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Proof of the potential of new non-heat treated aluminum high-pressure die-cast alloys for crash-impact areas

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RHEINFELDEN Solutions thru Innovation

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

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Overview

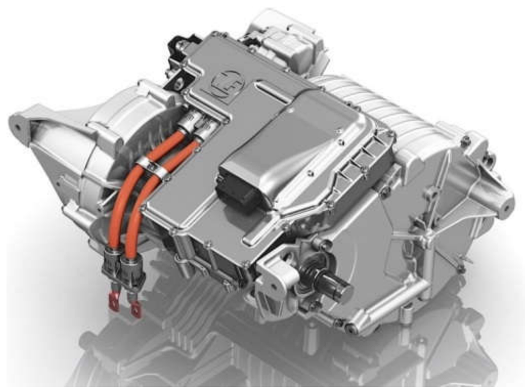
- Aluminum high-pressure die-cast
  - Analysis of current trends
  - Casted structural components and research projects at DLR
  - Challenges
- New high-pressure die-cast aluminum alloys
  - Castaduct®-42
  - Magsimal®-plus
- Methodology
- Proof of potential in strut tower
- Proof of potential in A-pillar cast node
- Summary

Aluminum high-pressure die-cast
- Analysis of current trends

- Structural die cast components:
  - Bigger, more complex components
  - Optimization of wall thickness along load path
  - Functional integration

source: VW AG / AUDI AG

- Electrification
  - New components
  - High potential of functional integration



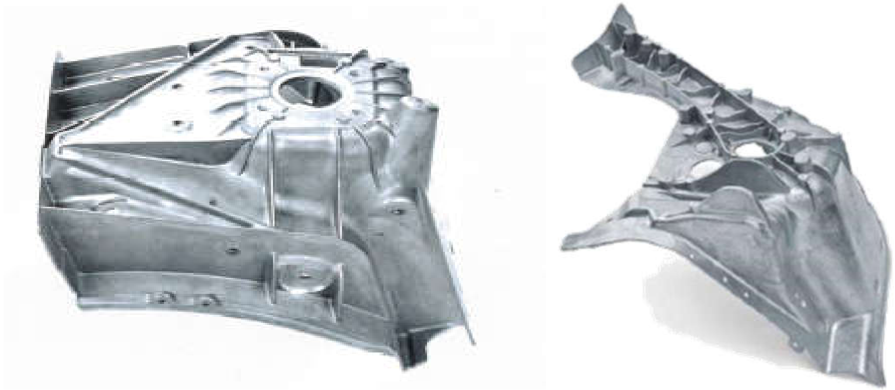
ZF Elektro-Achsenantrieb Drive 1
source: www.ZF.com

- Globalization
  - Manufacturing around the globe
  - Same standard

Aluminum high-pressure die-cast
- Structural die cast components

Strut tower

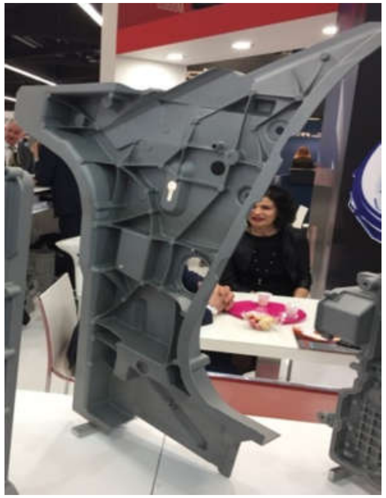
- High fatigue strength
- Optimization of wall thickness along load path
- Weight reduction up to 45 % in comparison to conventional design



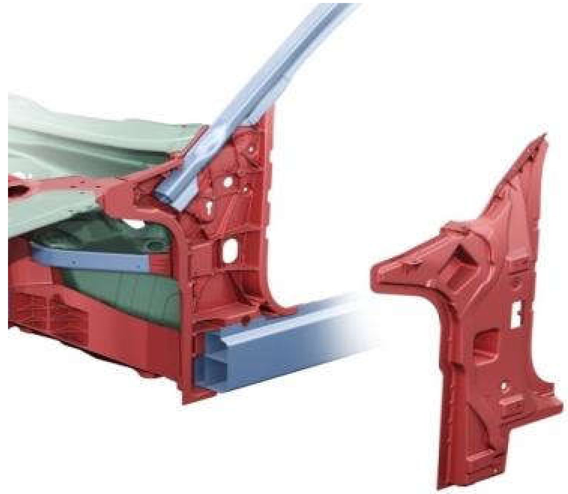
source: RHEINFELDEN ALLOYS GmbH

A-pillar cast node

- Example: A-pillar cast node of Audi A8 consisting of two half-shells



source: own photo @ EUROGUSS 2018



source: Audi AG

Aluminum high-pressure die-cast
- Casted structural components and research projects at DLR

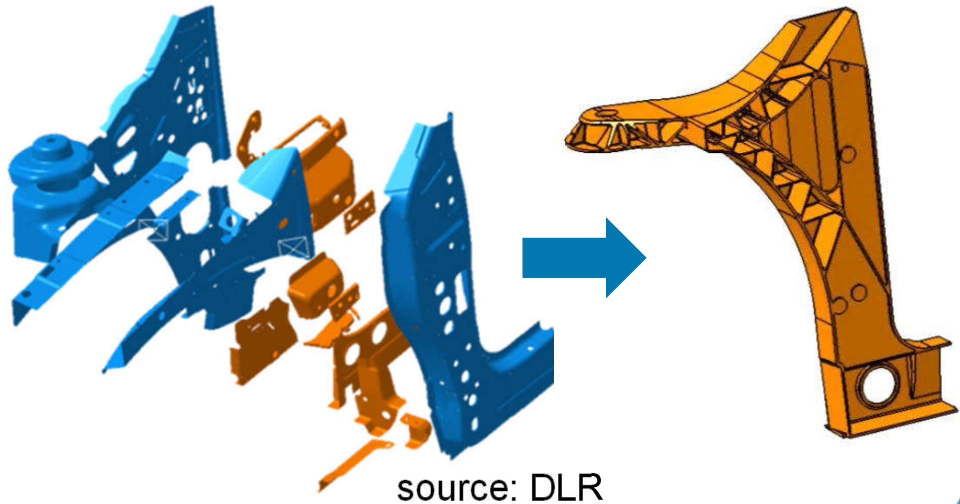
SuperLightCar (SLC)

