European Commission | Horizon 2020 European Union funding for Research & Innovation

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AffordabLe LIghtweight Automobiles AlliaNCE

Future of Automotive Lightweighting Day

September 19, 2019

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Process technologies – Manufacturing

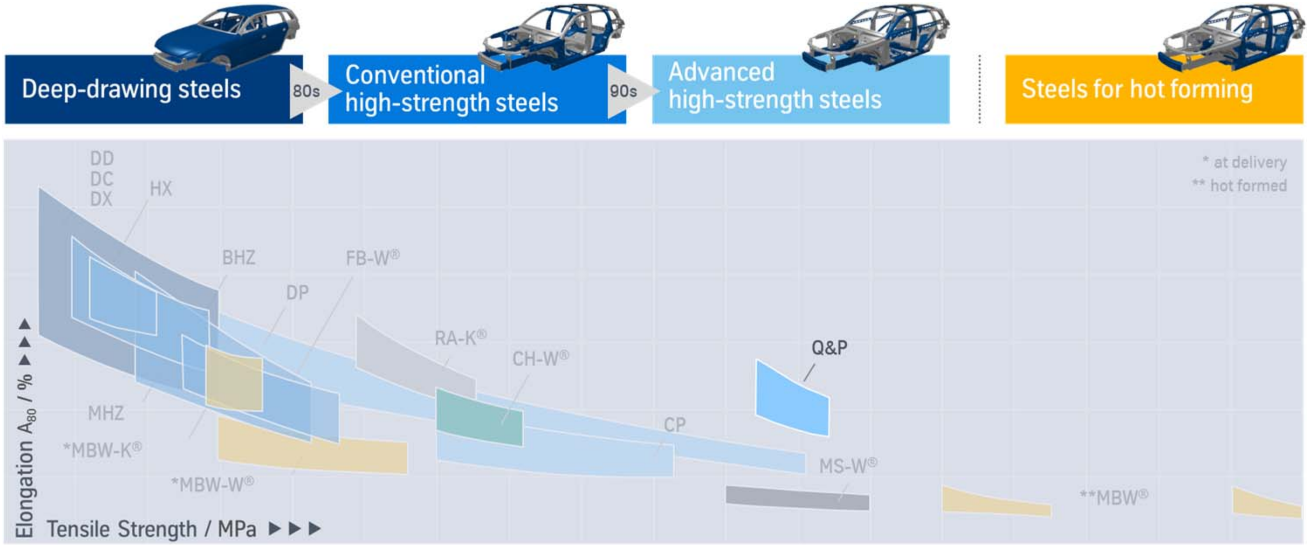
Daniele Bassan / CRF

Introduction & Objectives

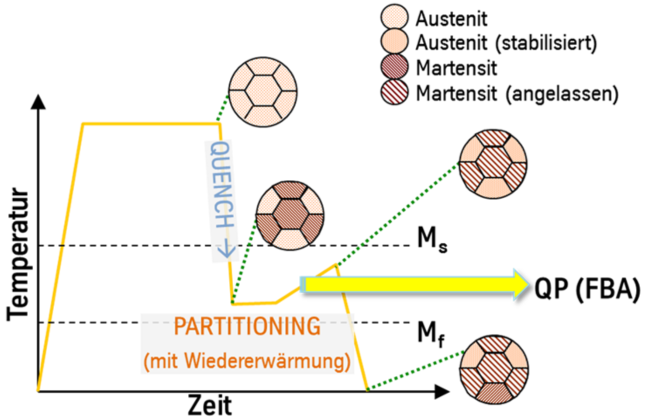
- In order to assess **lightweight** and **cost ALLIANCE project targets**, a development and technological feasibility evaluation of advanced forming processes has been performed, including the development of multi-material joining and assembly technologies for the materials under consideration
- In work package **WP3**, the ALLIANCE consortium was working on **efficient manufacturing and joining process development**, aiming at:
  - reducing energy consumption,
  - increasing automation, and
  - decreasing cycle times.
- **Different manufacturing processes has been investigated, with focus on**
  - Advanced metal forming technologies, **with new QP steel generation**
  - Hybrids, metal with plastic reinforcement, with **Innovative hybrid metal-composite thermoforming process**
  - Improved thermoplastic composite manufacturing process,
  - Joining technologies development

Advanced metal forming technologies: QP steel

Motivation



→ Among other properties, the Q&P-steel shows a higher ductility than steels of comparable tensile strength



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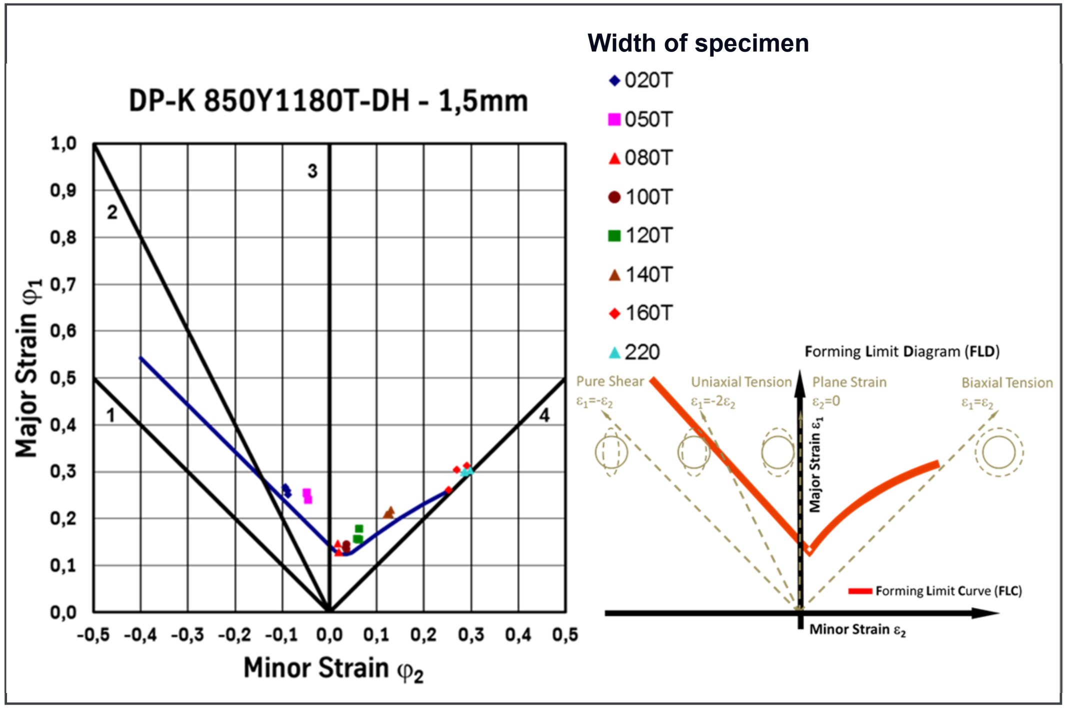
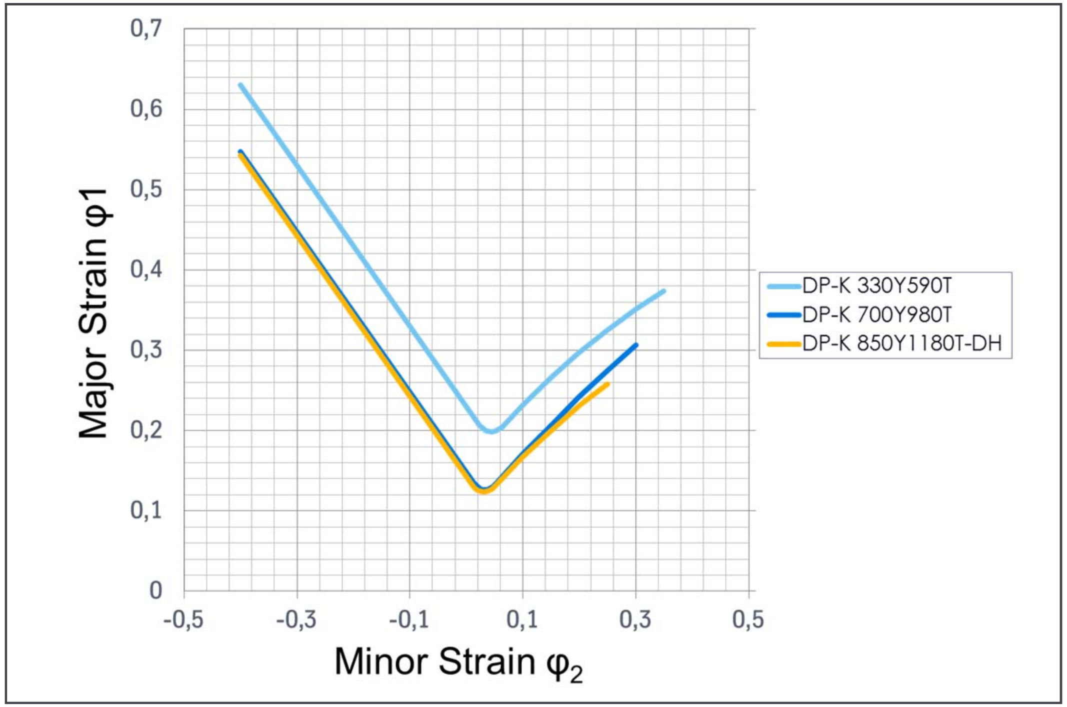
Advanced metal forming technologies: QP steel

