toughness than thermosets and are improved impact resistance compared to thermoset composites. [8]

Another advantage is that thermoplastic composites can be shaped easily after heating up. Using this technique complex three-dimensional shaped sandwich parts can be created. [8]

4. CHARACTERISATION OF THE THERMOPLASTIC CORE MATERIAL

For the evaluation of the potential of possible sandwich structure three different PA6 core densities (35 kg/m³, 50 kg/m³ and 70 kg/m³) were characterized. The closed cell and cross-linked polyamide-6 foams were tested under the following test conditions:

- Compression test perpendicular to DIN EN ISO 604 [9]
- Dynamic compression test according to [10]
- Tensile test perpendicular to DIN EN ISO 1798 [11]

Some results of the tensile tests are shown in Fig. 3. The results indicate a significant influence of the specimen preparation procedure on the material behavior under tension loading. A further strain-rate dependent material behavior was identified under tensile loads.

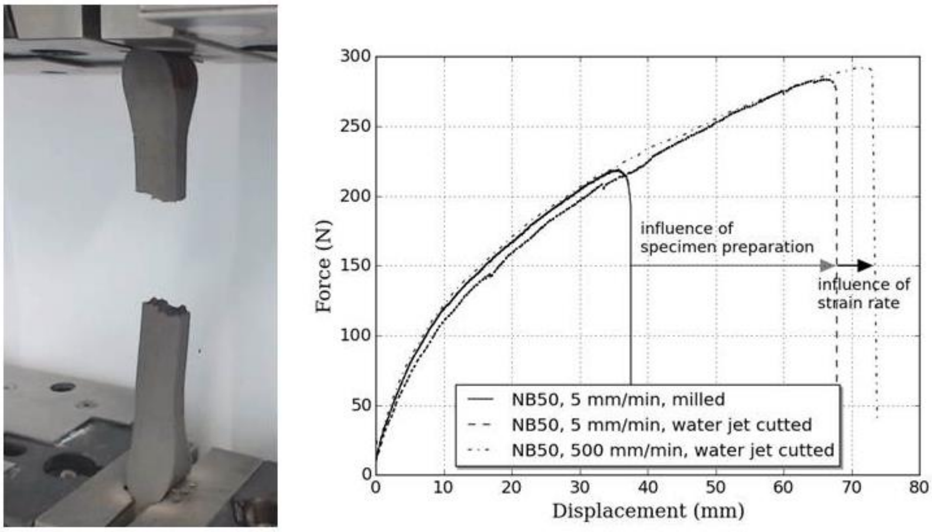

Fig. 3: Results of the tensile tests with influences of specimen preparation and strain rate

5. SIMULATION OF THE MATERIAL BEHAVIOUR

For the simulation of the sandwich structure three virtual material descriptions have to be developed. Firstly, the facesheets made of fiber reinforced thermoplastics, secondly the thermoplastic foam core, which has a recoverable material behavior. And finally the interface between these two partners. The scope of this presentation is on the dynamic material behavior of the thermoplastic foam.

For the generation of the strain rate dependent foam material card the 4a impetus was used. This system enables the automatic mechanical characterization of dynamically loaded test specimens. [10]

For the simulation a strain rate dependent hyperelastic material description was selected which is implemented in the nonlinear FEM Solver LS-DYNA from LSTC.

6. APPLICATION IN CRASH

For the evaluation of the potential of the thermoplastic sandwich structure under crash load a thermoplastic sandwich firewall will be virtually tested in a full vehicle crash simulation and finally compared with a currently build version made out of steel.

For the comparison the mass and the intrusions into the passenger compartment are considered. It is expected that the sandwich solution has less weight by similar mechanical performance. Due to the use of thermoplastics this solution is also suitable for a high-volume production.

ACKNOWLEDGEMENTS

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Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Characterization of Thermoplastic Foam Core Materials for Sandwich Applications Under Crash Load

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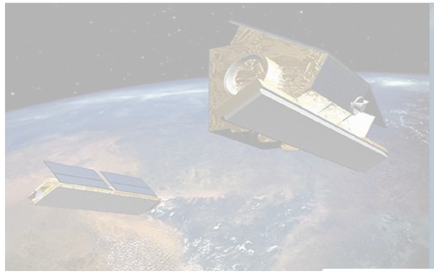
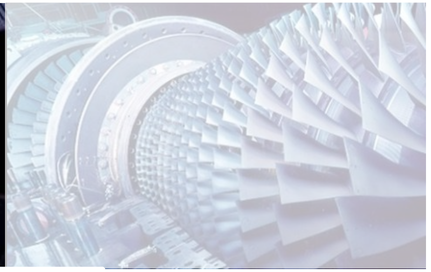
Table of Content

DLR – German Aerospace Center
Institute of Vehicle Concepts

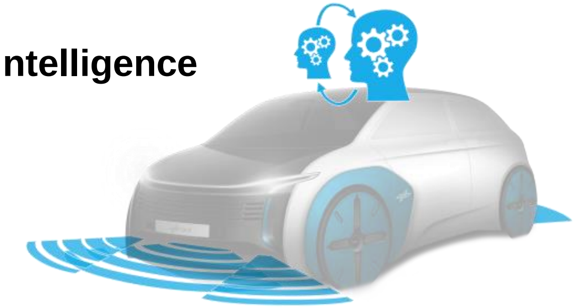
- Vehicle systems and technology assessment
- Vehicle energy concepts
- Alternative energy conversion
- Vehicle Architectures and Lightweight Design Concepts
- Material and Process Applications for Road and Rail Vehicles

SPACE	AERONAUTICS	TRANSPORT	ENERGY
			

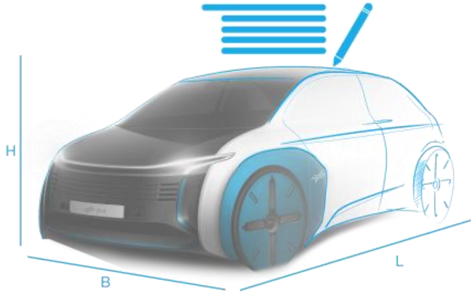
SECURITY

DLR Meta Project - Next Generation Car

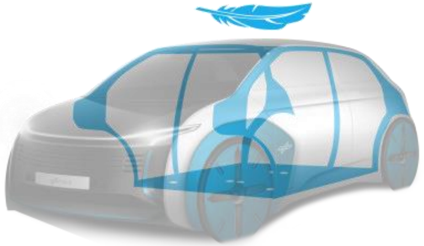
Vehicle Intelligence



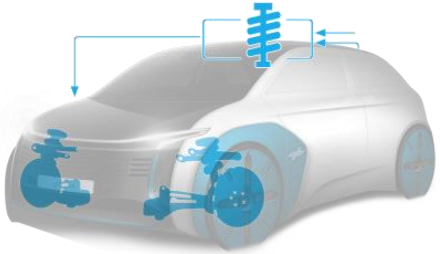
Vehicle Concept



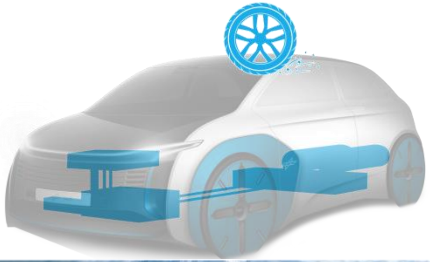
Vehicle Structure



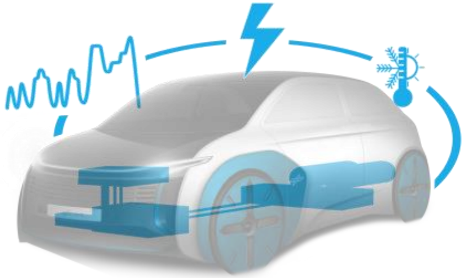
The objective of this project is the cross-linking of different technologies, methods and tools for the holistic development of vehicles of the future in terms of vehicle design, vehicle structure, power and thermal management, vehicle intelligence and power train