- Strut tower made of cast Mg
- Lightweight potential of 63 %
- Additional costs of ~1.80 $ per kg saved weight

DLR A-pillar cast node

- Integrates up to 20 parts
- Optimization of additional costs through smart functional integration
- Lightweight potential > 40% possible

source: DLR



source: DLR

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Aluminum high-pressure die-cast - Challenges

- Structural components:
  - High mechanical properties
  - High ductility during crash
- Bigger, complex components:
  - Close tolerances
  - Large flow length
  - Same structure during solidification
  - Warping
- Joining
- Global aspects:
  - Reduction of costs
  - Reduction of global CO_2-footprint

- How can these challenges be addressed?
- Common project with Rheinfelden Alloys GmbH & Co. KG
  - Investigation of two new high-pressure die-cast aluminum alloys
  - No heat treatment needed

Castaduct®-42 (AlMg4Fe2)

- High mechanical properties in as cast state (F)
- Simple handling in casting process
- Excellent corrosion resistance
- High dimensional stability
- Weldable

cast state	wall thickness [mm]	$YS_{0,2\%}$ [MPa]	UTS [MPa]	ε [%]
F	2-4	120-135	240-280	11-22

source: RHEINFELDEN ALLOYS GmbH

source: D.Quitter/konstruktionspraxis | RHEINFELDEN ALLOYS GmbH

New high-pressure die-cast aluminum alloys
- Magsimal-plus

Magsimal®-plus (AlMg6Si2MnZr)

- High-strength Al-alloy in as cast state (F)
- Excellent corrosion resistance
- High dimensional stability
- Weldable

cast state	wall thickness [mm]	$YS_{0,2\%}$ [MPa]	UTS [MPa]	ε [%]
F	2-3	200-220	340-360	9-12
T5	2-3	230-250	350-380	8-12

source: RHEINFELDEN ALLOYS GmbH

battery compartment
source: VW AG/Audi AG | +GF+

strut tower with integrated brace
source: Porsche Automobil Holding SE | +GF+

Methodology
- Methodology for predicting the lightweight potential

Basic understanding of the material

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Calibration of material model

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Validation of material model

↓

Proof of lightweight potential through validated simulations

Methodology
- Methodology for predicting the lightweight potential

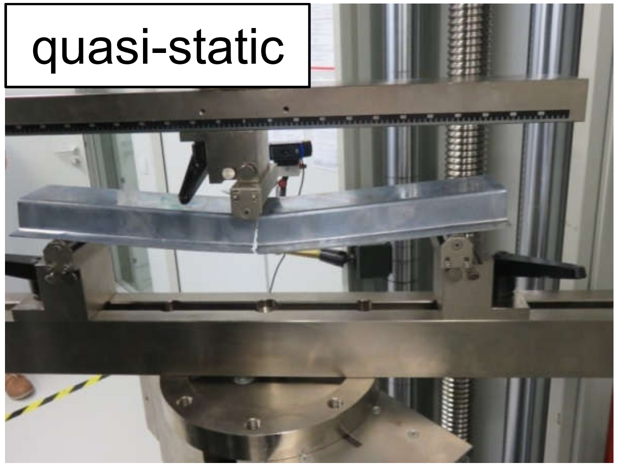
- Test data of tensile test and fatigue tests
- Three-point-bending flexural tests (3PBFT) of top-hat profiles

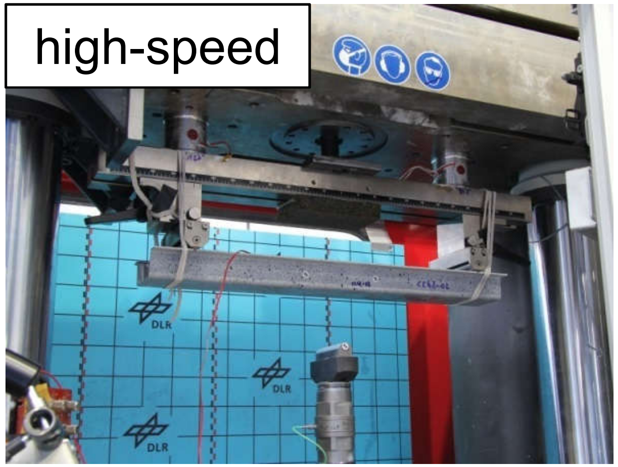
- With test data from 3PBFT: Reverse engineering of
  - Young's modulus
  - Stress-strain curve
  - Rate dependent failure strain