Forming Potential, Forming Limit Diagram

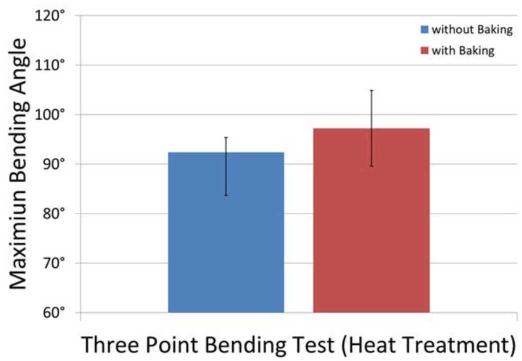


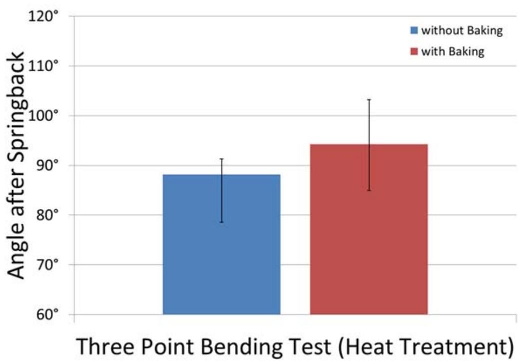


→ The global formability, described by FLD, is good in comparison to other steels of this material class

Advanced metal forming technologies: QP steel

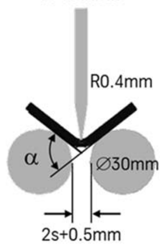
Forming Potential, Bending properties



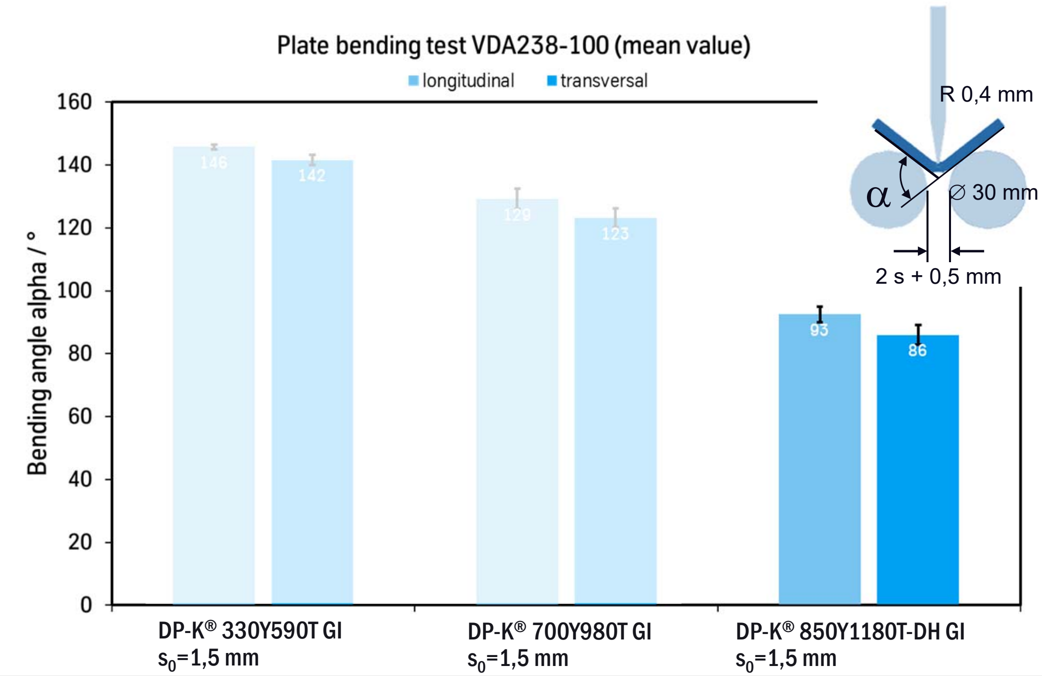


without Heat Treatment	Angle after Springback	Maximun Angle
Angle (Average)	88,182	92,432
maximun Deviation	91,26	95,36
minimum Deviation	78,56	83,71
with Heat Treatment	**Angle after Springback**	**Maximun Angle**
Angle (Average)	94,274	97,26
maximun Deviation	103,27	104,94
minimum Deviation	84,97	89,58

Tool data:



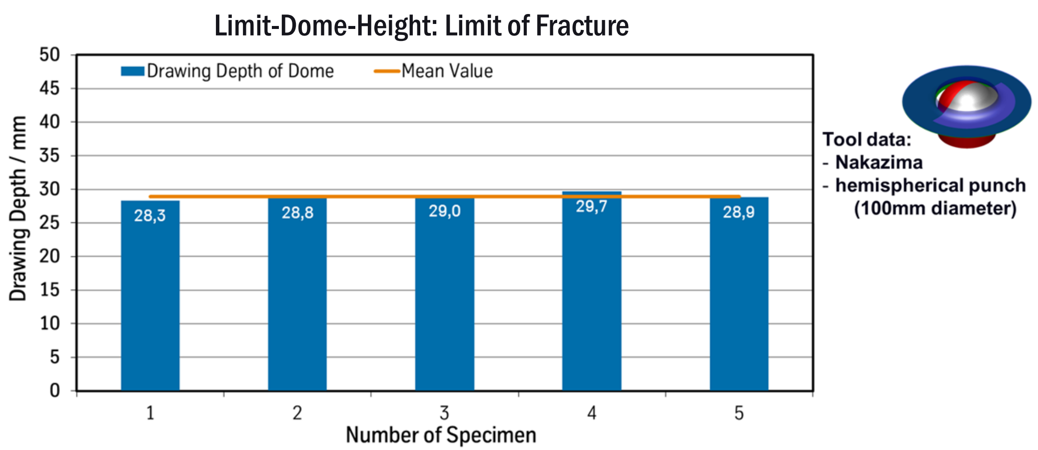
→Typical values for this material class



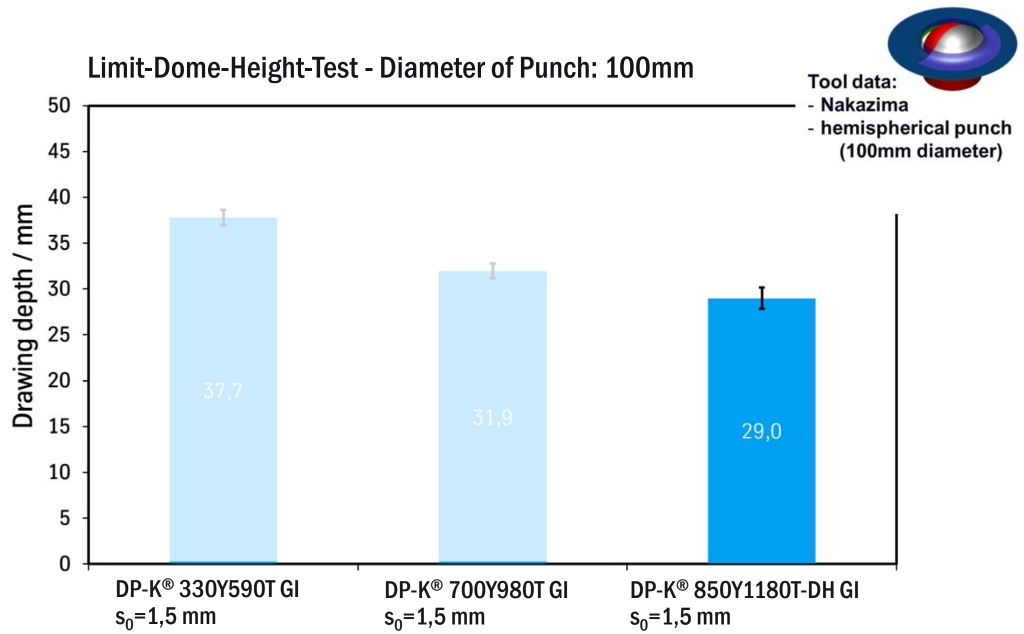
→ The bending angle of this test fits into the different material-specific classes. Differentiations of the bending angle as a function of the rolling direction, heat treatment and the state before and after springback are present.