Chassis Mechatronics

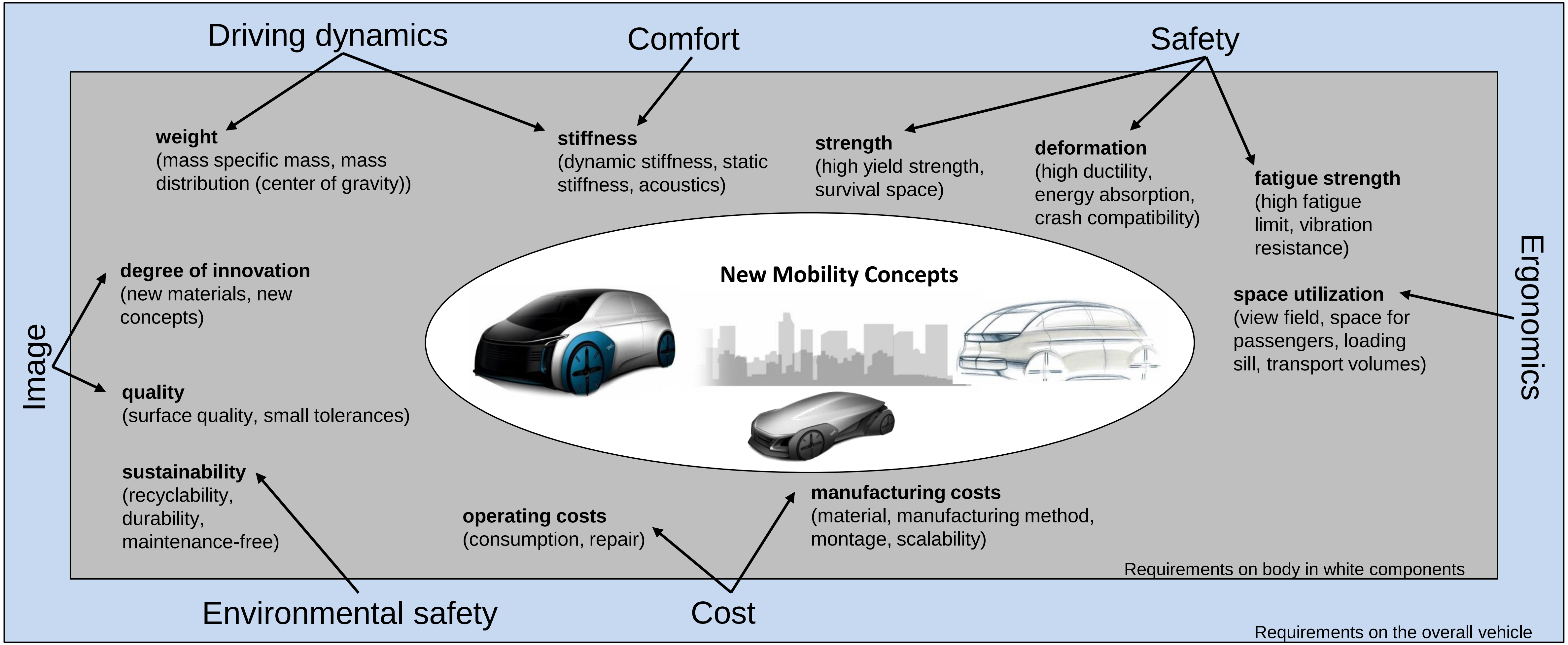


Powertrain



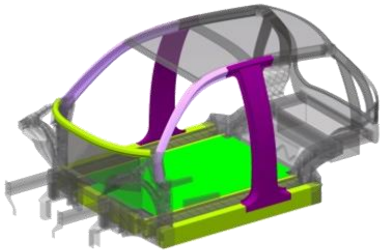
Energy Management

Requirements on the overall vehicle and body in white components



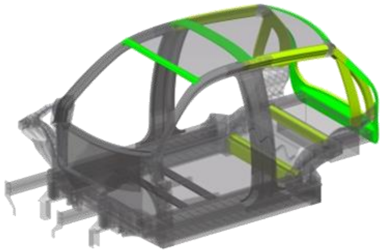
Sources: : [Kellner2014]

Aspects of lightweight construction and optimization objectives in the various application areas of a car body



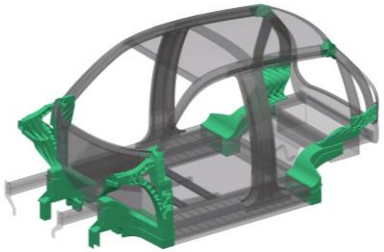
Crash structures

High strength



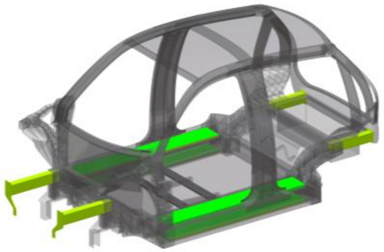
Stiffness structures

High section modulus



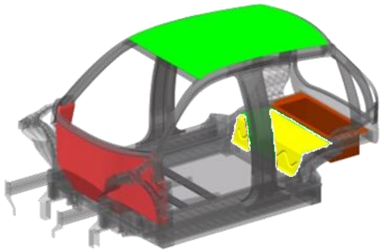
Structural nodes

Functional integration



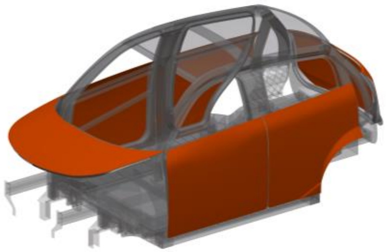
Energy absorbing structures

High energy consumption

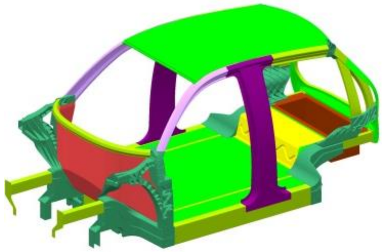


Shear fields

Bodyside outer skin



Doors and closures



Σ

- Aluminum extrusion profiles
- Cast aluminum
- Fiber reinforced plastics
- Ultra high strength steels
- Aluminum sheets
- Magnesium
- Press hardened steel
- Plastics

Sources: : [Schäffer2017]

Current automotive applications of sandwich and organic sheet components

organic sheet applications

Seating shell

Bracket for the
infotainment system

Break pedal
over molded organic sheet

sandwich applications

Roof module

Floor assembly

Sources: [Schnorr2013], [BASF2012],[Erbstoeßer2015], [Lanxess2014],[Haeffelin2017], [Klucyk2011], [Hillebrecht2013]

