11th LS-DYNA Forum, 9 - 10 October 2012, Ulm Germany

CAE of Organo-Sheet Material

(Thermoplastic Woven Glass Composite)

09 October 2012

Engineering Design Department
Vehicle CAE
Jerome Coulton

HYUNDAI
MOTOR GROUP

Table of contents

1. Background

- In the global quest to reduce CO2 emissions, via reduced vehicle mass, there is an increasing use of high strength glass composites in the EU.
- Today there has been an innovation with the generation of new woven fibre composites with thermoplastic matrices (organo-sheet) and associated forming processes.
- Of these, glass based woven composites have been identified for high strength with low specific weight and cost.
- EU Serial Examples :
  - BMW M3 Bumpers
  - Audi A8 Frontend Module
- EU Prototype Examples :
  - Audi A4 Bumper Armature
  - Audi rear door anti-intrusion beam
  - Audi rear seatback

Organo	Matrix	Reinf	Process
Glass/PA6	PA6 GF30	Steel	Welding

BMW M3 Front Bumper http://techcenter.lanxess.com/

Organo	Matrix	Reinf	Process
Glass/PA6	PA6 GF30	Steel	overmold

Audi A8 Frontend Module http://techcenter.lanxess.com

Organo	Matrix	Reinf	Process
Glass/PA6	PA6 CF30	-	overmold

Audi A4 Bumper Armature http://www.ivw.uni-kl.de

Organo	Matrix	Reinf	Process
Glass/PA6	PA6 CF60	-	overmold

Audi Door Anti-intrusion Beam http://www.ivw.uni-kl.de

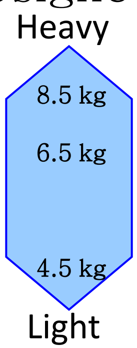
Organo	Matrix	Reinf	Process
Glass/PA6	PA6 CF30	Al.	Overmold + Gas-injection

Audi Rear Seatback http://www.jacobplastics.com/

EU Examples of glass based woven composites

2. Proposed Potential Application

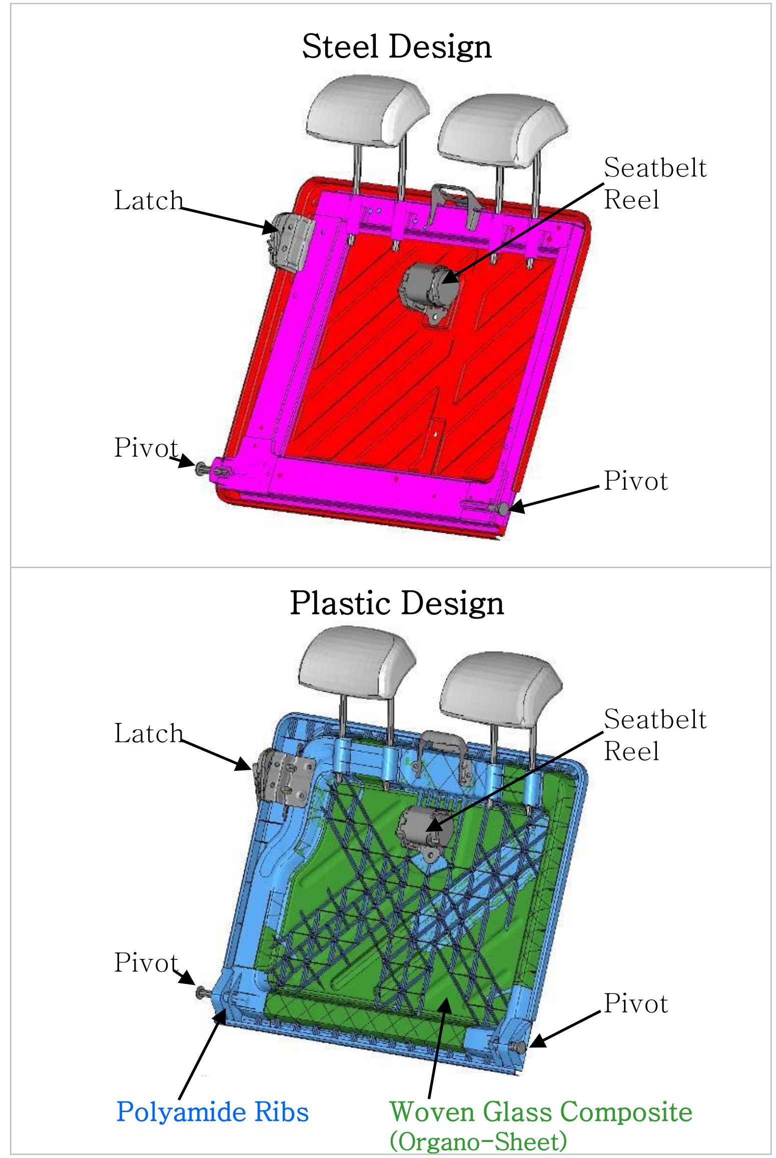
- ❖ Rear seatbacks can be designed with different materials e.g.
  - ➢ Standard grade steel
  - ➢ High strength steel
  - ➢ Aluminium
  - ➢ Plastic composite



- ❖ The redesign of the rear seatbacks to use standard strength compared to high strength steel resulted in a mass reduction of 2 kg for the 60% part.

- ❖ Assuming typical overmold materials:
  - ➢ Glass organo-sheet with PA6 matrix
  - ➢ PA6 GF30 ribs

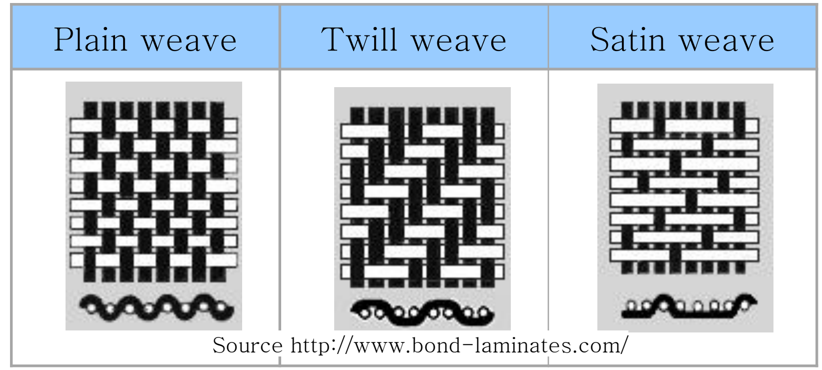
- ❖ Results in a potential mass saving of 4 kg (47%) for the 60% part compared to the original steel design.