Advanced metal forming technologies: QP steel

Biaxial Forming Potential, Limit Dome Height Test



Level of limit dome height is typical for this material class



→ The biaxial forming potential is good for this class of material

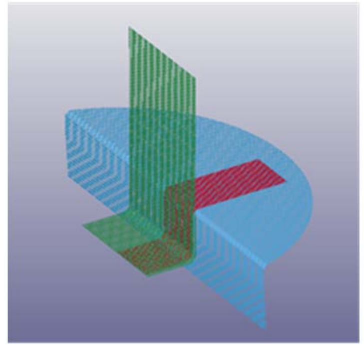
Advanced metal forming technologies: DP steel model

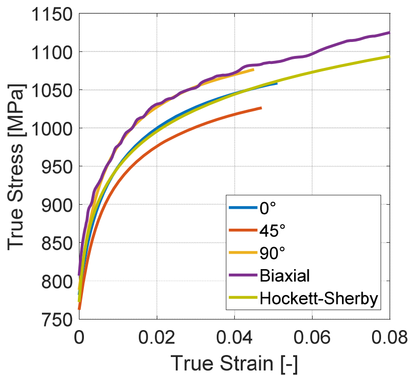
Springback prediction of DP-K® 700Y980T

Material characterization

- Complete material card
- Cyclic tension-compression tests for anisotropic hardening
- Calibration of various anisotropic hardening models

- Process modelling in LS-DYNA
- Investigation of hat profile
- Comparison of model performance



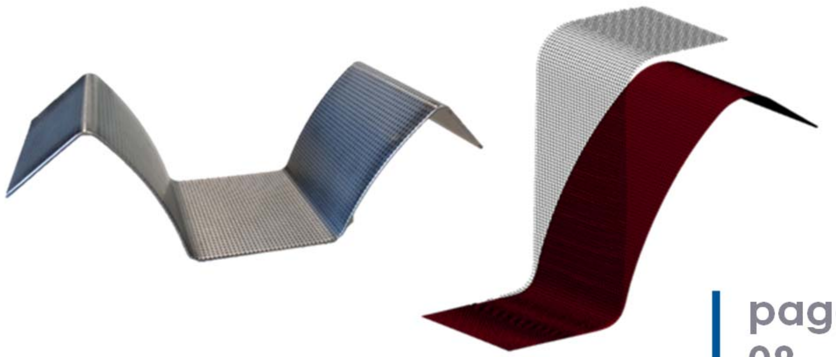


Tensile tests		0°	45°	90°
Yield stress	[MPa]	783	760	790
Young's Modulus	[GPa]	191	188	201
UTS	[MPa]	1060	1027	1076
Uniform Elongation	[-]	0.051	0.047	0.044
Total Elongation	[-]	0.095	0.086	0.081

Bulge-Experiment		
σ_{biax}	[MPa]	807

Hockett-Sherby yield curve parameter

S_{sat}	S_0	m	n
1466.1 MPa	783 MPa	1.2937	0.3134



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Advanced metal forming technologies: DP steel model

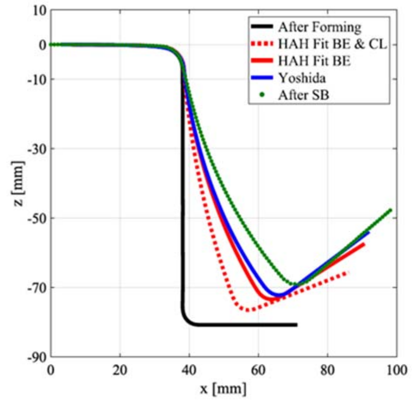
Springback prediction of DP-K® 700Y980T

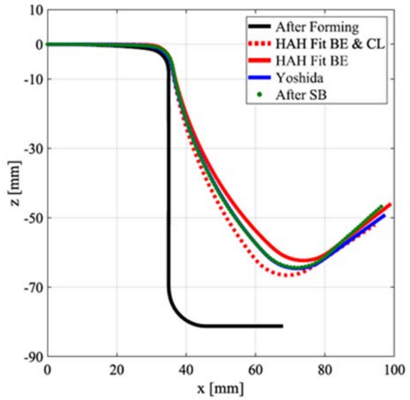
Comparison of model prediction

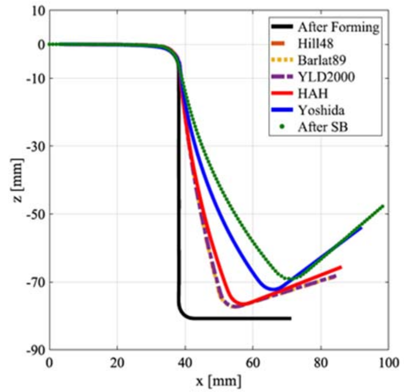
- Yoshida shows best prediction
- Prediction quality dependent on calibration procedure

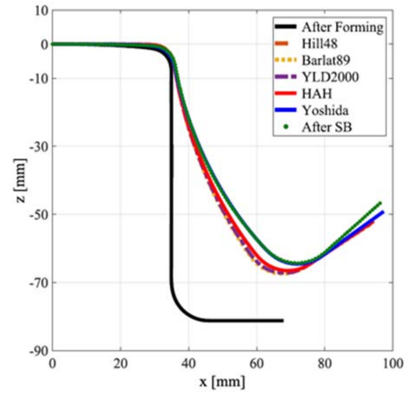
Comparison of kinematic hardening models with conventional models

- Advanced models show significant advantages









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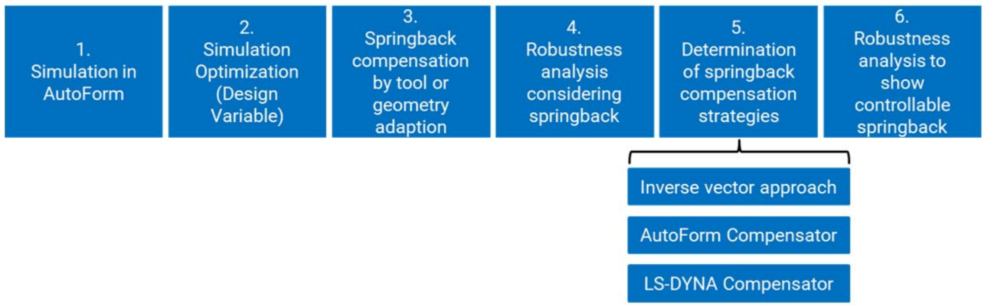
Advanced metal forming technologies: DP steel model

Springback prediction of DP-K® 700Y980T

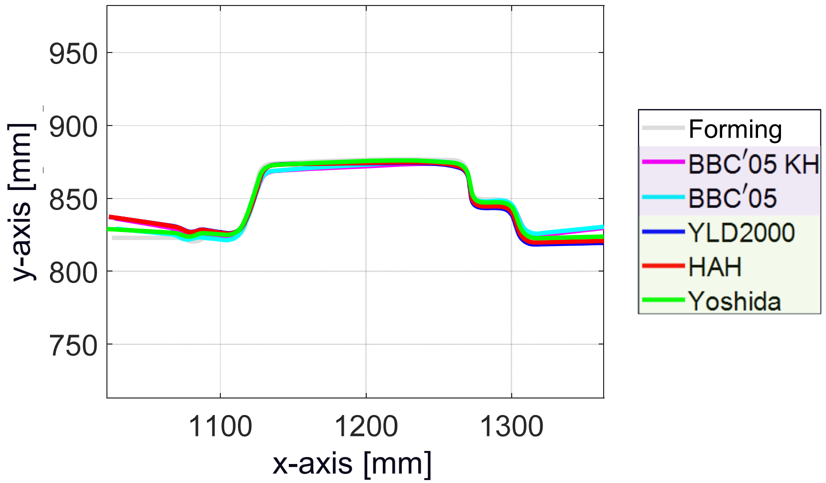
Procedure for robust springback analysis