Required test data for the characterization of a thermoplastic sandwich with foam core and organic face sheets

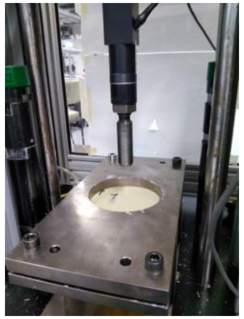
- core material
  - PA6-foam (closed cell foam,
    densities: 35 kg/m³, 50 kg/m³ & 70 kg/m³)
    - static compression (DIN EN ISO 844)
    - dynamic compression (4a Impact testing machine)
    - tension (ISO 1798)

- connection between core and face sheet without adhesive
    - basic feasibility study
    - further studies are currently done by a partner

- face sheet material
  - glass fiber fabric reinforced thermoplastics (PA6)
    - compression (ASTM D6641)
    - tension (DIN EN ISO 527-4 / Typ 3)
    - dynamic impact (DIN EN 6038)







simulation of a thermoplastic sandwich under crash load

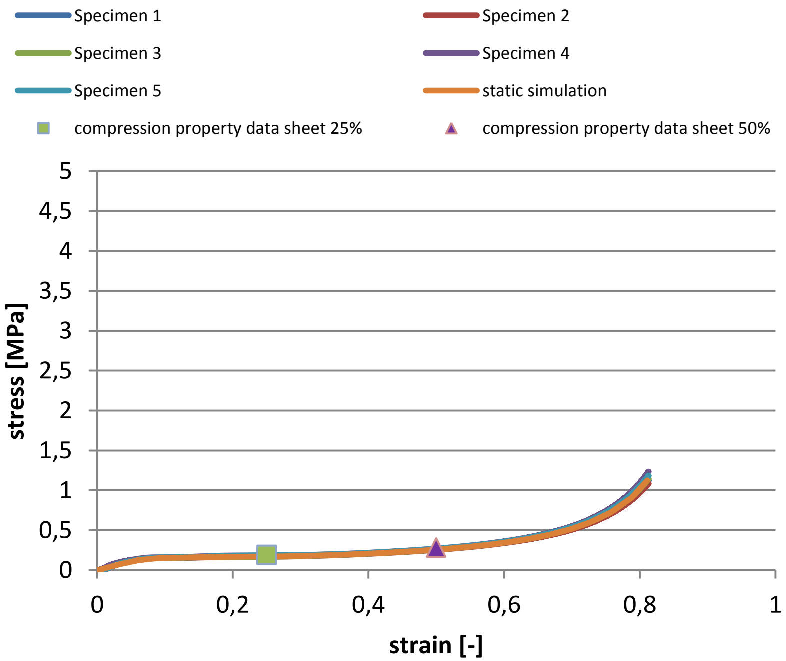
Core material: PA6 foam – static & dynamic compression tests
Influence of specimen size on the static compression behavior

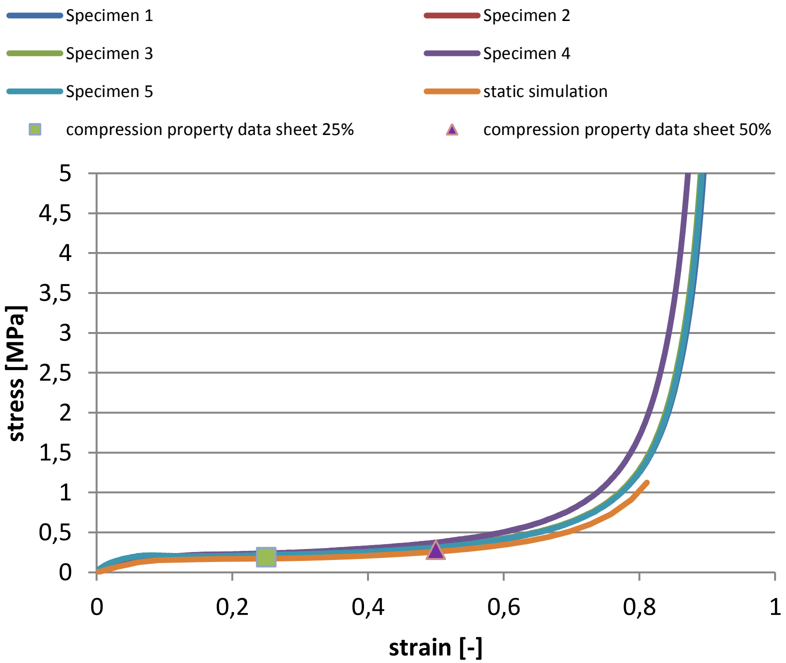
- Specimen size without an influence on the static compression behavior
- Important result for the dynamic characterization of the foam and the numerical simulation of the material behavior
- Material behavior is independent of the component size

→ no regularization is necessary in the simulation of component

Size 1:
100 mm x 100 mm x 32 mm

Size 2:
20 mm x 20 mm x 20 mm





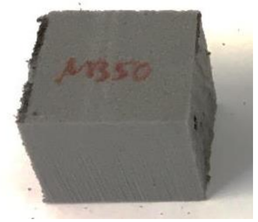
Core material: PA6 foam – static & dynamic compression tests Strain rate behavior

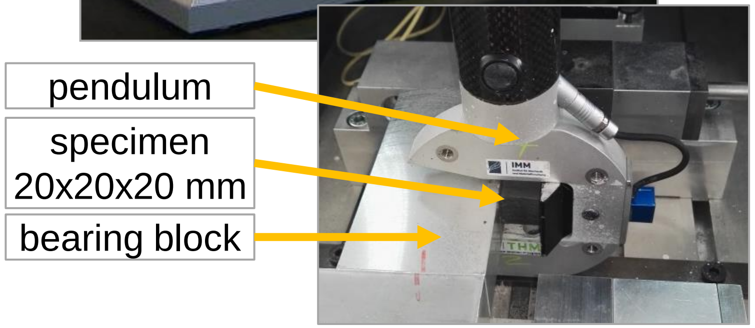
- Strain rate has an influence on the compression behavior of the foam