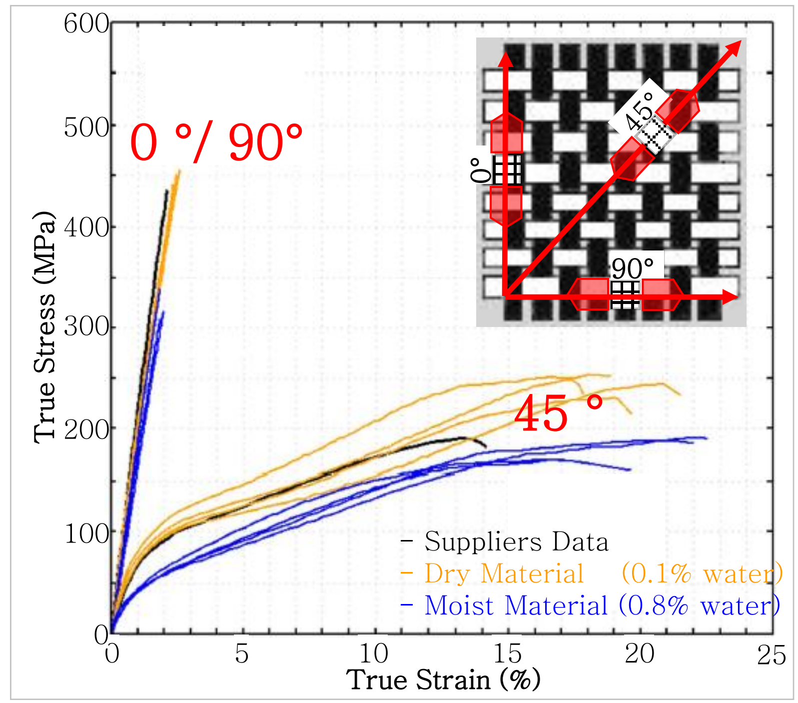
Comparison of Steel and Plastic Designs

3. Material Details

- Organo-sheet is a woven material:
  - Fibre:
    - Glass
    - Carbon fibres
  - Matrix
    - Polyamide
    - Polypropylene
- Unlike steel, the material stiffness is anisotropic i.e. the stiffness and strength is unequal in different directions. This makes CAE much more difficult
- Unfortunately there are no openly available validated material models for organo-sheet
  - This creates the need to generate new validated material models to predict part performance



Organo-sheet weaves

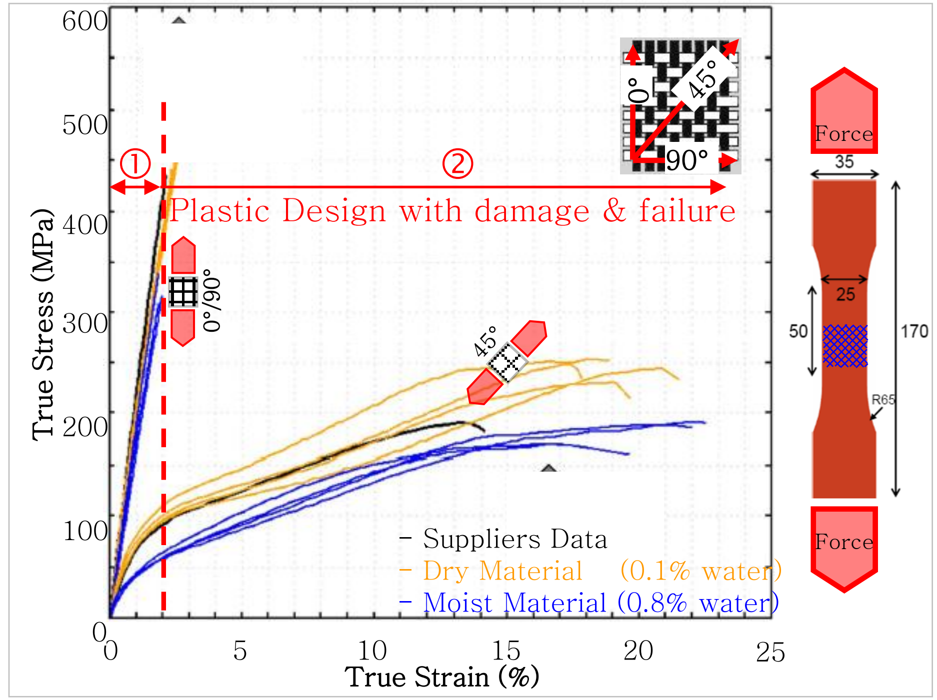


Tensile Tests – Effect of Fibre Angle

1. CAE Model Targets

- CAE design optimization requires accurate prediction both:
  - ① Below material yield point
  - ② Between yield point and ultimate failure

- At the start of the project two criteria were defined:
  1. Desired CAE Accuracy:
     - Elastic Design >90% (steel >95%)
     - Plastic Design >70% (steel >85%)
  2. Compare two proposed matrix systems:
     - Polyamide vs. Polypropylene (Potential cost down)



Tensile Tests – PA Organo-Sheet

OEM	Elastic Design – no damage	Plastic Design – damage & failure
# 1	90 %	90 %
# 2	95 %	75 %
# 3	80 %	23 %