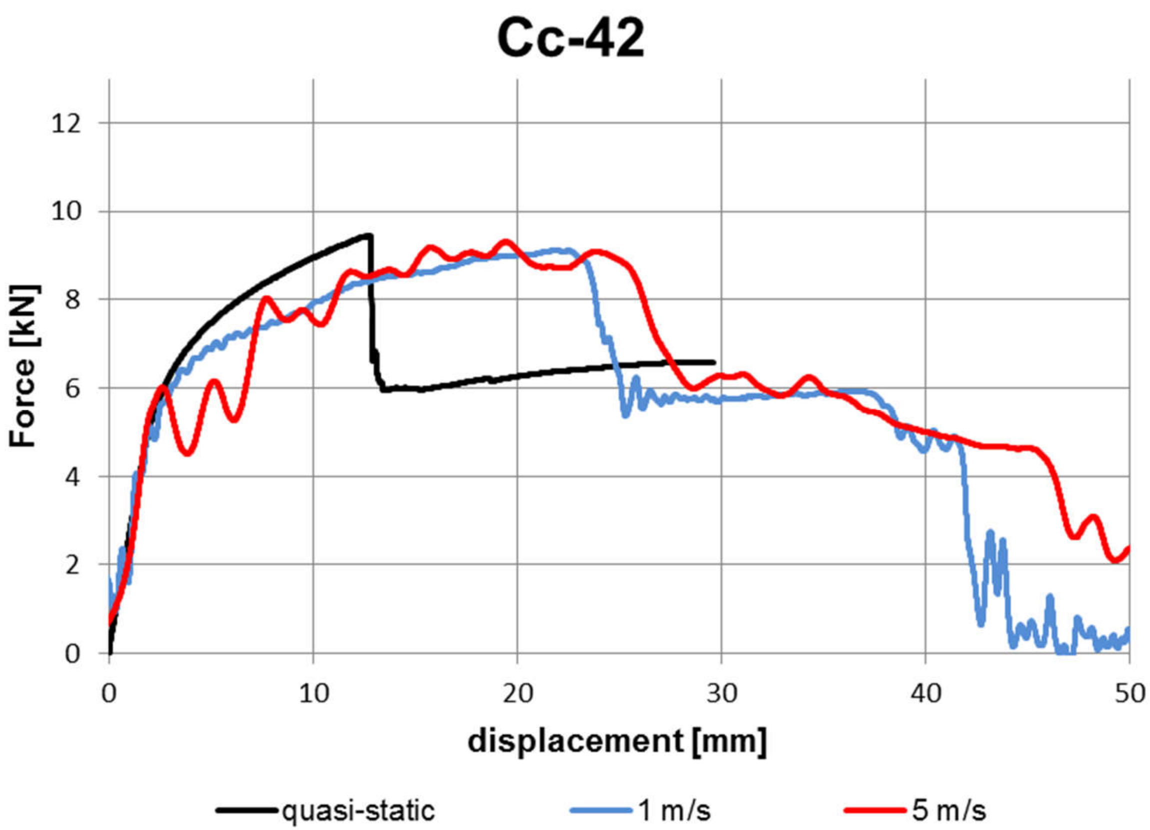
- Simulation of three-point-bending flexural tests of flipped top-hat profiles
- Three-point-bending flexural tests of flipped top-hat profiles

- Project SLC: validated simulation model for strut tower
- Project A-pillar cast node: validated simulation model for cast node

Methodology
- Testing of three-point-bending flexural tests of top-hat profiles







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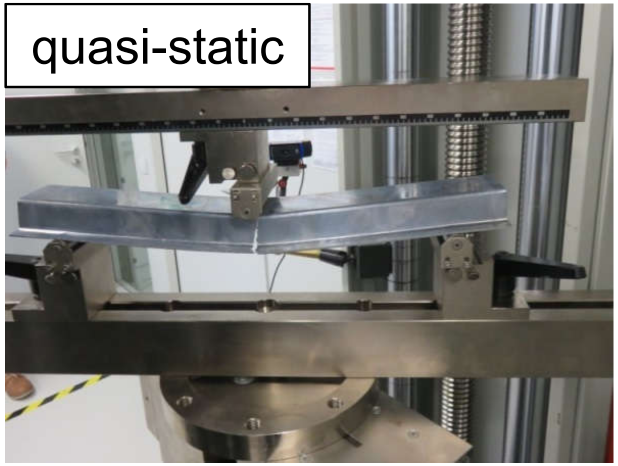
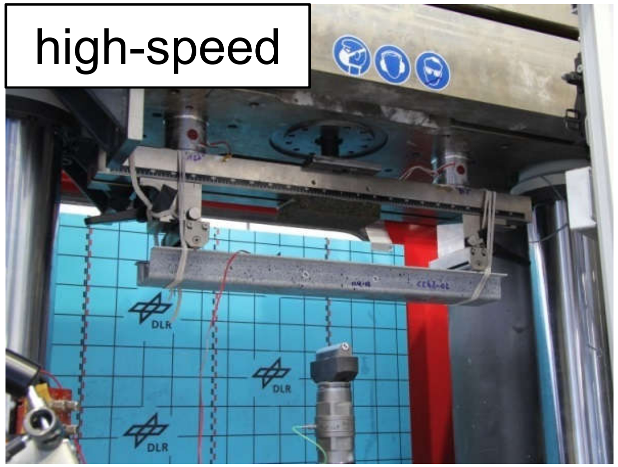
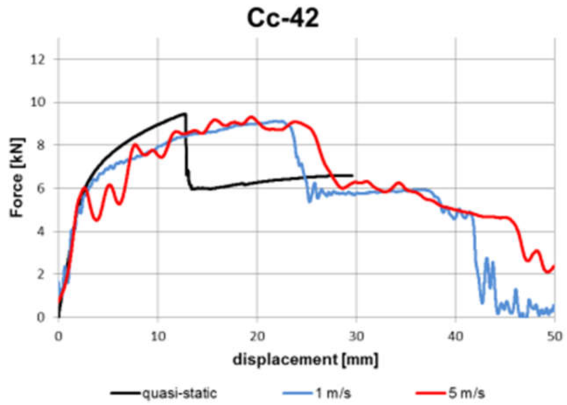
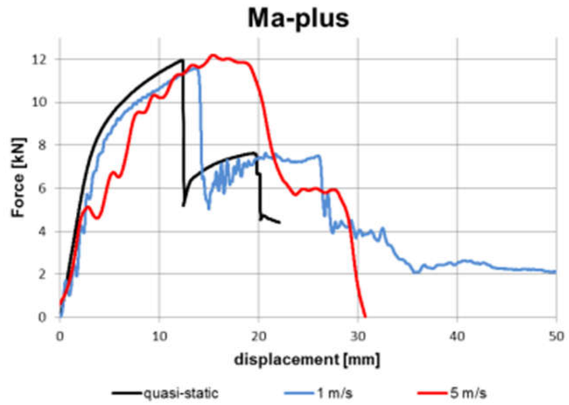
Methodology
- Testing of three-point-bending flexural tests of top-hat profiles