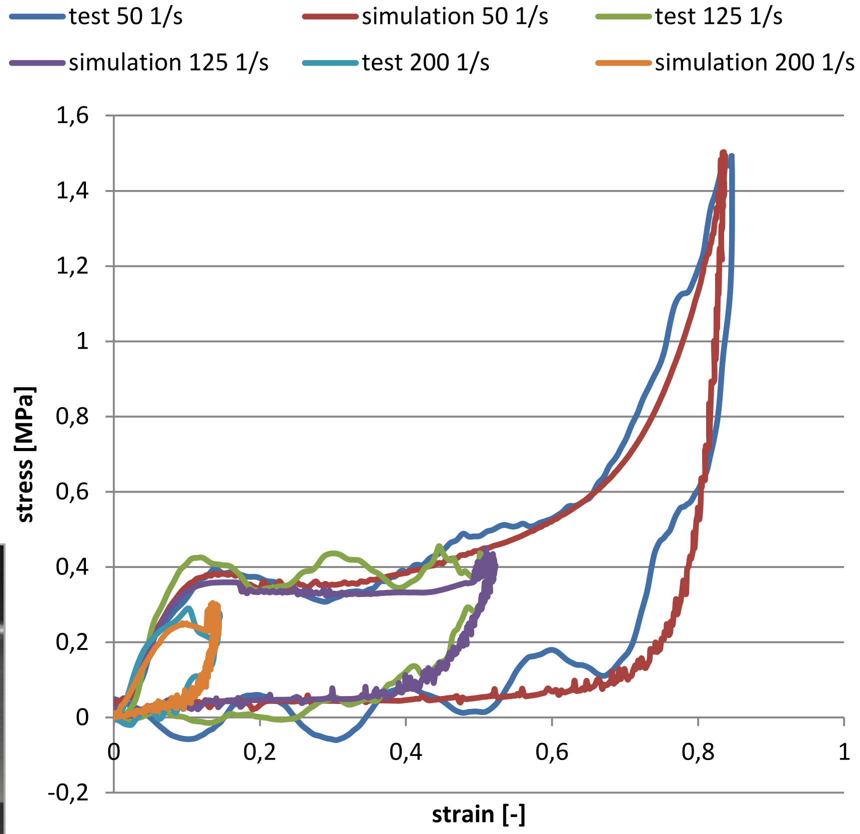
- Mass of pendulum: 0.4183 kg
- Impact velocities: 1 m/s, 2.5 m/s, 4 m/s

- Material model is able to predict strain rate dependent compression behavior

4a Impact testing machine

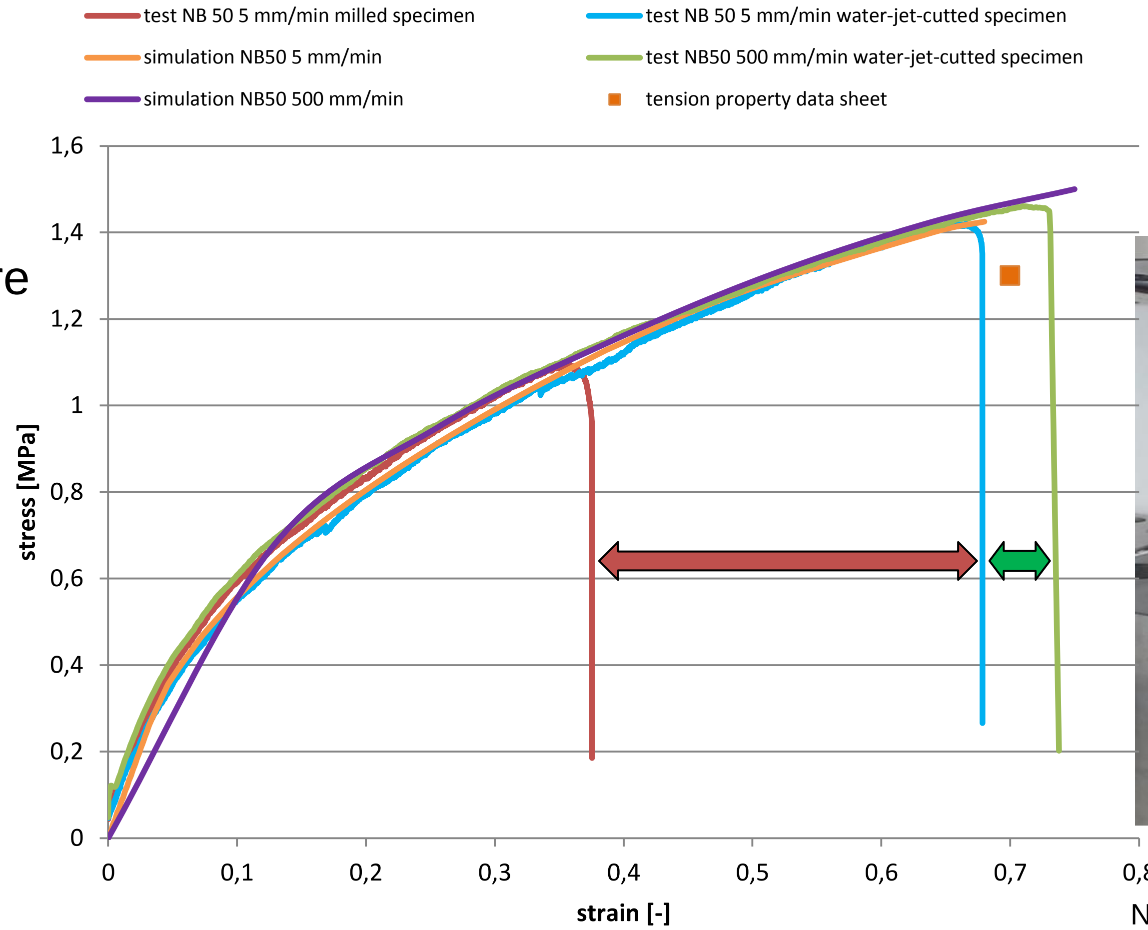






Core material: PA6 foam – tension tests
Influence of manufacturing process and “strain rate”

- **Influence of manufacturing process:**
  - stiffness: no influence
  - failure: significant influence on tension failure
- **Influence of test velocity:**
  - stiffness: low influence
  - failure: influence on tension failure



NB50 500 mm/min

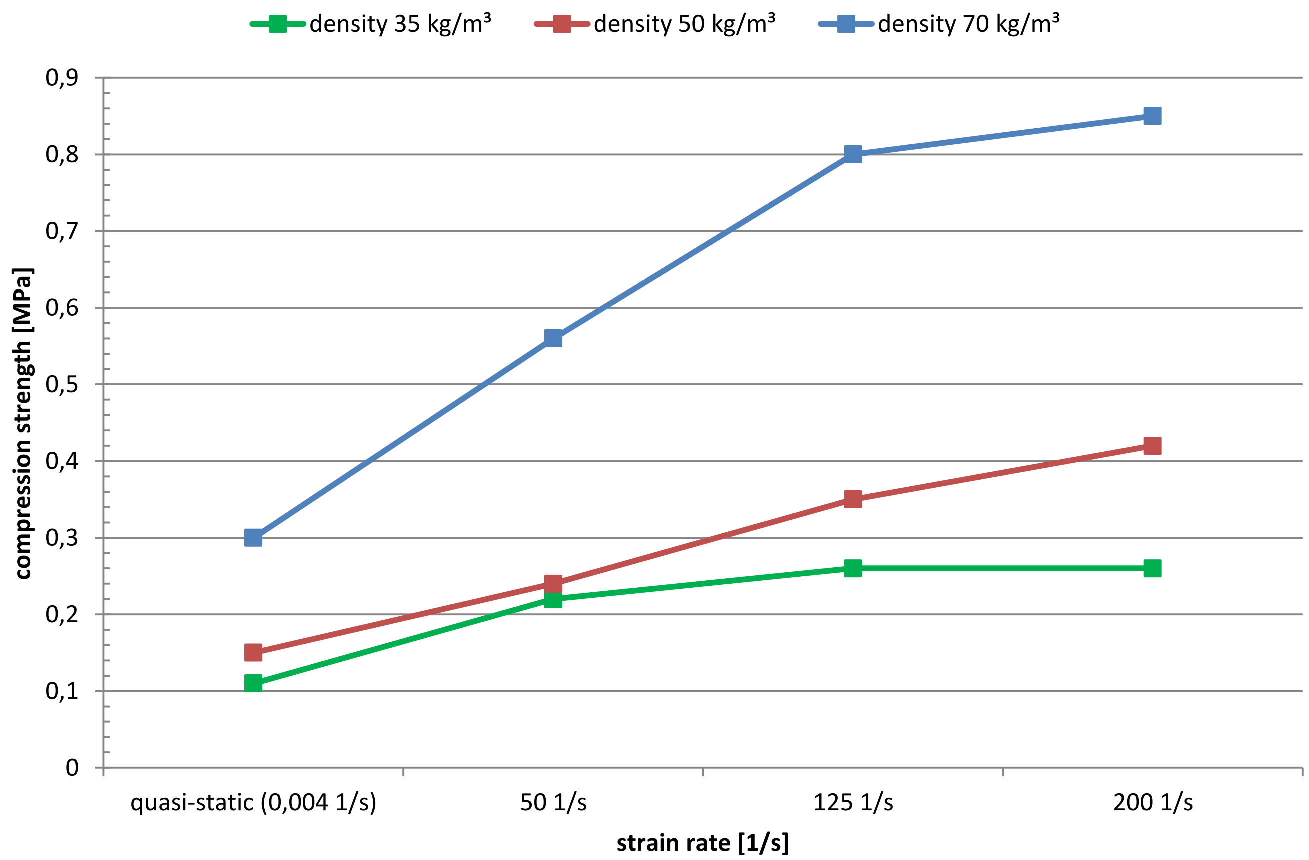
Comparison of compression behavior depending on the foam densities