CAE Composite accuracy reported at VDI Conference 2011

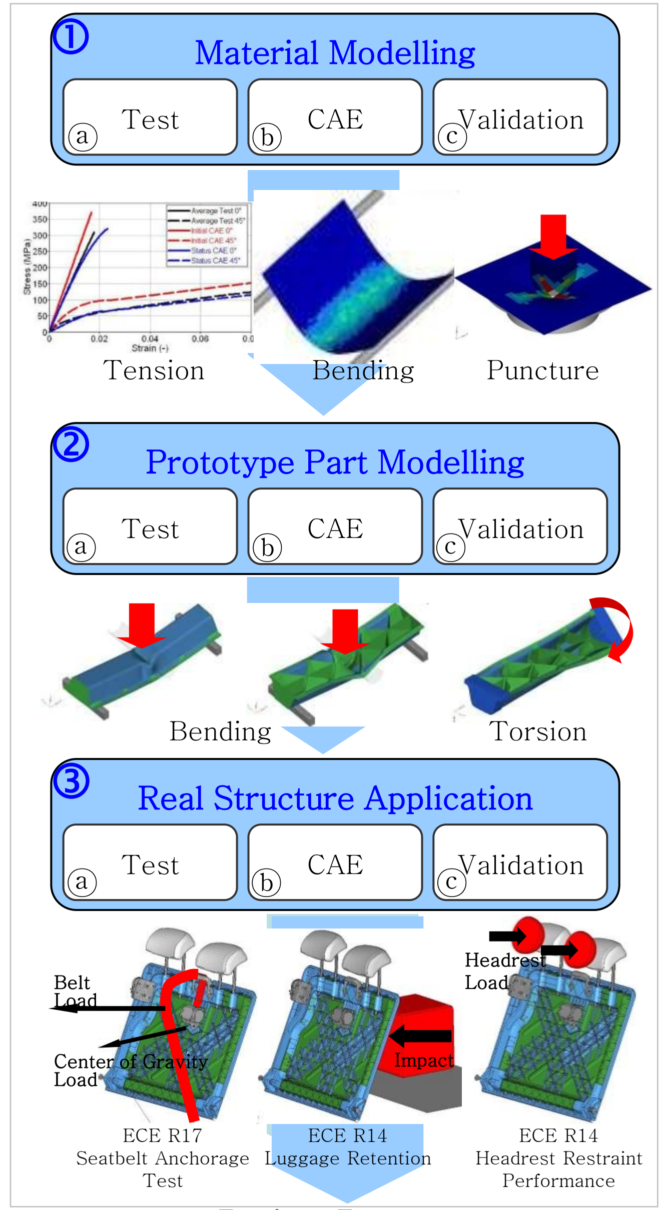
Comparison of CAE Accuracy at EU OEMs

2. Project Plan

- ❖ The development of the validated material models was achieved in three phases:
  - ① Material modelling
  - ② Prototype part modelling
  - ③ Real structure application

- ❖ Within each of these three phases there were three sub activities:
  - ⓐ Testing
  - ⓑ CAE modelling and simulation
  - ⓒ Validation

- ❖ All three phases interlinked using the same data:
  - ➢Traceable transparency of data source.



Project Process

III Material Testing

1. Test Plan

❖ Goal of testing:
- Extract parameters for LS-DYNA
- Measure strain rate sensitivity
- Compare material performances

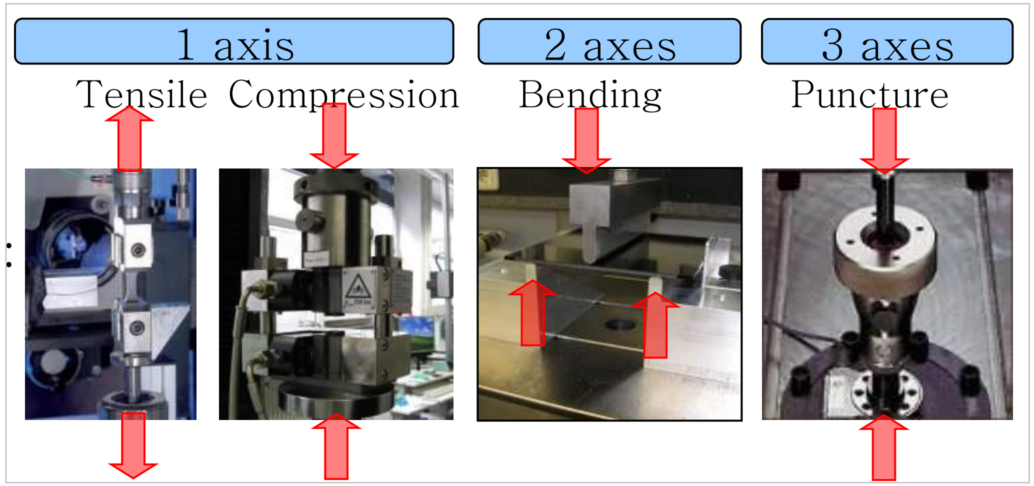
❖ Required Data:
- Stiffness
- Strength
- Damage

❖ Orientation effect:
- 0/45/90°
- Tension/compression

❖ The materials were tested in 3 steps:
- 1-D: Tension & Compression
- 2-D: Bending
- 3-D: Puncture

Loading		Φ- Material Orientation	Test Velocity	
			Quasi-Static	High Velocity
1-D	Tensile	0/90°	Polyamide & Polypropylene	Polyamide & Polypropylene
	Shear	45°		
	Compression	0/90°		
	Shear	45°		Polypropylene
2-D	Bending	0/90°		Polyamide & Polypropylene
	Shear	45°		
3-D	Plate Puncture	N.A.		