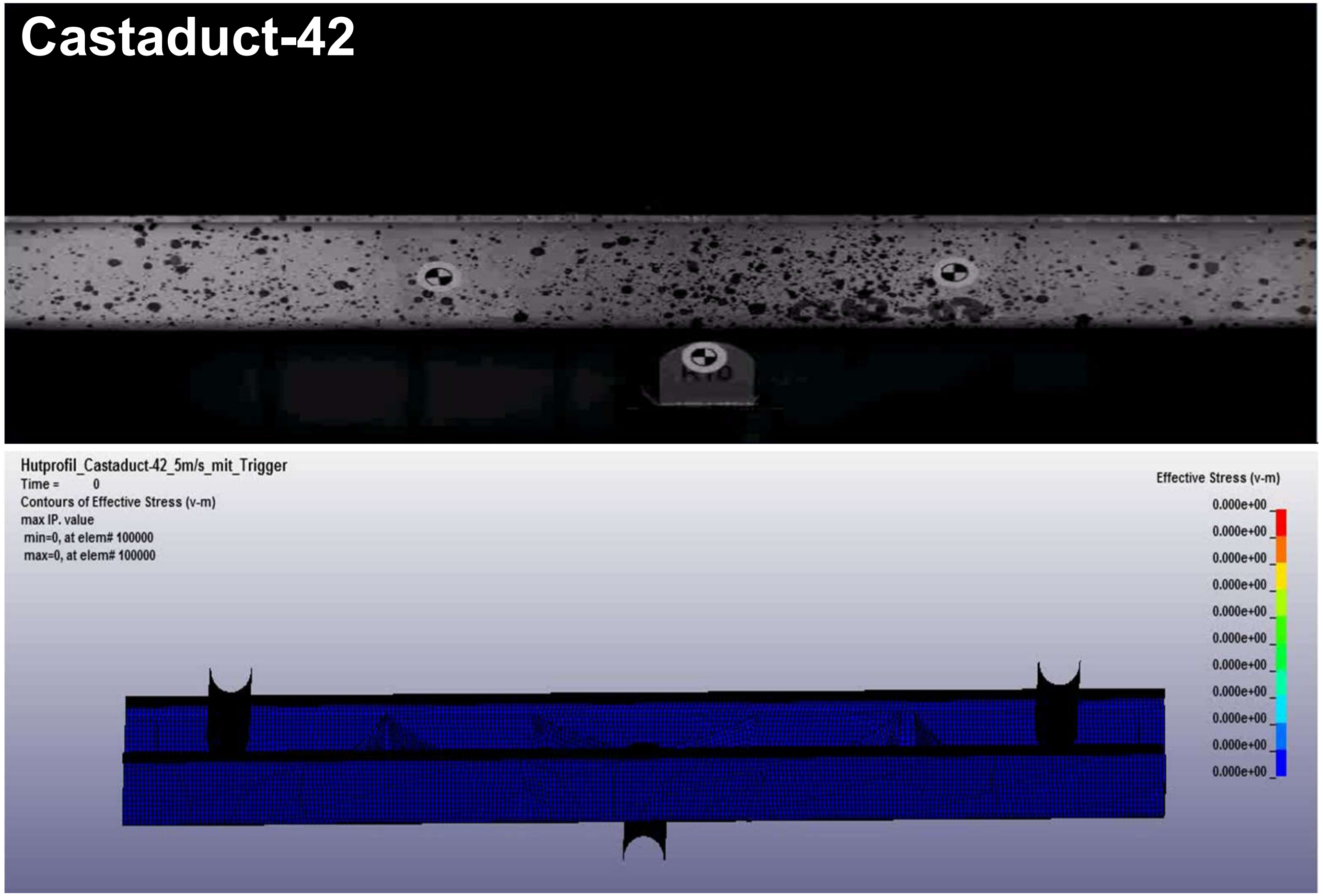




- Conclusion:
  - High reproducibility of force-displacement curve
  - Similar force level after crack
  - No decrease of failure stress
  - No brittle behaviour, but increase of ductility

→ Static dimensioning leads to higher safety in high-speed applications like crash