- Strength increases with density

- Strength increases with strain rate

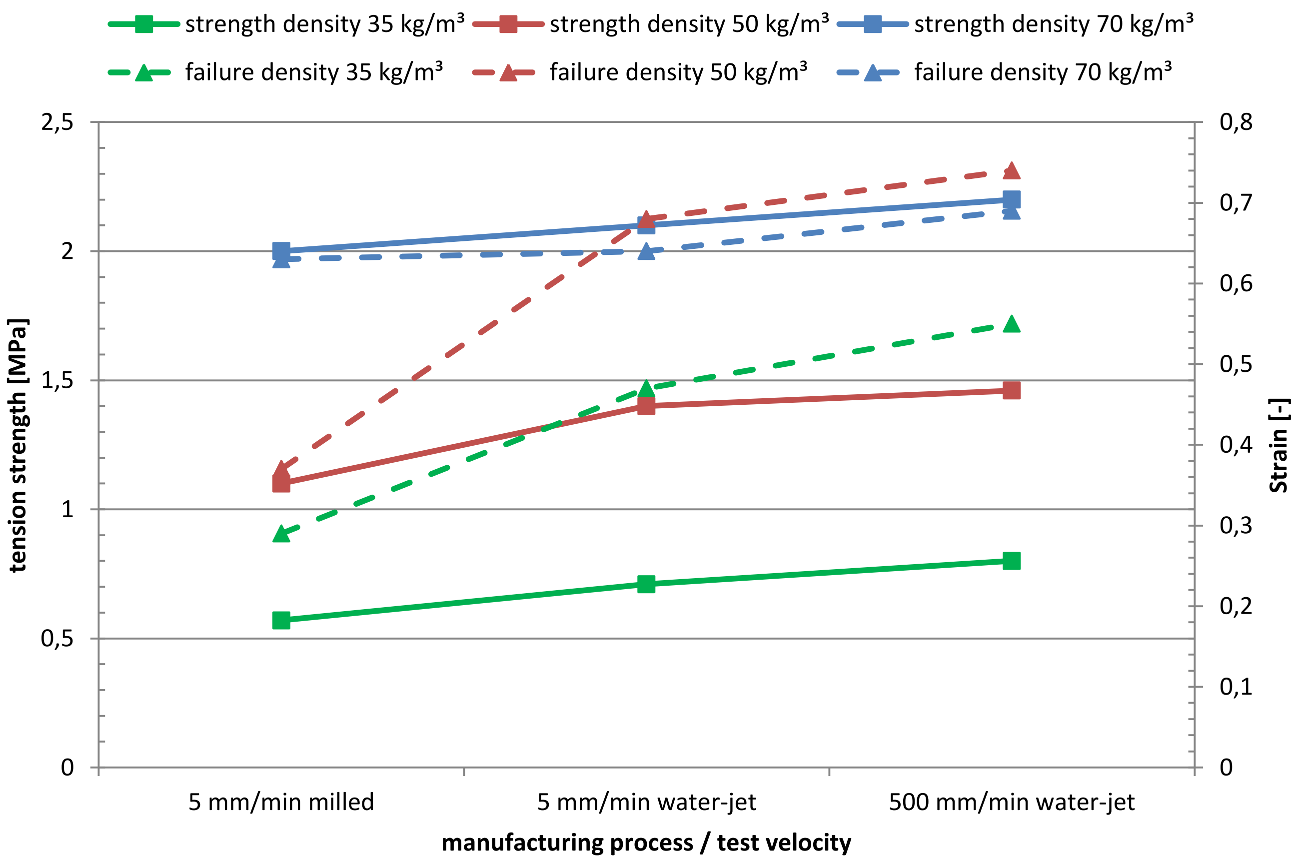
- With increasing strain rate the influence on the compression strength is decreasing

- In the interesting range of strain rate for a vehicle crash application (> 150 1/s) the compression strength is nearly tripled



Comparison of tension behavior depending on the foam densities

- Strength increases with density
- Strength increases slightly with test velocity
- Manufacturing process of specimens has low Influence on strength at density 70 kg/m³
- Manufacturing process of specimens has a significant influence on failure at density 35 kg/m³ and 50 kg/m³ but not at density 70 kg/m³
- Maximum failure strain at density 50 kg/m³ with water-jet-cutted specimens