Material Test Matrix

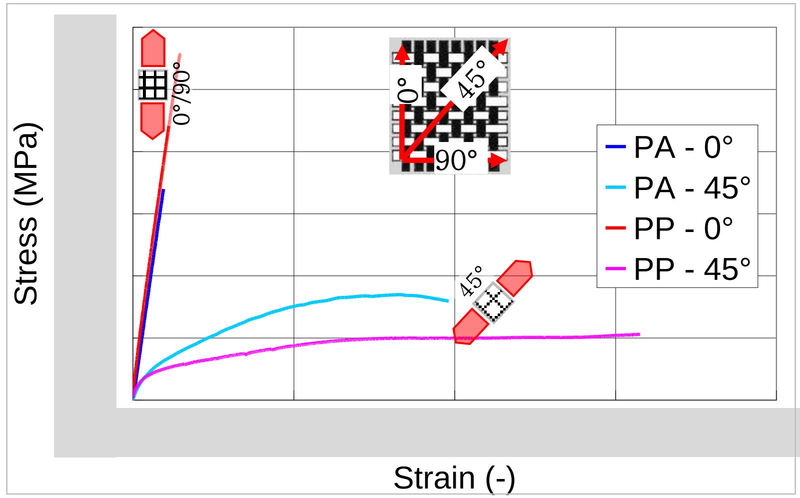


Material Test Configurations

2. Tensile Test Results

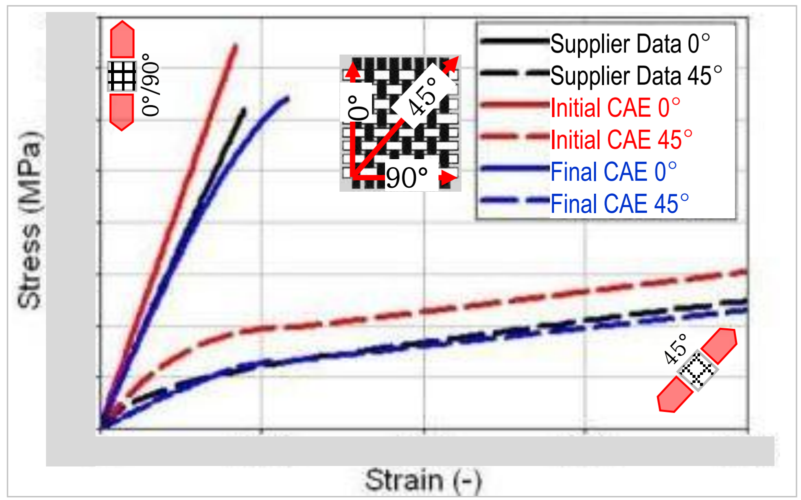
- Comparison of polyamide and polypropylene based materials:
  - The higher shear stiffness and strength of the polyamide matrix based material results in a more robust material than the softer and more ductile polypropylene matrix based material.

Dynamic Material Properties (strain rate 10 ε/s)			
Parameter		Polyamide	Polypropylene
Stiffness	E	100%	95%
	G		100%
Strength	σ		107%
	τ		69%
Shear Failure Strain			125%



Comparison of Polyamide & Polypropylene Data

- Moisture significantly effects polyamide based material (initial vs. final CAE model):
  - Lower Stiffness
  - Greater Ductility
  - Higher Strength

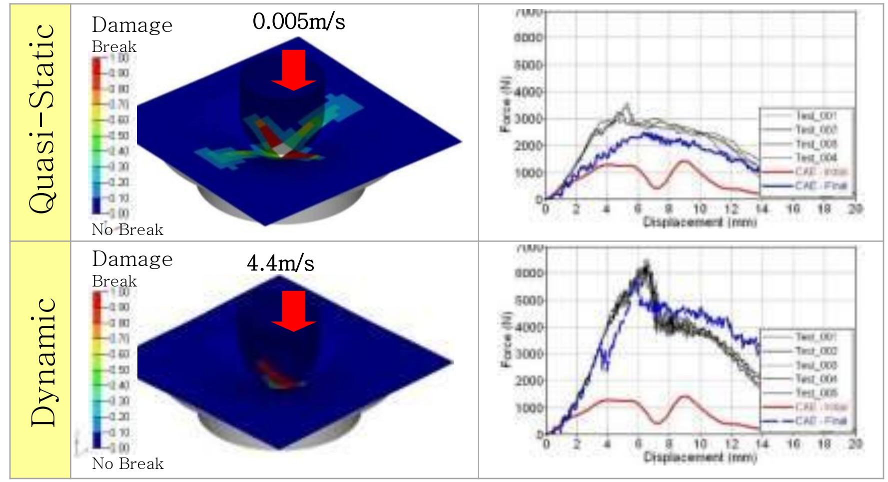


Comparison of Initial and Final Polyamide Data

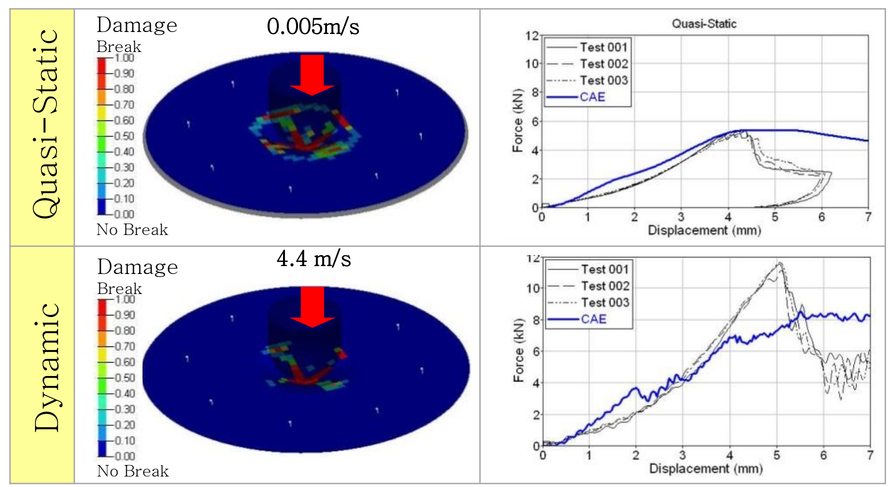
CAE Correlation Results

- Basic Material data extracted from 1-D tests
- The damage and breaking parameters:
  - Model the bending and puncture tests
  - Same mesh size as for CAE application
    - Critical for element erosion tuning
  - Reverse engineering to match tests
    Simultaneously for 1-D, 2-D & 3-D
- Material Models Meet Targets:
  - Increased CAE Accuracy:
    - Elastic design 92% ↑13% (target 90%)
    - %)