Methodology
- Calibration of material model with 3PBFT of top-hat profiles



Methodology
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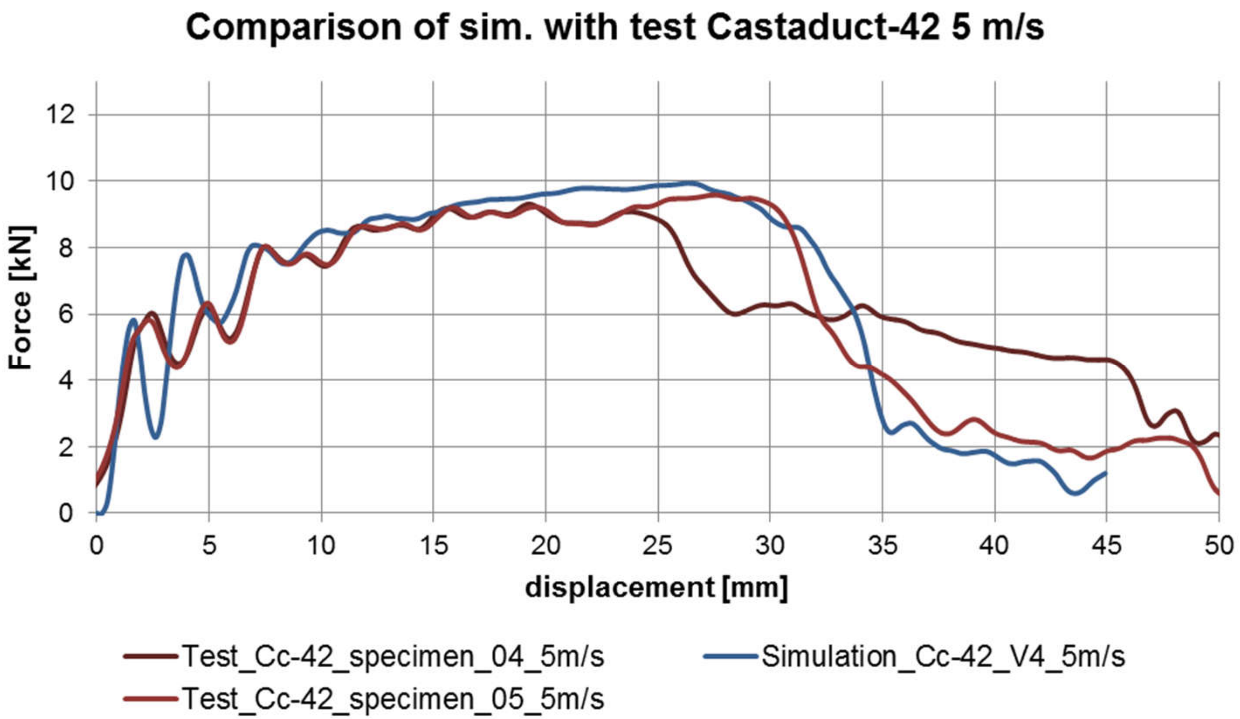
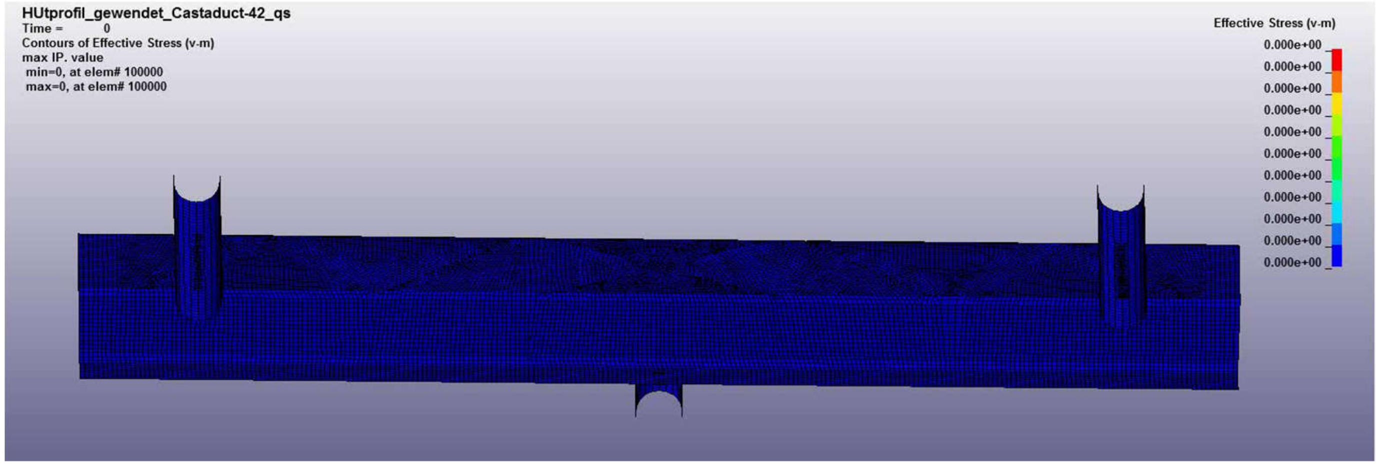


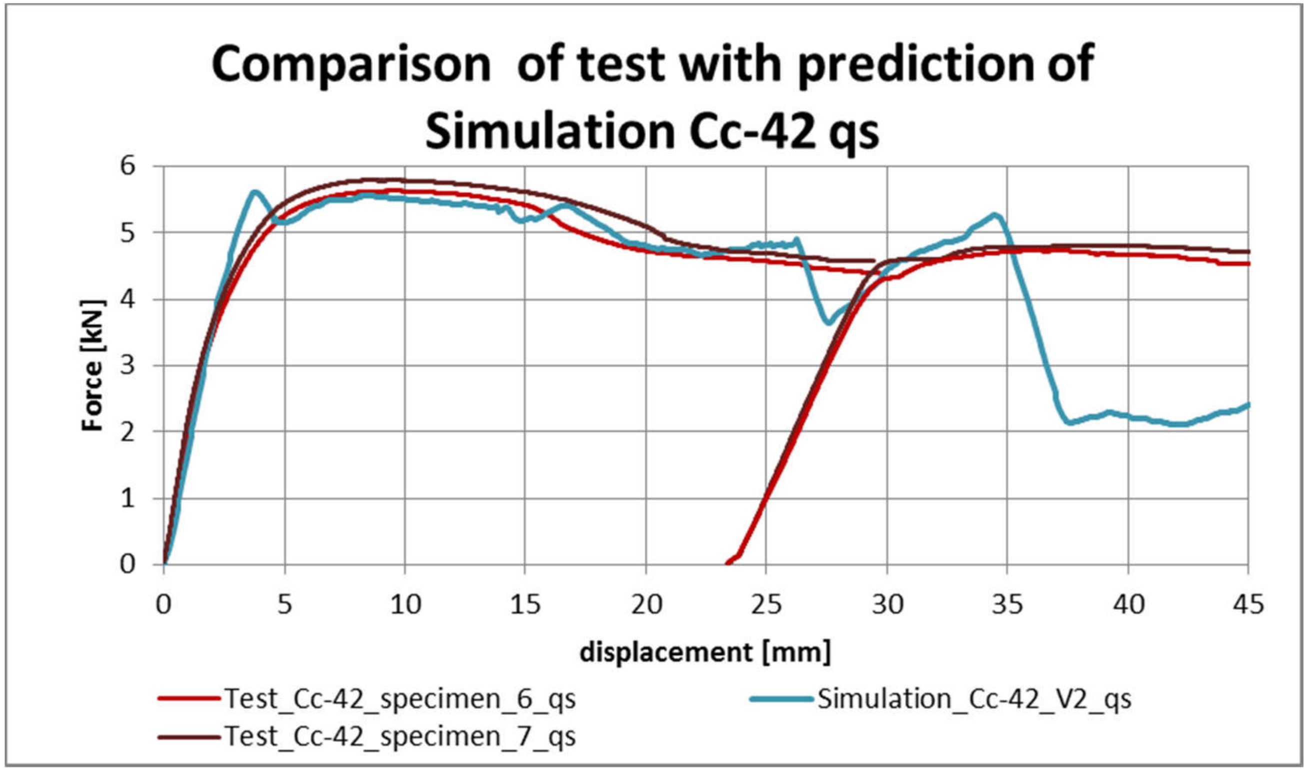
→ **Cc-42 material model has been calibrated**