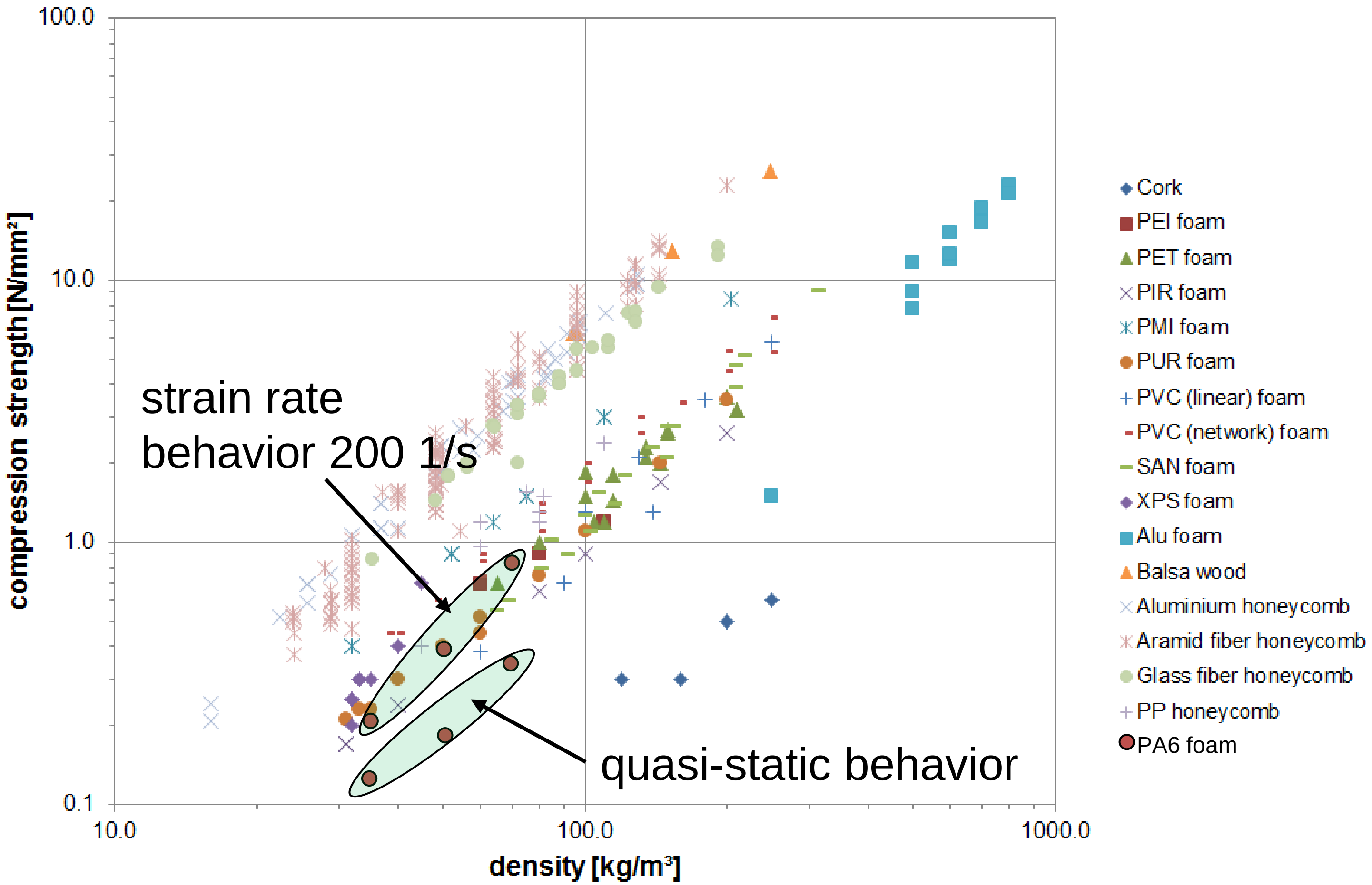


Comparison of compression behavior with other core materials

- In comparison with other foam core materials the quasi-static compression Strength is very low

- Considering the strain rate effects on the compression strength the PA6 foam is on the level of PET foam

- Important benefit for automotive application is the higher maximum operating temperature of PA6 foam

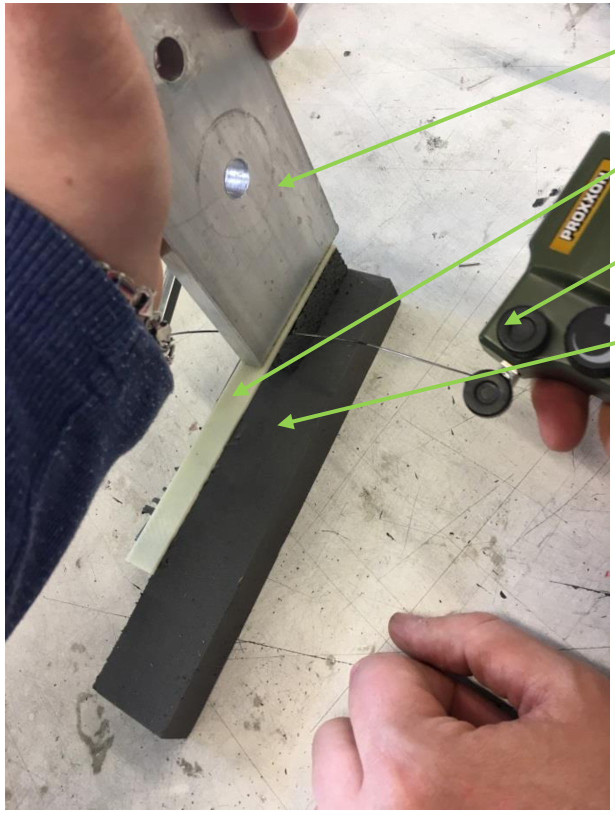


Source: [Schäffer2016]

Connection between core and face sheet basic feasibility study

Further studies are currently done by a partner

- Idea: thermal bonding between PA6 foam core and PA6 matrix in organic face sheet by fusing the foam core