Material		PA matrix			PP matrix	
Load Case		Initial	Final	Change	Initial	Final
A. Elastic design		Target >90%		>10%	Target >90%	
1	Tension/Compression	79%	92%	13%	n.a.	91%
B. Plastic Design		Target >70%		>10%	Target >70%	
1	Tension/Compression	77%	88%	11%	n/a	89%
2	Bending	47%	91%	44%		74%
3	Puncture	40%	79%	39%		77%



Polyamide Puncture Test Accuracy



Polypropylene Puncture Test Accuracy

V Prototype Parts – Erlangen Traeger

1. CAE Validation (Polyamide)

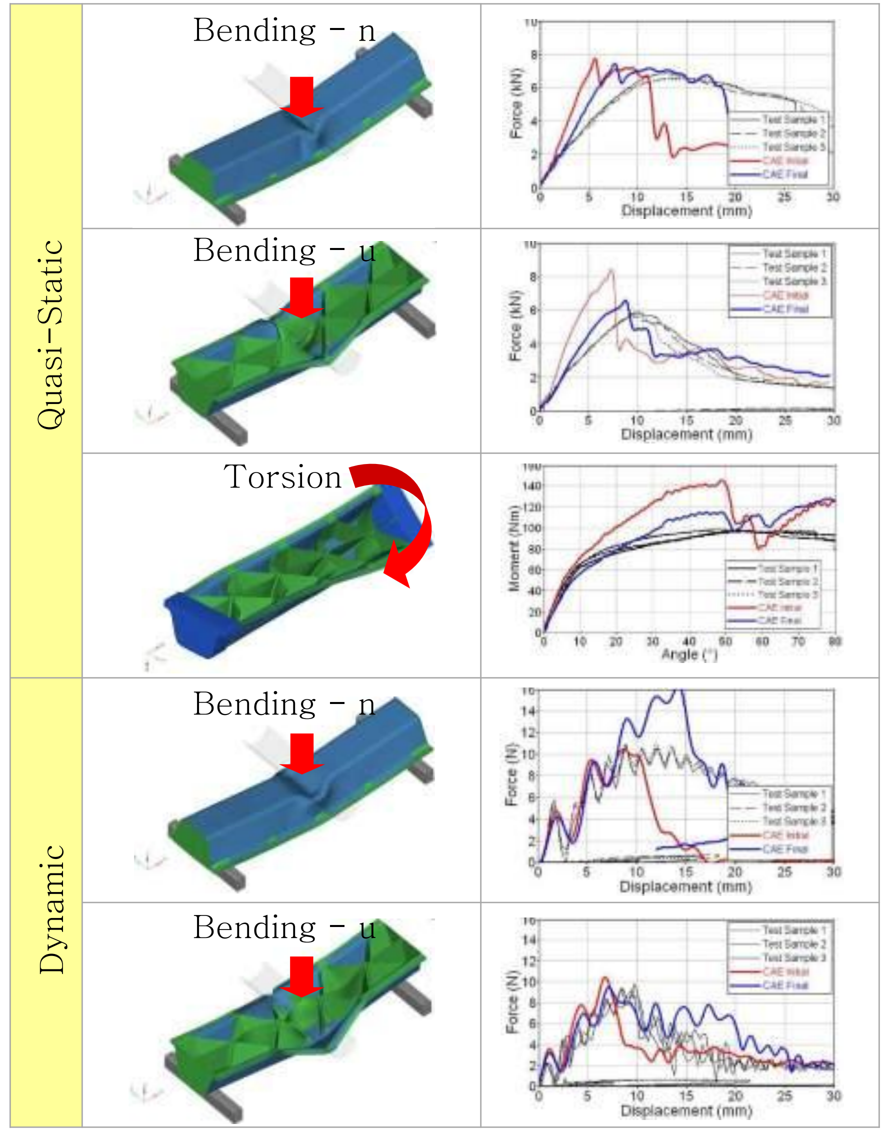
❖ Correlation, Prototype Part tests:

- ➢ Average 77% ↑12% (target 70%)
- ➢ Worst case 71% ↑17% (target 70%)

Loading		Φ – Material Orientation	Agreement	
			Initial	Final
Quasi-static	Bending – n	N.A. (0/90° weave)	54%	71%
Quasi-static	Bending – u		68%	83%
Quasi-static	Torsion		75%	80%
Dynamic	Bending – n		57%	74%
Dynamic	Bending – u		72%	75%

❖ Key to obtaining good agreement:

- ➢ Positioning of the organo-sheet neutral axis within the part section;
- ➢ Matching the strain rates in the measured parts and the numerical simulations;
- ➢ Material properties of the over-moulding – strain rate dependent properties and fibre orientations.



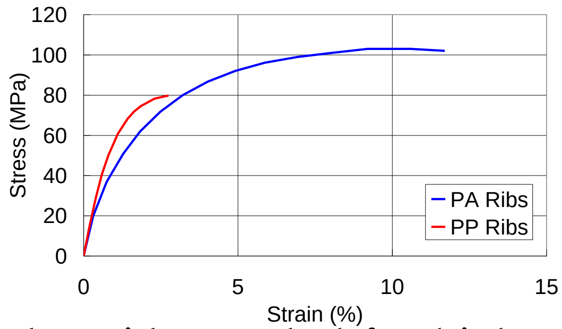
Comparison of Prototype Part Performances

2. Test Comparison, PA vs. PP

- Prototype parts made from:
  - Thermoformed Organo-sheet (woven long fibres)
  - Injection moulded ribs (short fibres)
- Polypropylene has lower mass and cost:

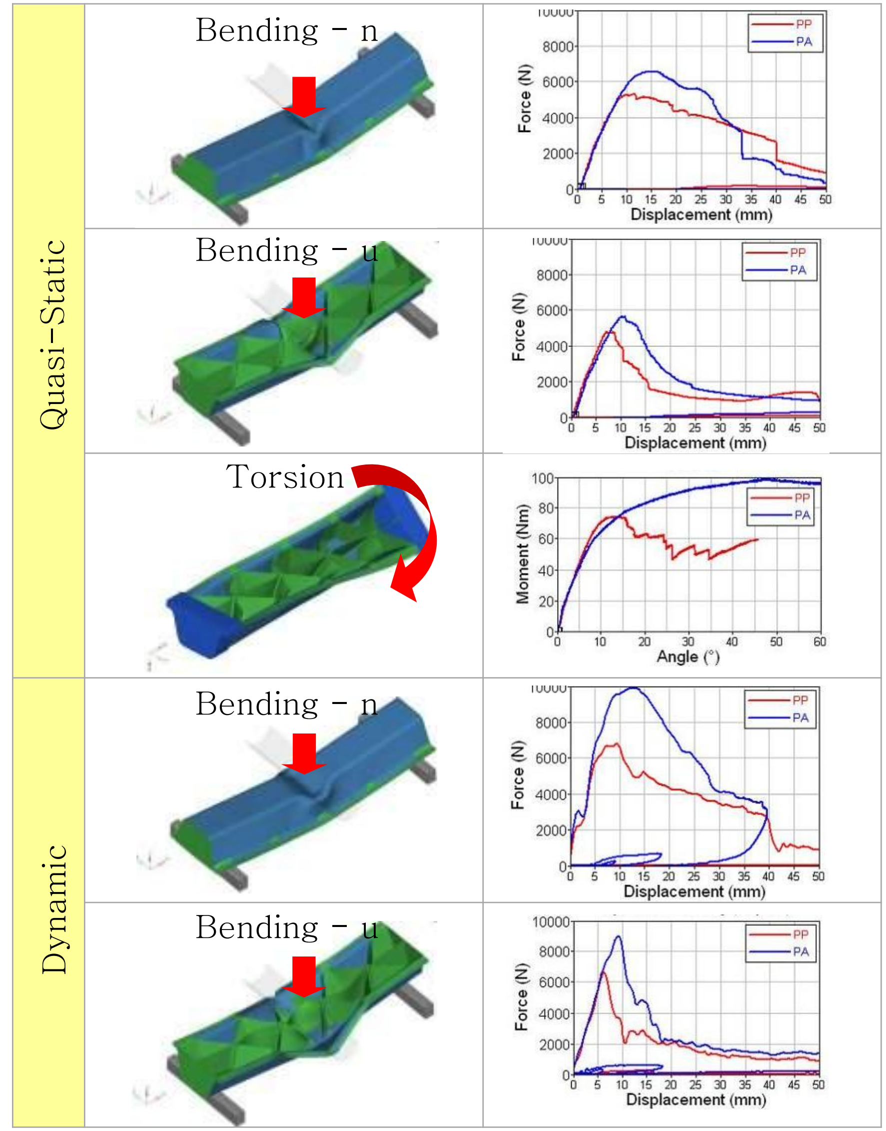
	PA	PP
Mass	100%	81%
Cost	100%	72%

- Part strength driven by rib performance
  - Polyamide ribs best: – higher strain to failure



- Polyamide needed for high performance

Loading		Stiffness PA	Stiffness PP	Strength PA	Strength PP
Quasi-static	Bending – n	100%	100%	100%	78%
Quasi-static	Bending – u	100%	100%	100%	85%
Quasi-static	Torsion	100%	119%	100%	79%
Dynamic	Bending – n	100%	100%	100%	59%
Dynamic	Bending – u	100%	100%	100%	77%



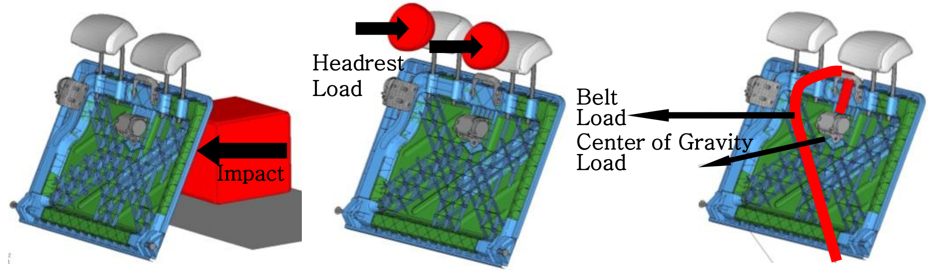
Comparison of Prototype Part Performances

VI Structural Application

CAE Correlation (Polyamide)

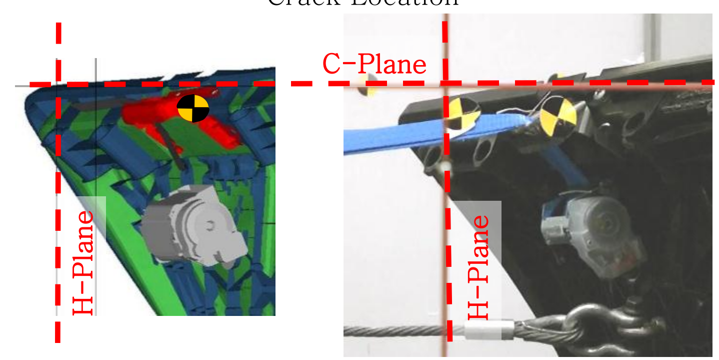
❖ Overall CAE Accuracy:

	Deformation		Cracking (Failure)		
			Load	Position	Timing
Luggage	Z-axis	98%	N. A.	✓	99%
Headrest	X-axis	95%	No cracking	None	N.A. (Quasi-static)
Seatbelt Anchorage	X-axis	97%	99%	✓	
	Z-axis	100%			