- Application on VW SEDRIC door reinforcement
- Robust springback prediction based on variation of noise variables and compensation strategy



Virtual comparison of hardening models

- Significant variations between simple and advanced hardening models



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Advanced metal forming technologies: QP steel

Final characteristics of process and Conclusion

- The global formability (Forming Limit Curve and Limit Dome Height-Test) shows a comparable or better behavior to other ultra high strength steel (same class of tensile strength)
- The local formability, i.e. the HER (acc. To ISO/TS) and the bending behavior, is sufficient and corresponds to the class of tensile strength
- The known general tendency of increasing springback behaviour of AHSS is of course a relevant topic, but controllable with appropriate compensation techniques
- The Q&P-Steel fulfils the requirements and demands for the target series production by conventional deep forming technologies
- Hence no additional methods and technologies are necessary

Advanced metal forming technologies

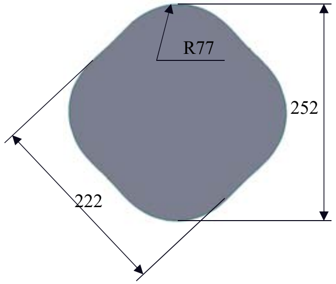
Forming of high-strength aluminium

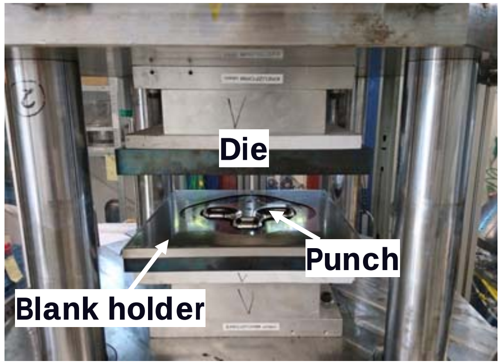
Goals:

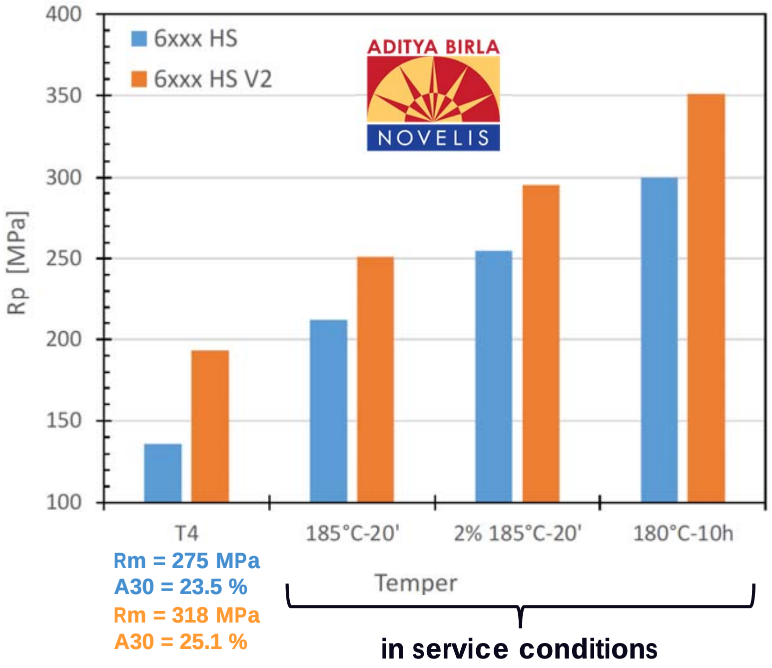
- Determination of the formability of advanced, high-strength 6xxx aluminium alloys

Investigations of

- the formability of cross-die parts depending on
  - the material composition (two different sheet alloys with increased Cu content [6xxx HS and 6xxx HS V2] **provided by NOVELIS**)
  - the material temper condition (w-temper, T4)
  - the blank holder force
  - the drawing depth





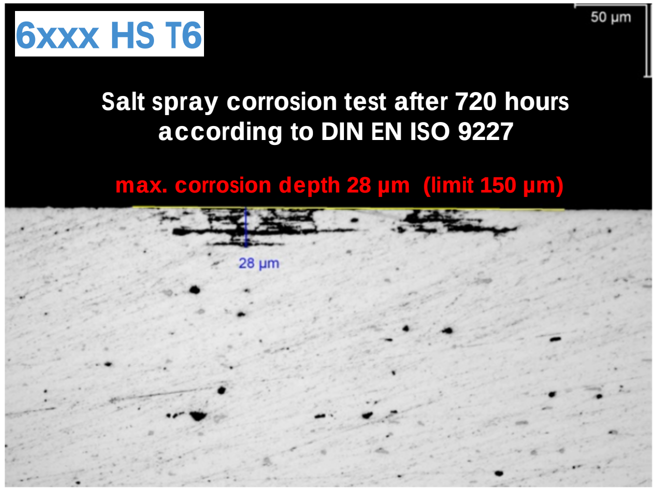


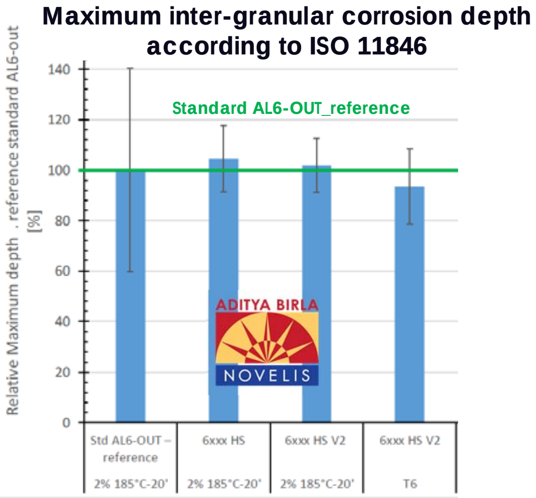
Advanced metal forming technologies

Forming of high-strength aluminium

Results:

- No drastic differences between w-temper forming and T4 forming for both alloys
- By trend, alloy **6xxx HS V2** has a better formability than alloy **6xxx HS** (especially in T4 temper)
- Good corrosion behaviour of both alloys in service condition





Cross-die parts
formed with different blank holder forces

hybrid metal-composite

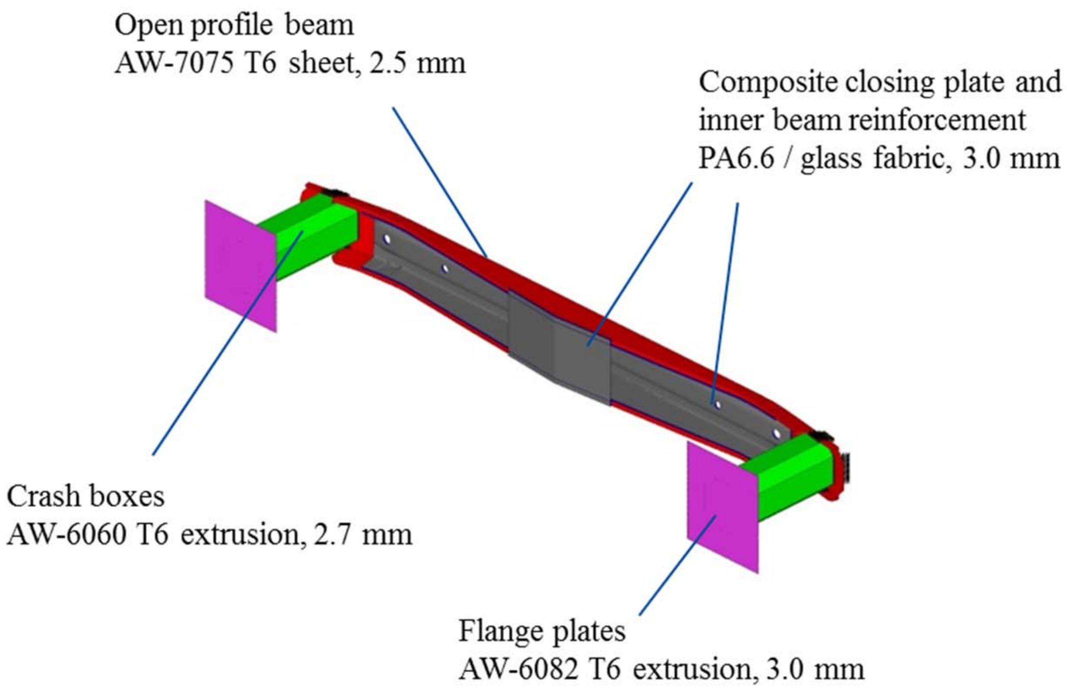
Fast curing of hybrid aluminum-composite joints