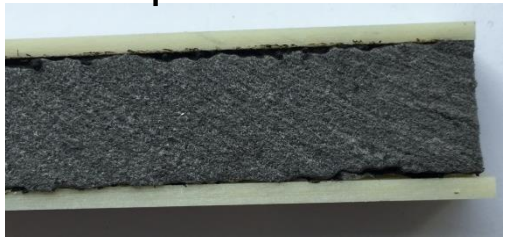
clamp

organic face sheet

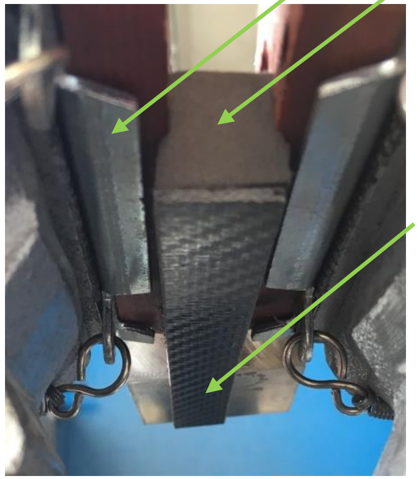
heating knife 250°C

foam core

merged thermoplastic sandwich



simple static test

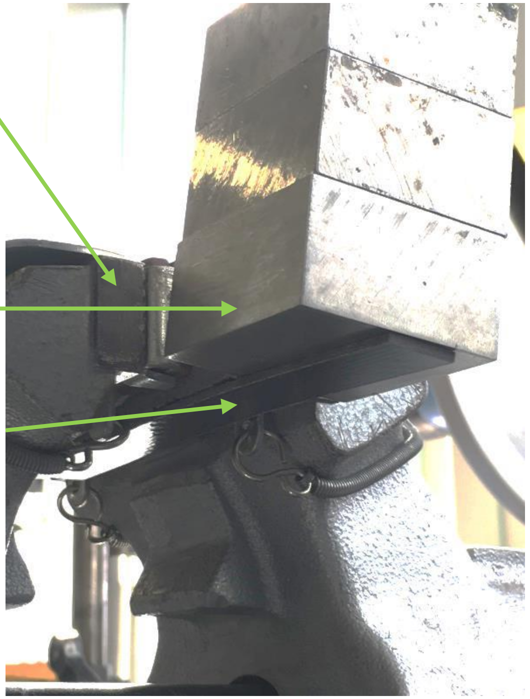


clamp

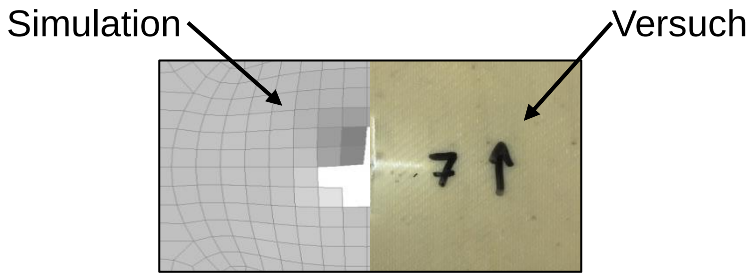
foam core

load

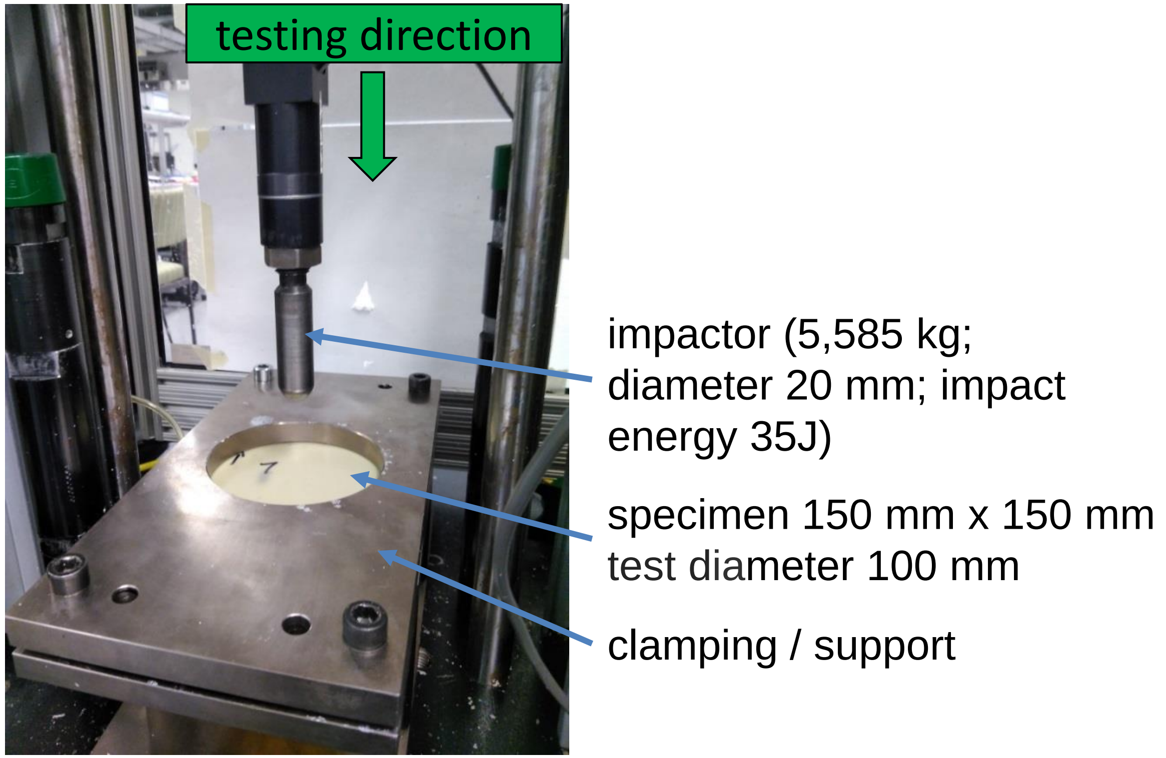
organic face sheet

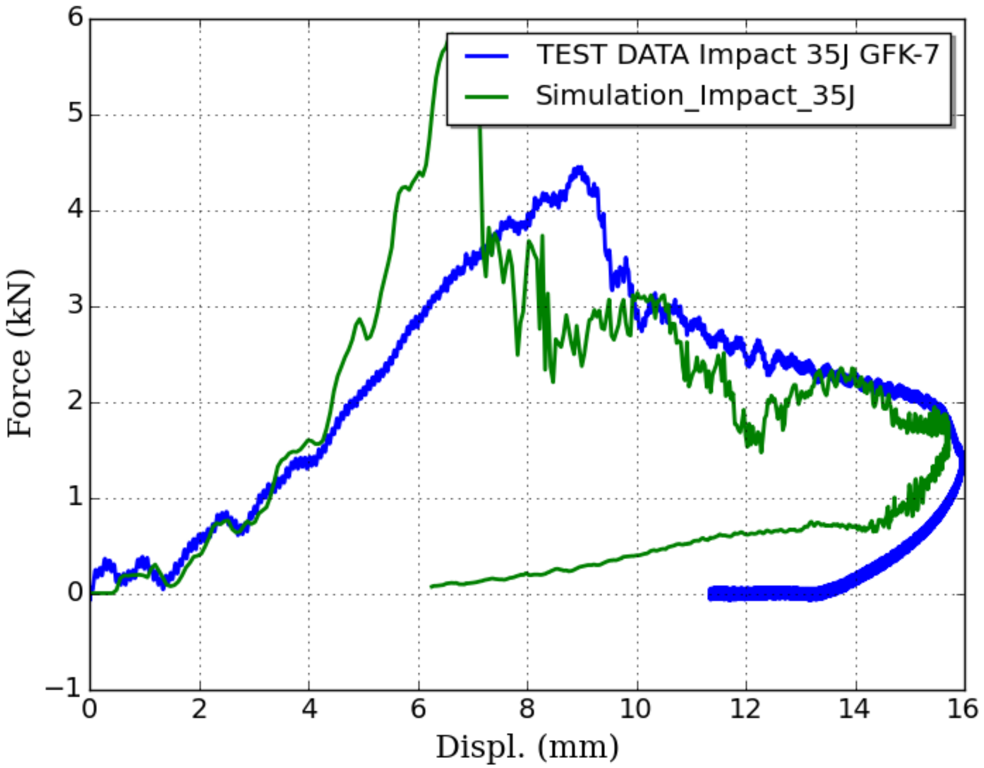


Impact tests on organic sheets



- Characterization of organic sheet with tension, compression and shear tests
- Validation of material model with impact tests

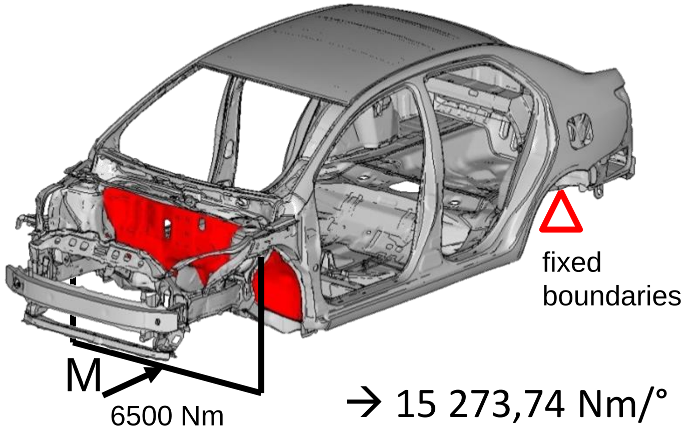




Determination of the optimization boundary conditions

- Considered load cases: Static torsional stiffness, 3 Crash load cases (US NCAP, Euro NCAP & IIHS Small Overlab)
- Benchmark: steel shell design in the open access crash vehicle model Toyota Yaris