Tested Load Cases

Crack Location



Deformation

Seatbelt Anchorage Structural Performance

VII Conclusion and Outlook

Conclusions

- All main targets met:
  - Increased CAE Accuracy:
    - Elastic Design 79% → 92% ↑13% (target 90%)
    - Plastic Design 40% → 79% ↑39% (target 70%)
  - Compare PA (polyamide) vs. PP (polypropylene)
    - For high strength applications polyamide based organo-sheet hybrid parts is best.
    1. Part strength driven by rib performance
    2. Polyamide ribs best: - higher strain to failure

OEM	Elastic Design	Plastic Design – damage & failure
# 1	90 %	90 %
# 2	95 %	75 %
HMETC	91 %	74 %
# 3	80 %	23 %

Comparison of CAE Accuracy at EU OEMs

Criteria	PA Matrix	PP Matrix
Mass	100%	81 %
Mat. Cost		75 %
Stiffness		100 – 119 %
Strength		59 – 85 %

Comparison of Prototype Part Performances

Outlook

- With these new material models it was possible accurately predict the performance, stiffness and strength, of organo-sheet hybrid parts and thereby optimize their performances including cost and mass.
- Recommendations for Future work:
  - Evaluate new LS-DYNA material models such as Camanho & Pinho

Criteria	Target	Plastic Composite
Cost	→ 0 %	0%
Weight	↓30%	↓47%
Load Case 1 (Quasi Static)	OK (stiffness) strength	OK (stiffness) strength
Load Case 2 (crash)		
Load Case 3 (Quasi Static)		

Application: Targets and Achievements (WRT steel)

Acknowledgements

- The work presented is the result of a consortium between :
  - Hyundai Motor Europe Technical Center GmbH
  - Johnson Controls GmbH
  - BASF SE

- The author would like to especially express his thanks to:
  - Matthias Goebel
  - Daniel Fertig

HYUNDAI MOTOR GROUP

Attachments

Attachments

1. Manufacturing Process
2. Material Models
3. Erlangen Traeger CAE Details

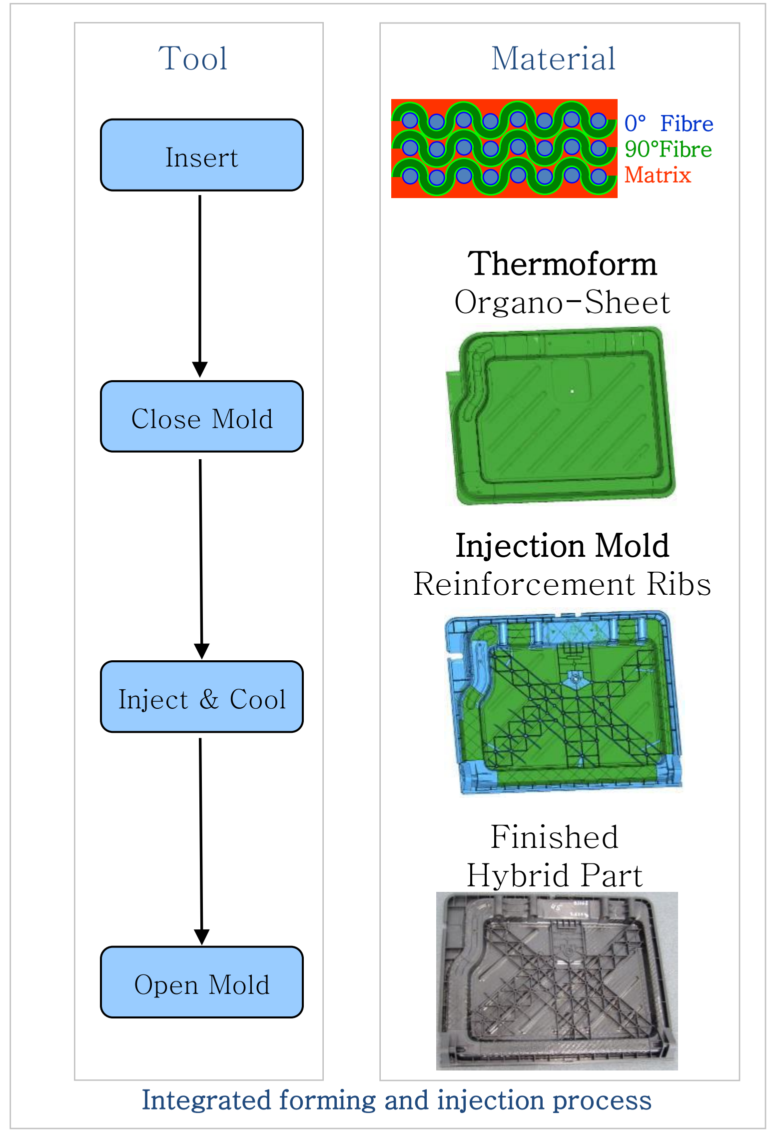
Annex 1. Manufacturing Process

SpriForm (in-mold forming)

- Woven glass composites with a thermoplastic matrix is generically called "organo-sheet" and consists of:
  - Plain woven (filament glass) fibre mat.
  - Polyamide-6 or Polypropylene matrices.

- A particular advantage of these organo-sheets is that they can be thermoformed and then over-moulded in one tool resulting in fast cycle times i.e. low production costs.

- In order to take advantage of the high strength of long fibre thermoplastic material systems and design new products, CAE optimisation of proposed designs are necessary.