Motivation:

- Cost efficient and lightweight hybrid CMS design
- Reduced CO_2-footprint
- **Joining process suitable for mass production** required

Goals for joining method:

- short curing time
- cohesive failure
- sufficient strength level



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BENTELER makes it happen

hybrid metal-composite

Fast curing of hybrid aluminum-composite joints

Investigations:

- Screening of 12 different adhesives
- Developing of two different heating methods
- Determination of optimal joining parameters
- Testing of corrosion behaviour
- Validation on component level

Results:

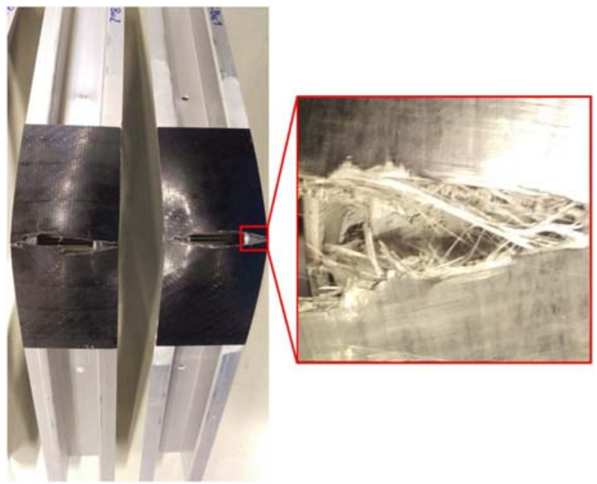
- Short cycle time of <60 s
- 11% higher crash forces
- Low corrosion performance (needs to be improved)

Process overview

Prepared aluminium part

Prepared composite part

Adhesive joining → Induction heating → Finished part



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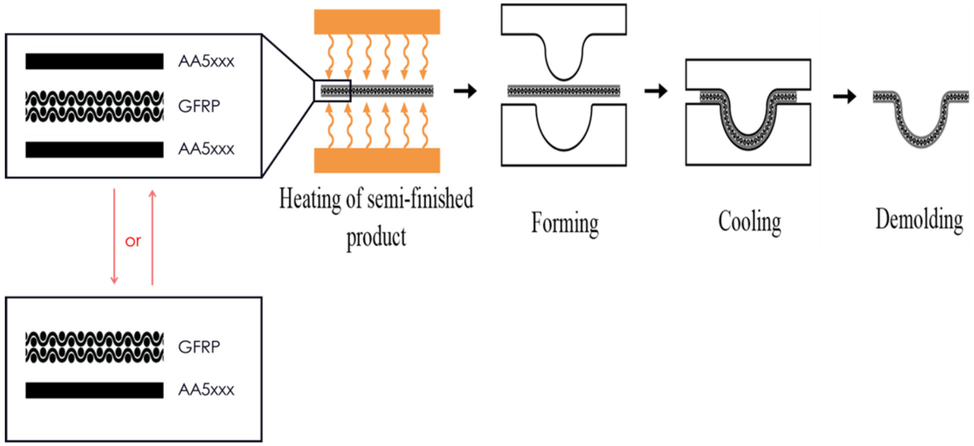
BENTELER
makes it happen

Innovative hybrid metal-composite thermoforming process

Motivation

Process scheme



•Advanced forming technology focused to form in temperature new generation aluminium sheet and TP reinforcement material. The technology consist to heat the aluminium sheet and a TP material , combine theme and stamp in a traditional stamping tooling.

- •Thickness sandw-mat 2 mm
- •AL-GF-AL (0,5mm-1mm-0,5mm)
- •AL-GF (1mm-1mm)
- •Alluminium material AA5182*

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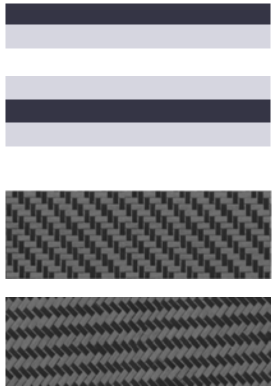
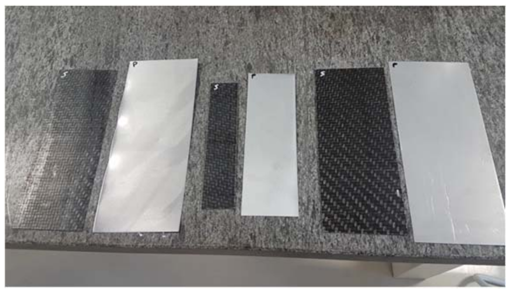
Sandwich layouts

•According to the mechanical target properties, sandwich can be prepared on specification, with different layers, weft orientation, and thicknesses



	Layer1	Layer2	Layer 3
Case 1	AA5182 tk. 0.5mm	GFRP tk. 1mm Weft 45°	AA5182 tk. 0.5mm
Case 2	AA5182 k. 0.5mm	GFRP tk. 1mm Weft 0°	AA5182 tk. 0.5mm
Case 3	AA5182 tk. 0.5 mm	GFRP tk. 1mm Weft 45°	/
Case 3	AA5182 tk. 0.5 mm	GFRP tk. 1mm Weft 0°	/

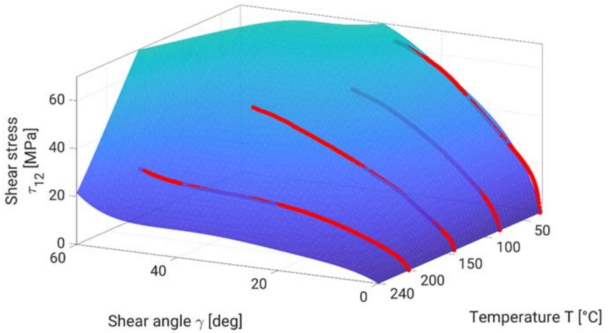


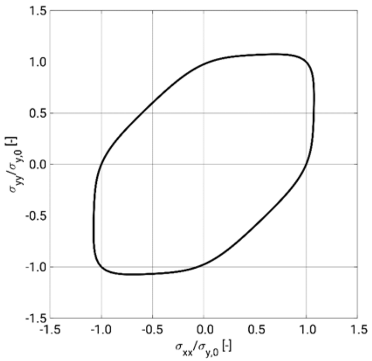
Innovative hybrid metal-composite thermoforming process

Hybrid thermoforming of GFRP and AA5182

Material characterization

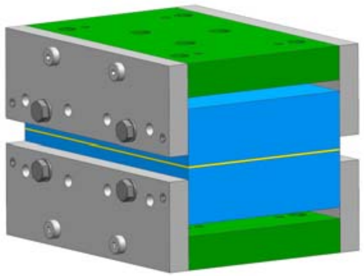
- Temperature dependent material behaviour
- Measurement of thermal material properties and process boundaries
- Friction modelling
- Failure modelling

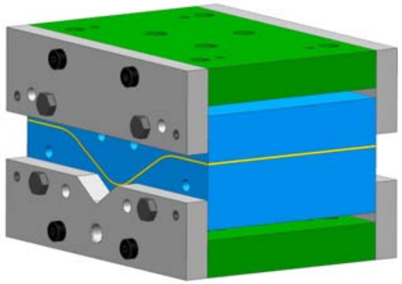




Investigation of process parameters

- Influence of temperature, closing pressure and cooling speed on bonding strength and bending resistance
- Qualitative investigation on void formation
- Flat pressing and V-shaped tool





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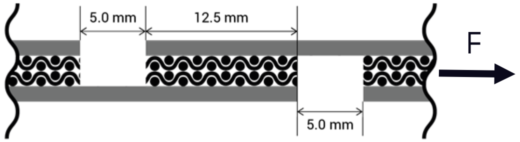
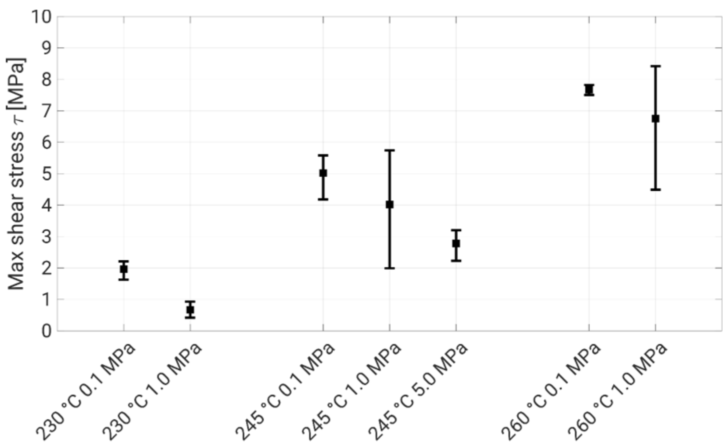
Innovative hybrid metal-composite thermoforming process