→ **Ma-plus material model was calibrated analogously**

Methodology
- Validation of material model with 3PBFT of flipped top-hat profiles



Methodology
- Validation of material model with 3PBFT of flipped top-hat profiles



→ **Cc-42 material model has been validated**

→ **Ma-plus material model was validated analogously**

Proof of potential in strut tower
- SLC reference

SLC strut tower

- Structural die cast component made of AM50 with mounting parts
- Operational stability: 80 MPa
- Weight of **AM50 cast only: 2.110 kg**

Material substitution with Al-alloy

- Commonly used AlSi10MnMg T7
- Operational stability 80 MPa
- Weight of **AlSi10MnMg cast: 3.130 kg**

Load Case:

- static load of 12 kN in z-direction

SLC-Demonstrator with casted strut tower

Proof of potential in strut tower
- Castaduct-42

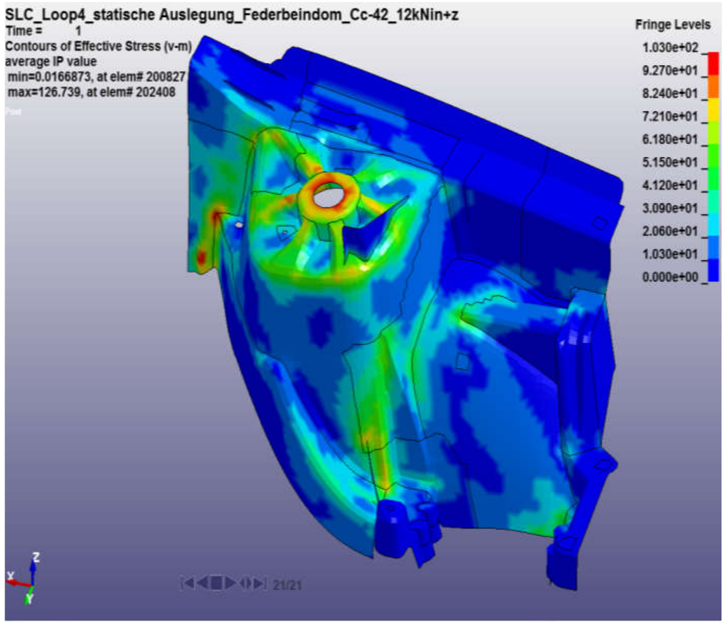
Cc-42 strut tower:

- Initial weight: 3.130 kg
- Operational stability(5 %/10^7 cycles): 103 MPa

- Iterative dimensioning between static simulation, adjustment of wall thickness and full-vehicle crash simulation

- Weight analysis:
  - **Castaduct-42: 2.520 kg**
  - Difference to AM50: +0.430 kg **+19.4 %**
  - Difference to AlSi10MnMg: -0.620 kg **-19.5 %**

Loop 1



static simulation with load case 1

Proof of potential in strut tower
- Magsimal-plus

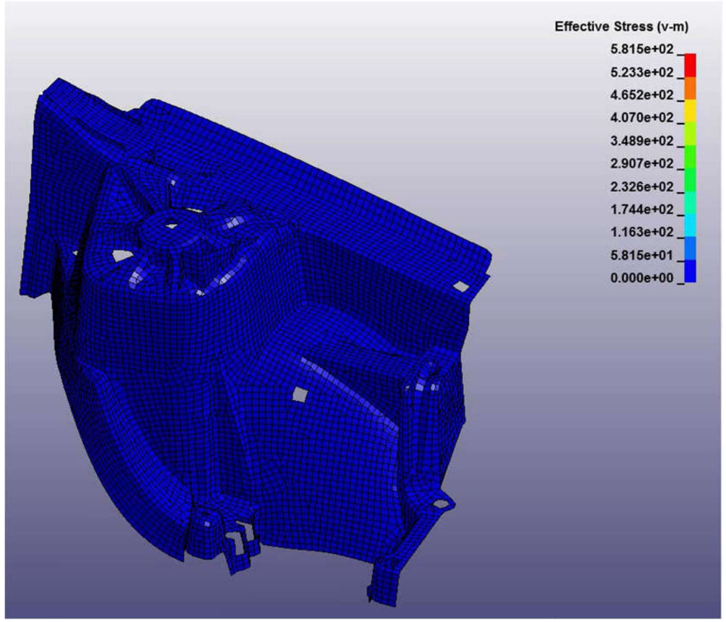
Ma-plus strut tower:

- Initial weight: 3.100 kg
- Operational stability(5 %/10^7 cycles): 112 MPa

- Iterative dimensioning between static simulation, adjustment of wall thickness and full-vehicle crash simulation

- Weight analysis:
  - **Magsimal-plus: 2.430 kg**
  - Difference to AM50: +0.370 kg **+15.2 %**
  - Difference to AlSi10MnMg: -0.680 kg **-22.4 %**