The SpriForm Process (in-mold forming)

Required Material Models

❖ Theoretically three models are required:

1. Organo-Sheet
2. Joint between organo-sheet and ribs
3. Over moulded ribs etc.

1. Organo-Sheet

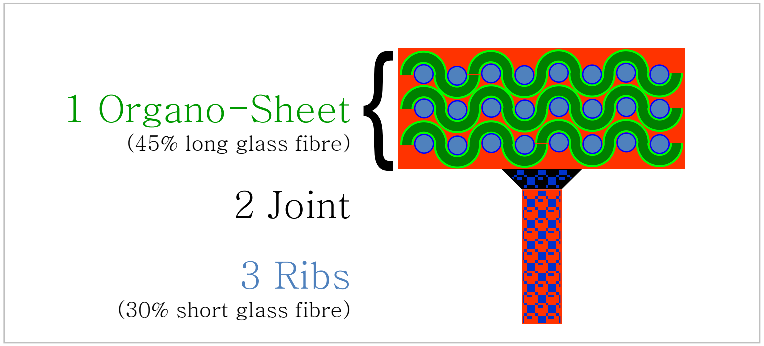
- # layers via *PART_COMPOSITE
- Each layer modelled using *MAT_LAMINATED_COMPOSITE_FABRIC (Best ability to model known shear behaviour)

2. Joint

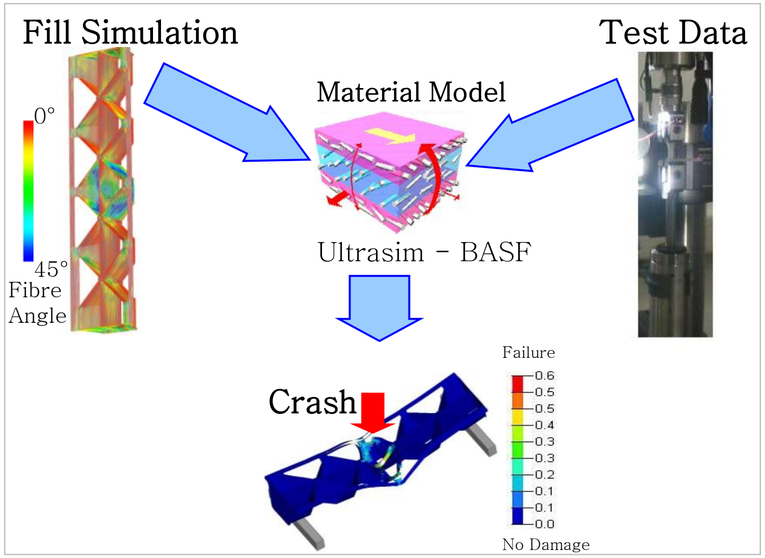
- No need to model as no failure observed – Knitting of short fibres into long fibre mat.

3. Over-moulded ribs

- Modelled via Ultrasim
- Includes:
  - Fibre Orientation
  - Hydrostatic state – Loading direction
  - Strain rate



Hybrid Material Model



Over-Moulded Ribs, Material Model

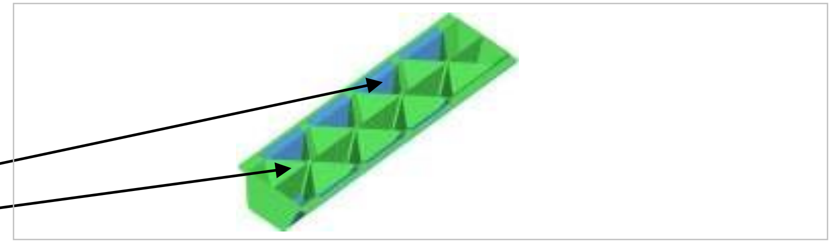
Annex 3. Erlangen Traeger CAE Details

Over Moulded Prototype Parts

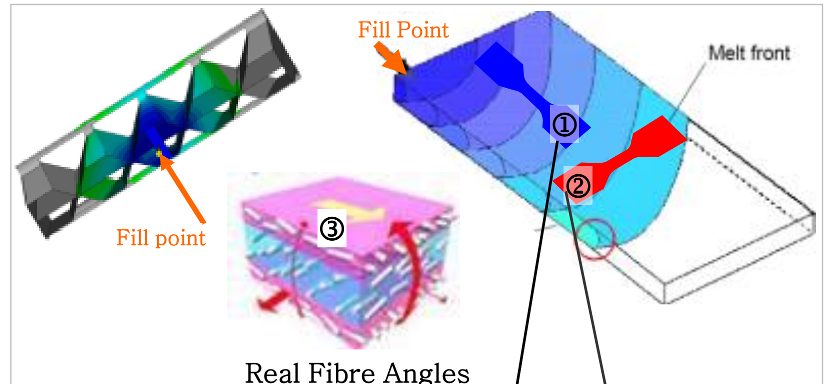
- ❖ Prototype part made from two components:
  - ➢ Thermoformed Organo-sheet (long fibres)
  - ➢ Injection moulded ribs (short fibres)

- ❖ Fibre angles due to processing:
  - ➢ Organo-sheet: Thermoformed
    - – Aligned with tool 0/90°
  - ➢ Ribs: Injection Moulded
    - – Radial fill pattern

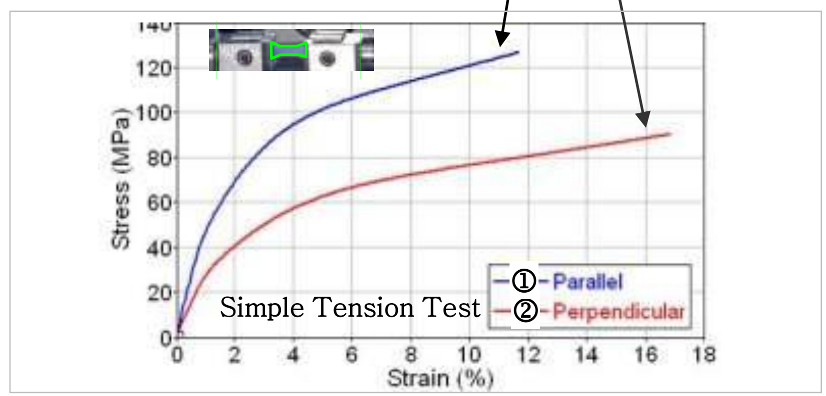
- ❖ CAE Material model for Ribs (Ultrasim):
  1. Real Orientation (via Moldflow)
  2. Coupling to LSDYNA:
  - ➢ Inclusion of fibre orientation
  - ➢ Inclusion of knit line effects.
  - ➢ Inclusion of strain rate effects



Prototype Part – Erlangen Traeger



Fibre Orientation from Injection Moulding



Effect of Fibre Orientation on Material Stiffness