Hybrid thermoforming of GFRP and AA5182

Interlayer shearing strength

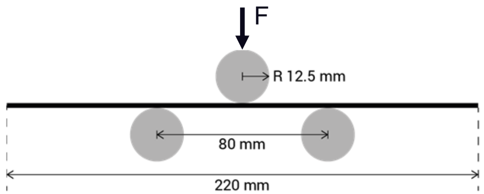
- Lap shear strength

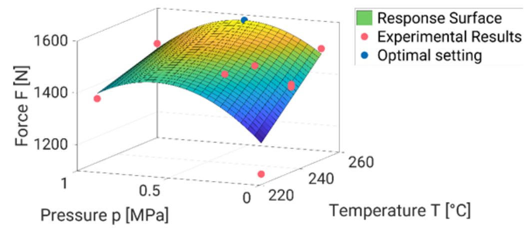




Bending properties

- 3-point bending test
- **Higher bending stiffness at 21 % less weight**





Configuration	Total thickness [mm]	Density [g/cm³]	Flexural Modulus [GPa]	Specific flexural modulus [10^6 m²s⁻²]
Pure aluminum blank	2.2	2.7	69	25.56
Hybrid blank	2.2	2.14	58.87	27.51

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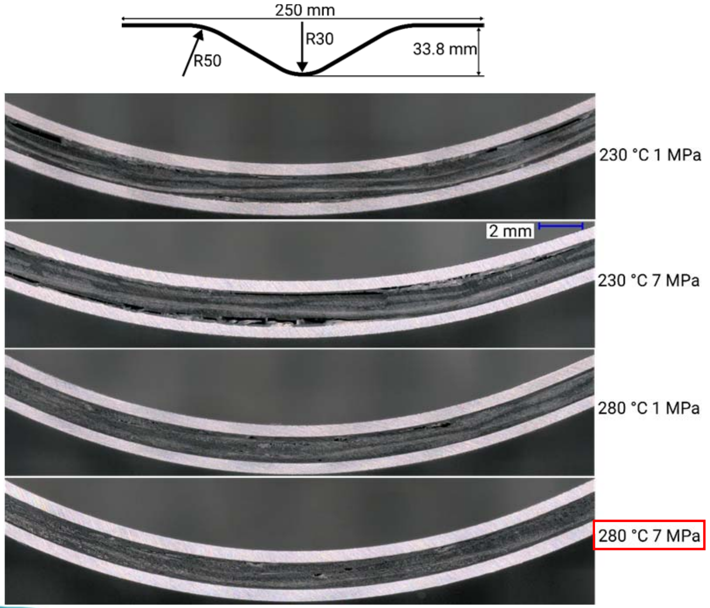
Innovative hybrid metal-composite thermoforming process

Hybrid thermoforming of GFRP and AA5182

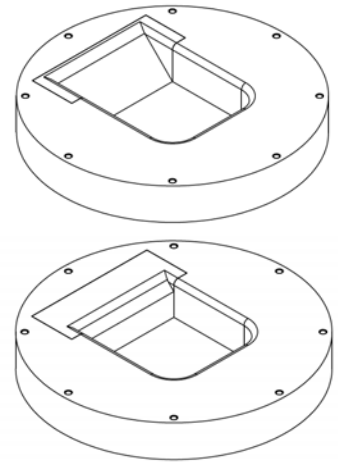
V-shaped tools

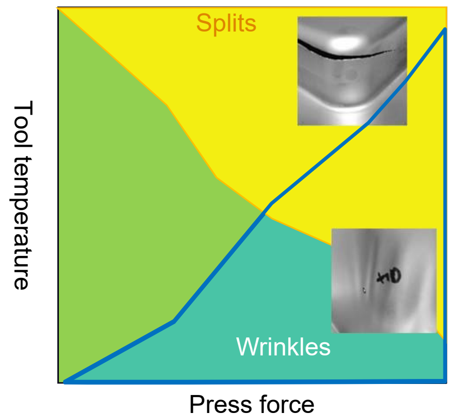
- Simple 2D drawing process
- Optical evaluation on void formation



Ongoing

- Application on complex 3D-shape
- Definition of process window for robust production





Innovative hybrid metal-composite thermoforming process

Process development for demonstrator validation

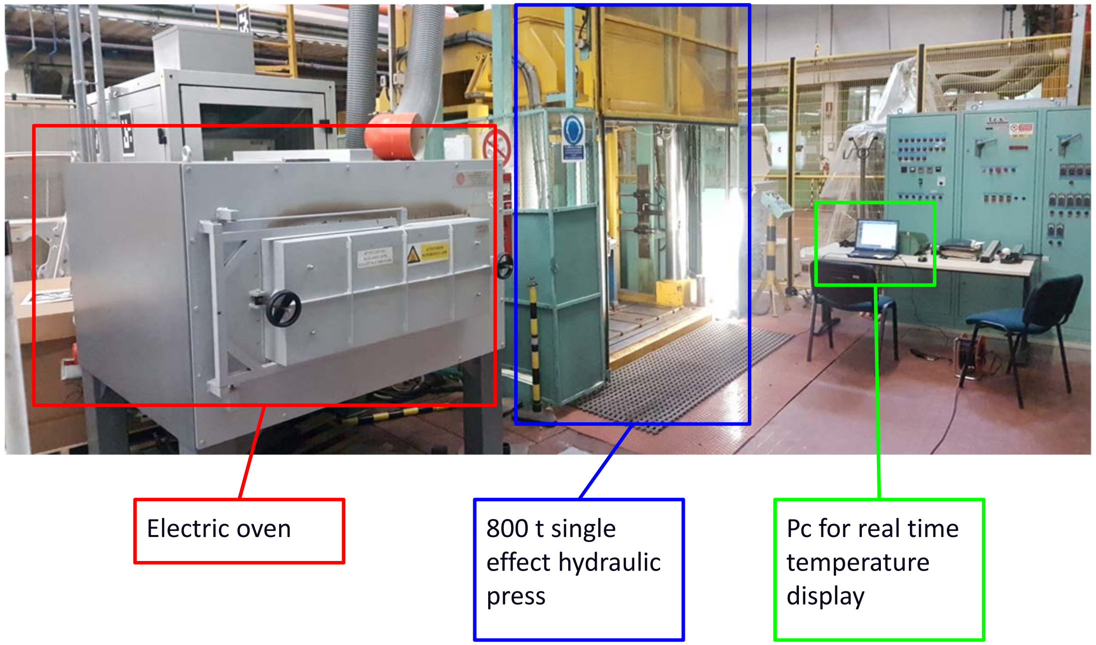
- **Thermoforming process equipment**

Process: crash forming

Press speed max: 200 mm/s

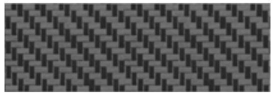
Press speed in forming phase: <5 mm/s

Max press force: 800 ton



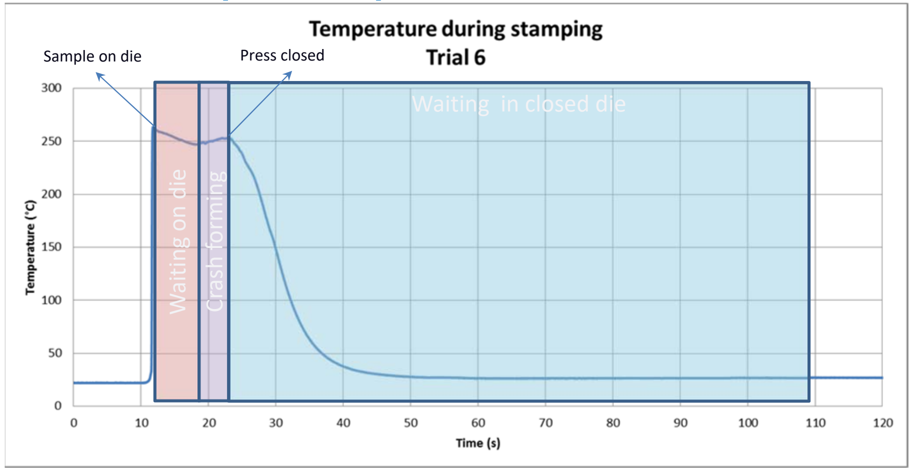
Innovative hybrid metal-composite thermoforming process