Loop 3



full vehicle crash simulation

Proof of potential in strut tower
- Overview of findings

Castaduct®-42

- Good-natured failure behavior due to high elongation at break
- No cracks between strut tower and connection to A-pillar
- Failure in wheel arch not critical

→ **Structural integrity maintained**

- Lightweight potential compared to:
  - **AM50: +19.4 %**
  - **AlSi10MnMg: -19.5 %**

→ **Characteristics of Cc-42 better suited for strut tower**

Magsimal®-plus

- Elongation at break just enough for this component
- No cracks between strut tower and connection to A-pillar
- Failure in wheel arch not critical

→ **Structural integrity maintained**

- Lightweight potential compared to:
  - **AM50: +15.2 %**
  - **AlSi10MnMg: -22.4 %**

→ **Potential of Ma-plus not fully exploitable due to castability**

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Proof of potential in A-pillar cast node
- DLR reference model

A-pillar cast node (DLR)

- Structural die cast component made of AM50

- Operational stability: 80 MPa
- Tensile strength: 210 MPa
- Compressive strength: 130 MPa

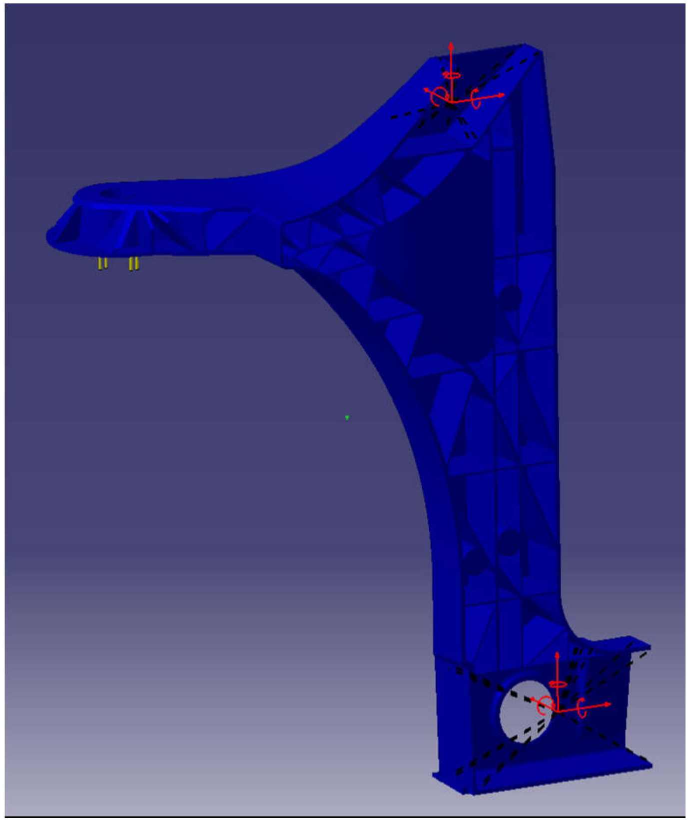
- Weight analysis:
  - **Steel** sheet metal assembly: **10.390 kg**
  - A-pillar cast node **(AM50):** **5.920 kg** -43.0 %

Variant of A-pillar cast node made of AM50

Proof of potential in A-pillar cast node
- Magsimal-plus with load case 1

Magsimal-plus A-pillar cast node:

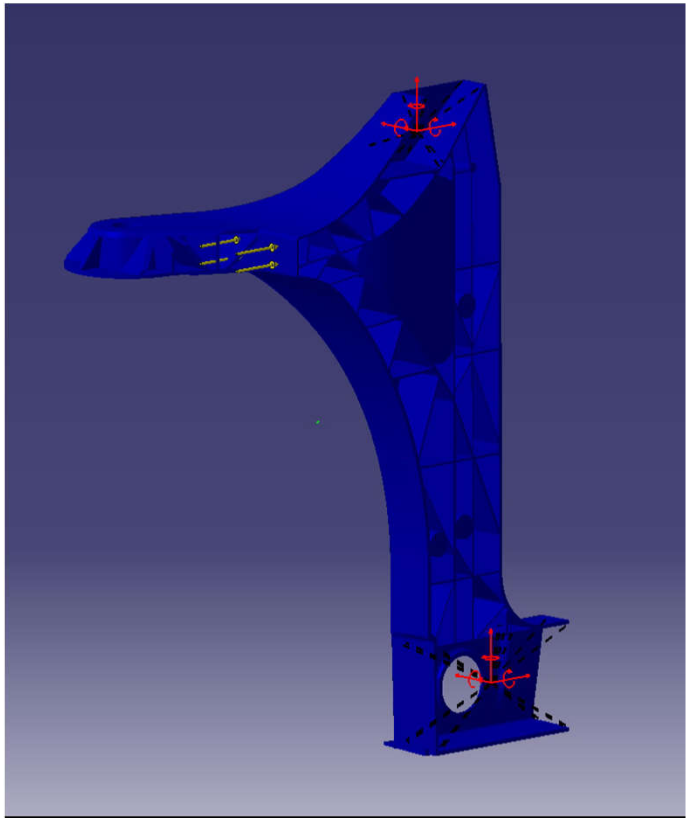
- Initial weight: **8.690 kg**
- **Load Case 1**:
  - Static load of 12 kN in z-direction
  - Operational stability of 112 MPa relevant
  - → Minimum wall thickness reduction by 1.4
- 3 areas:
  - Red: reduction only by 1.4 possible
  - Green: reduction by more than 1.4 possible
  - Blue: not needed for this load case
- But: **LC2** and **castability** not considered


Magsimal-plus model with load case 1

Proof of potential in A-pillar cast node
- Magsimal-plus with load case 2

Magsimal-plus A-pillar cast node:

- Initial weight: **8.690 kg**
- **Load Case 2**:
  - Static substitute load of 50 kN in x-direction
  - Tensile/compress. strength of 380 MPa relevant
  - → Minimum wall thickness reduction by 2.9
- 3 areas:
  - Red: reduction only by 2.9 possible
  - Green: reduction by more than 2.9 possible
  - Blue: not needed for this load case
- But: **LC1** and **castability** not considered



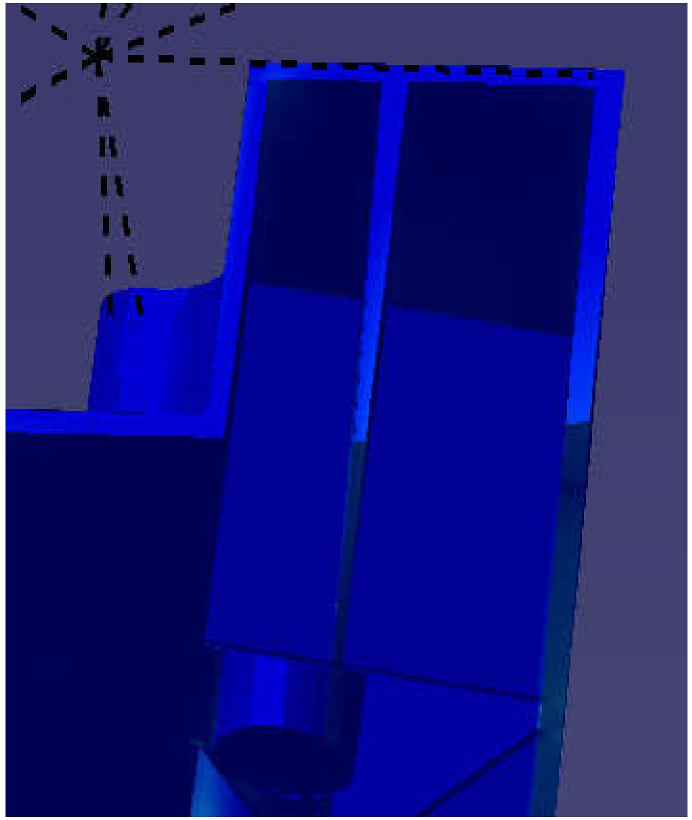
Magsimal-plus model with load case 2

Proof of potential in A-pillar cast node
- Castability of Ma-plus

Castability of Ma-plus

- Small ribs with 2.1 mm thickness at head found in reference CAD-model
- Minimum castable wall thickness 1.8 mm

→ Maximum wall thickness reduction by 1.15
→ Potential not fully utilized here

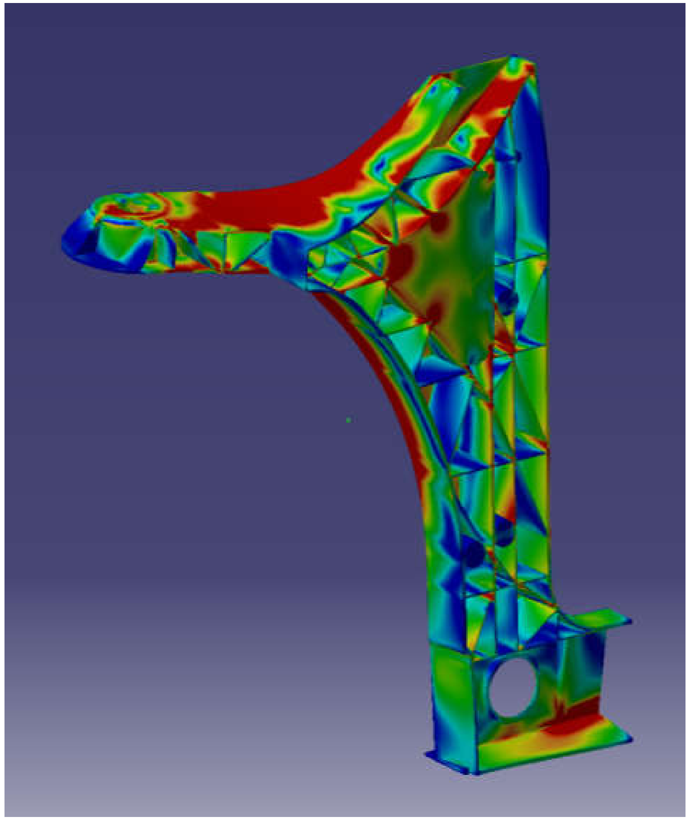


A-pillar cut through CAD-model

Proof of potential in A-pillar cast node
- Magsimal-plus estimated weight reduction

Estimated weight reduction for Ma-plus

- Initial weight: **8.690 kg**
- Total reduction red areas: -0.696 kg
- Total reduction green areas: -1.469 kg
- Total reduction blue areas: -0.120 kg
- Final estimated weight: **6.405 kg**
- Difference **to AM50**: +0.485 kg **+8.2 %**
- Difference **to steel** sheet metal assembly: -3.985 kg **-38.4 %**



Magsimal-plus model with load case 1

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Proof of potential in A-pillar cast node - Overview of findings

- Failure stresses and strains taken into account
- Castability taken into account
- Most relevant load cases taken into account

→ **Magsimal®-plus can be used in A-pillar cast node**

- **Lightweight potential** compared to:
  - **magnesium AM50 casted node: +8.2 %**
  - **steel sheet metal assembly: -38.4 %**

→ Proof of lightweight potential through simulation for **Magsimal®-plus**

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Summary

Methodology

Basic understanding of the material

↓

Calibration of material model

↓

Validation of material model

↓

Proof of lightweight potential through validated simulations

Non-heat treated Al-HPDC alloys

- Proof of lightweight potential
- No heat treatment
  - Reduction of process steps
  - Minimal/no straightening needed
    → Easier, faster production
    → Reduced production costs
- Reduction of used energy
  - Smaller carbon footprint
  - Reduced energy costs
- **Simulation method for structural components available at DLR**

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Thank you

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