Static torsional stiffness



→ 15 273,74 Nm/°

Crash load case

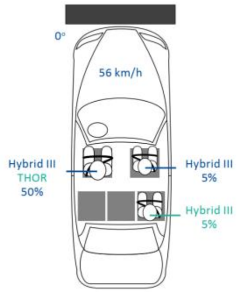
Determination of the intrusion of the firewall:

- maximum intrusion at one node
- specific evaluation points (e.g. pedals, steering wheel)
- evaluation areas (1 to 15 evaluation areas → max. 90)

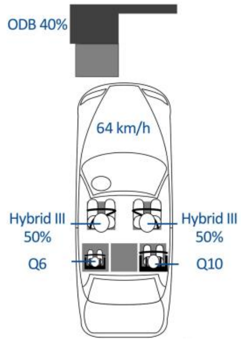
one to three evaluation areas over the height

one to five evaluation areas over the width

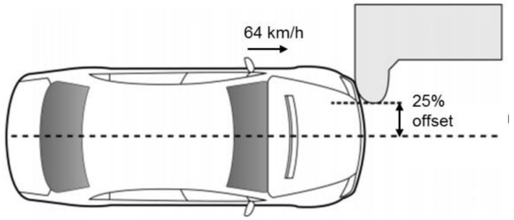
US NCAP



Euro NCAP



IIHS Small Overlab



FE-model source: [NCAC2012], [IIHS2014], [carhs1], [carhs2]

Optimization setup and results by varying the number of constraints

Optimization setup

Parameters for the optimization:
- Number of 0°/90° layer
- Number of +-45° layer
- sandwich height

Optimization results by varying the number of constraints

US NCAP front crash

Number of constraints over the height	Number of constraints over the width	Mass [kg]
1	**1**	**5,352**
1	**2**	**5,352**
2	**1**	**5,352**
…	**…**	**…**
2	**5**	**-**
3	**5**	**-**

IIHS Small Overlap

Number of constraints over the height	Number of constraints over the width	Mass [kg]
1	**1**	**5,842**
1	**2**	**5,842**
2	**1**	**5,906**
…	**…**	**…**
2	**5**	**-**
3	**5**	**-**

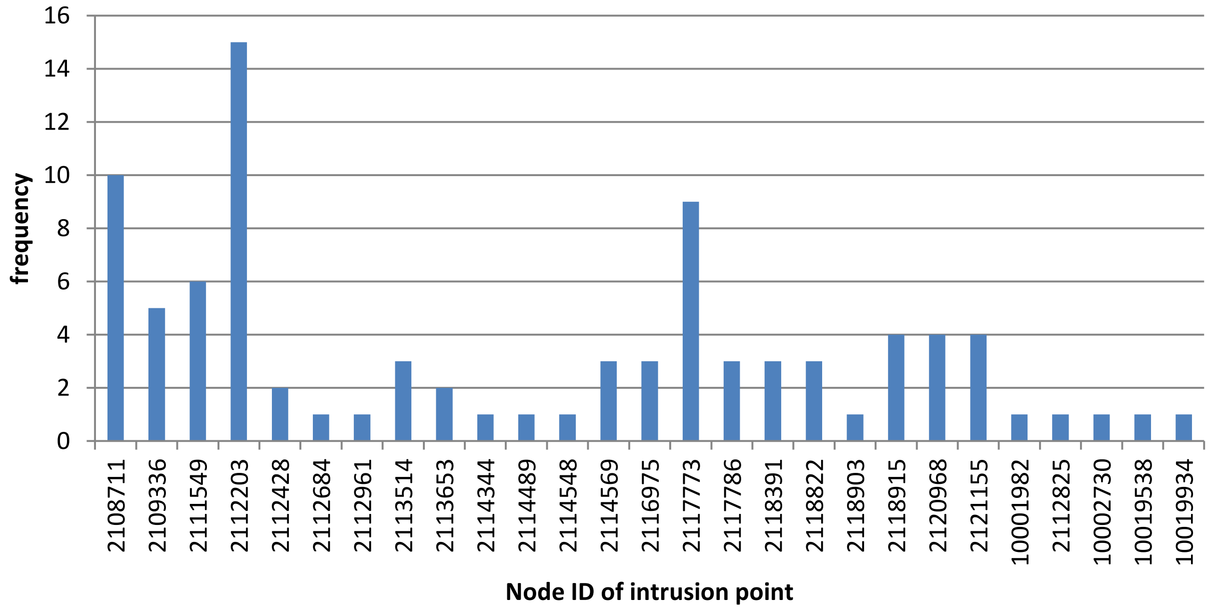
Problem: overconstrainted optimization problem by considering to many constraints

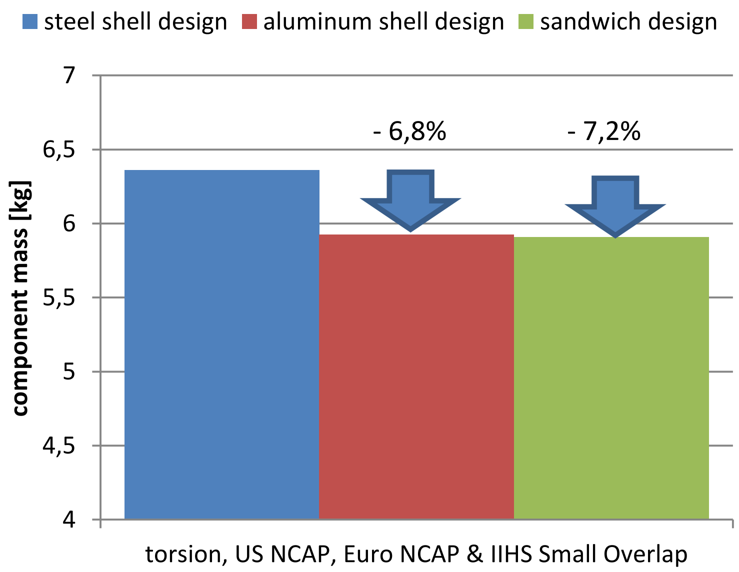
How can you ensure that the considered constraints are the important constraints for each load case

Optimization results by considering the importance of the constraints

Approach:
Considering the frequency of the constraints for each load case by using a frequency distribution

Example: IIHS Small overlap





- By using a frequency distribution for the intrusion node IDs, the important nodes for each load case can be considered in the optimization loop
- The mass can be reduced by 7.2% by using a symmetric sandwich with continuous core height

Summary and Outlook

- Required test data for the characterization of a thermoplastic sandwich with foam core and organic face sheets
  - core material
  - connection between core and face sheet without adhesive (feasibility study)
  - face sheet material

- Optimization results by considering the importance of the constraints
  - The mass can be reduced by 7% by using a symmetric sandwich with continuous core height

Further topics:

- Further studies to characterize the connection between core and face sheet without adhesive
- Enlargement of mass saving by using
  - variable heights of the core material
  - carbon fiber reinforced face sheets

Thank you for your attention

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carhs1	http://www.safetywissen.com/#/object/B01/B01.6ri734847fylzkd2izr48173rs64nr63490742573/safetywissen?prev=%2Fobject%2FA11%2FA11.yfy736849d2zjykx8xo76243qe4zac63663743443%2Fsafetywissen
carhs2	http://www.safetywissen.com/#/object/B10/B10.nw37346182s1mokz8mq64428r5m0on63470973228/safetywissen?prev=%2Fsearch%2F
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