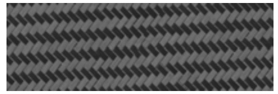
Process validation on demonstrator



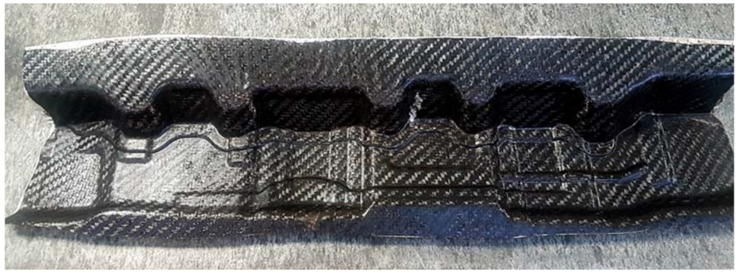
Trial # 14	
Configuration	AA5182 + GFRP 0°-90°
Oven temperature	260°C
Time in oven	10 min
Forming temperature	240 °C
Holding time	110 s
Extraction temperature	25°C
Holding force	250 t

Example of temperature measurement





Trial # 18 and 19	
Configuration	AA5182 + GFRP 45°+AA5182
Oven temperature	260°C
Time in oven	10 min + 10 min
Forming temperature	220 °C
Holding time	60 s
Extraction temperature	25°C
Holding force	250 t



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Final characteristics of process

- Time inside the oven is dependent both on the oven type and on kind of assembly, due to aluminum low emissivity (oven is electric, so heat is transferred by partial contact from the lower side and convection/radiation on the upper side)
- fiber weave orientation is a key choice for feasibility: 0°-90 ° fiber orientation respect to piece orientation causes fiber breaking because of lack of elongation, 45° orientation - instead - allows enough relative sliding to compensate the lack of elongation and continuous fibers do not break
- Due to crash-forming process - no blankholder - sandwich configuration is affected by wrinkling on both aluminum faces. In the final manufacturing process a blankholder configuration is likely to be considered.
- In order to improve adhesion among different layers, specific aluminium surface treatment are going to be developed

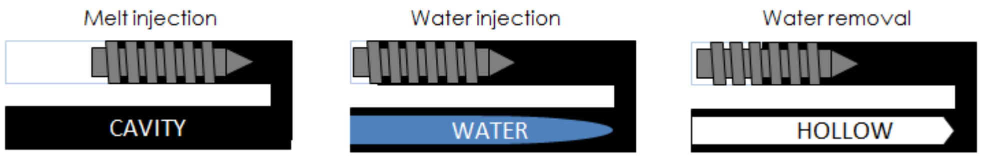
Improved thermoplastic composite manufacturing process

Motivation & Goals

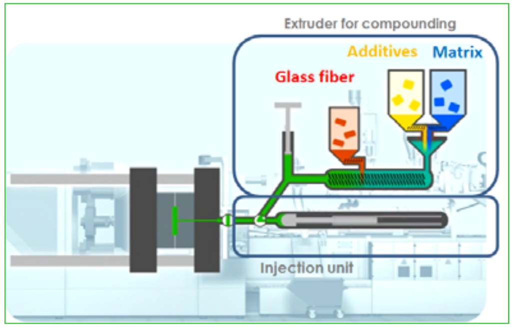
- **Hybridize technologies which by self offers high potential for competitive light-weighting and develop robust virtual evaluation of its performance linked of the manufacturing process is a potential solution for feasible composite migration in big parts,**
  - Full characterization of the raw materials selected as proper for the IMC+WIT process technology under process parameters criteria.
  - List of requirements of potential raw materials for this kind of technology.
  - Definition of the technical specifications for integration WIT and IMC technology in one (software, peripherals, and injection machine modifications)
  - Development of a robust virtual evaluation process to have an accurate prediction of the future mechanical performance of the part.
  - Analysis of the water flow, glass fibre orientation, raw material feeder system impact by simulation and its correlation.
  - Definition of process parameters to obtain and accurate process for prototyping
  - Process simulation of the rear floor pan demonstrator applying the improvements obtained during the process development.

Improved thermoplastic composite manufacturing process

Process development



Plastic compounding & injection



Mold

Water injector

Water injection machine

Software & Hardware

Pressure valve

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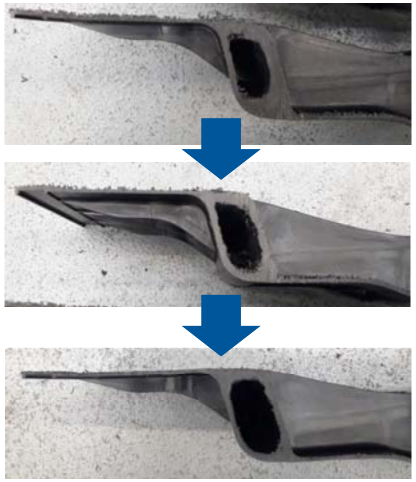
Improved thermoplastic composite manufacturing process

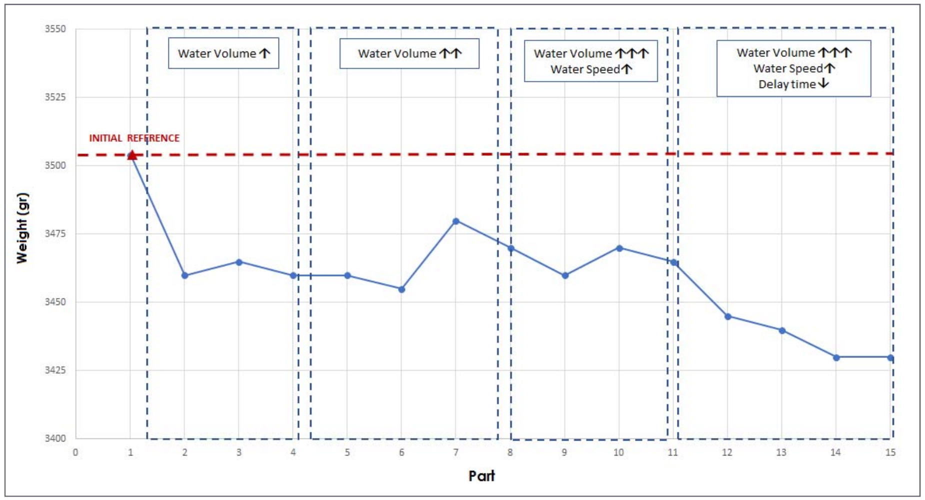
Validation

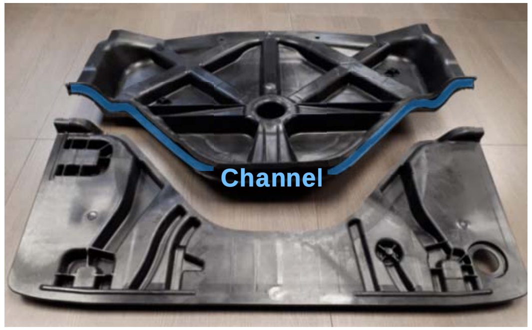
- **Optimization of process parameters to obtain the targets of weight and inner hollow geometry**



WEIGHT (gr)	CAD	VIRTUAL (Process simulation)	REAL (Prototype process)
RR floor full plastic part	3,451*	3,185	3,430 ✓

Weight evolution





* *Considering theoretical constant thickness of inner hollow structure*

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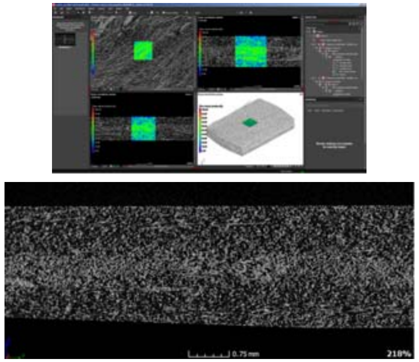
Validation

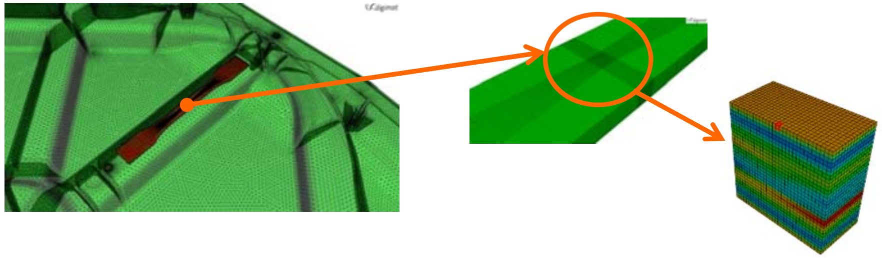
- **Full characterization of the raw materials selected under process parameters criteria (anisotropy)**

  Materials curves calibrated considering the level of prediction in terms of glass fiber orientation throughout the part thickness.

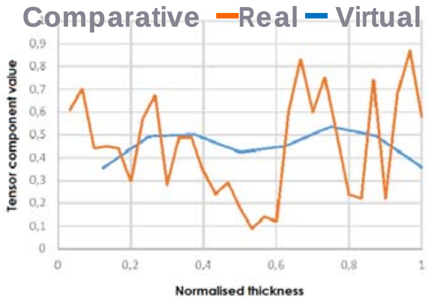
Tomography

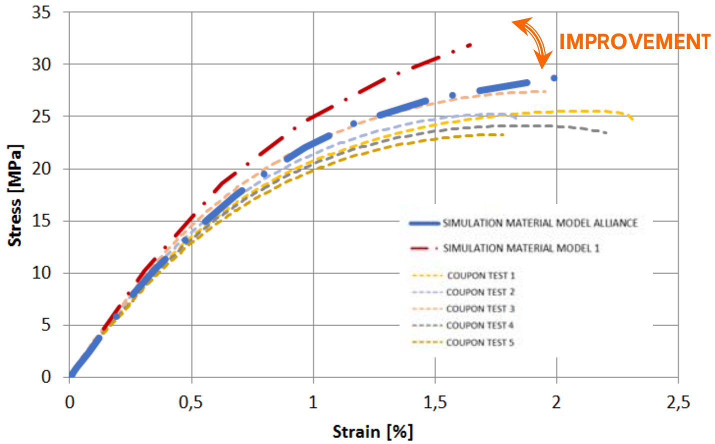


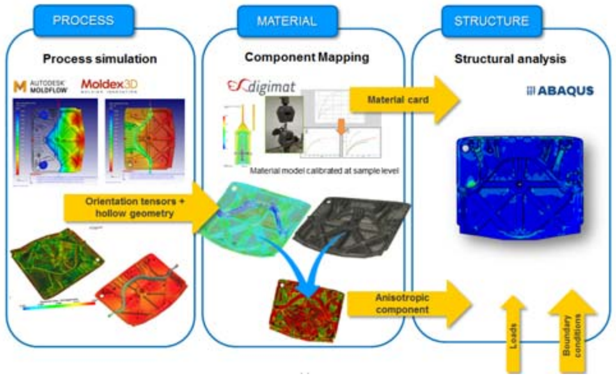
Virtual mapping



FIBER ORIENTATION







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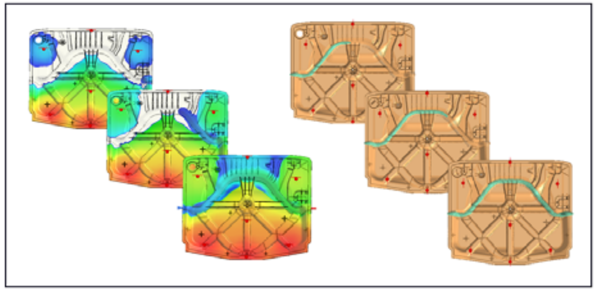
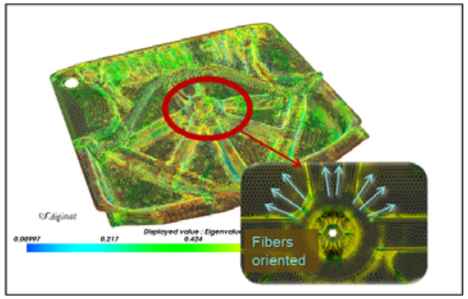
Validation

- **Improvement in the prediction of the inner hollow geometry by simulation**

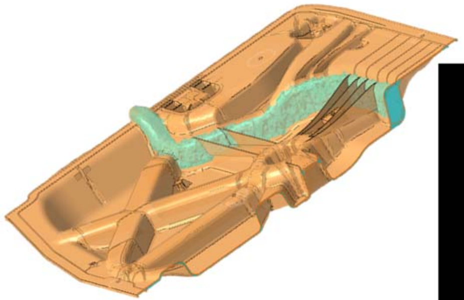
  Process simulation focusing on achieving the inner geometry previously defined and proper glass fiber orientation.

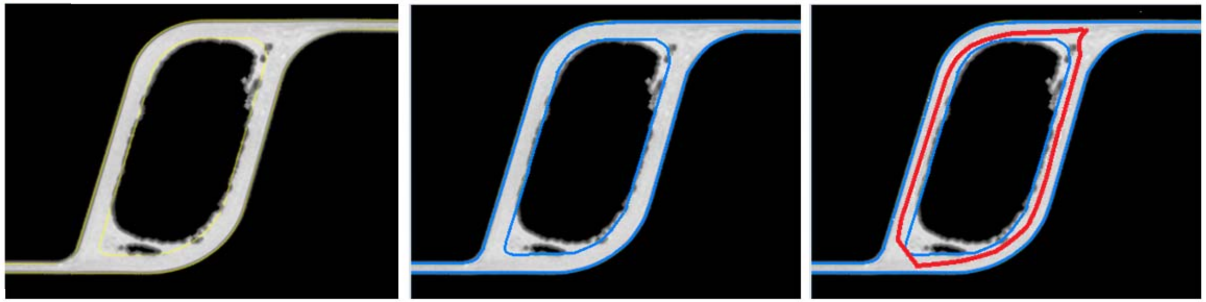


Plastic and water injection



Analysis of glass fibre orientation





REAL (Tomography) 3D PRE-DEFINED CAE PREDICTED

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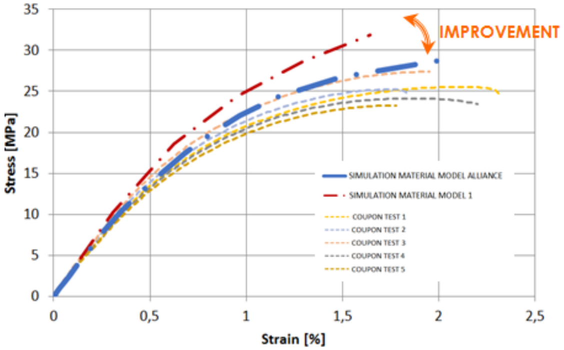
Final characteristics of process

Material Characterization

- Complete material card (Long glass fibre) validated in component
- Calibration of the anisotropy of the material due to the process parameters

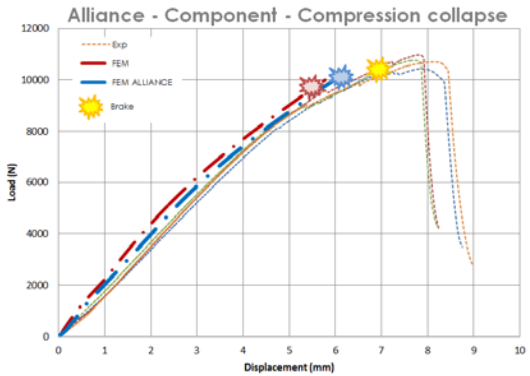


Investigation of process parameters

- Influence of volume and speed of water and the delay time on the inner hollow structure and the final mechanical performance of the part
- Weight and geometry of the part close to the predicted.

Virtual comparison

- Significant improvement in the prediction of inner hollow structure using long glass fiber composites
- The anisotropic model introduces the variable of the process and indicates a potential to optimize the design (more potential for mass production) thanks to have more accurate virtual results



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Conclusion

- WP3 progresses are online with the activity planned
- Within the project activity, different forming technologies and material combinations have been developed to provide new solutions with reduced energy consumption, in the mass production boundary condition
- Novel forming technology approaches have been validated
- A different manufacturing processes portfolio has been exploited, suitable for different applications in the BiW and hang-on, tailored to the final component performance required (lightweight, performance, ...)

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