Process technologies - Manufacturing

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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
Among other properties, the Q&P-steel shows a higher ductility than steels of comparable tensile strength.
The global formability, described by FLD, is good in comparison to other steels of 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

The biaxial forming potential is good for this class of material.
Advanced metal forming technologies: DP steel model
Spring back 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

<table>
<thead>
<tr>
<th>Tensile test</th>
<th>$0^\circ$</th>
<th>$45^\circ$</th>
<th>$90^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield stress [MPa]</td>
<td>783</td>
<td>760</td>
<td>790</td>
</tr>
<tr>
<td>Young's Modulus [GPa]</td>
<td>191</td>
<td>118</td>
<td>201</td>
</tr>
<tr>
<td>UTS [MPa]</td>
<td>1060</td>
<td>1027</td>
<td>976</td>
</tr>
<tr>
<td>Uniform Elongation [-]</td>
<td>0.051</td>
<td>0.047</td>
<td>0.044</td>
</tr>
<tr>
<td>Total Elongation [-]</td>
<td>0.095</td>
<td>0.086</td>
<td>0.081</td>
</tr>
</tbody>
</table>

Hill's-Experiment

| $\sigma_{0.2}$ [MPa] | 807 |

Hooke-Sherry yield curve parameter

<table>
<thead>
<tr>
<th>$S_{02}$</th>
<th>$S_0$</th>
<th>m</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.456 MPa</td>
<td>743 MPa</td>
<td>1.293</td>
<td>0.3134</td>
</tr>
</tbody>
</table>
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
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

Forming
BBC'05 KH
BBC'05
YLD2000
HAH
Yoshida

1. Simulation in AutoForm
2. Simulation Optimization (Design Variable)
3. Springback compensation by tool or geometry adaption
4. Robustness analysis considering springback
5. Determination of springback compensation strategies
6. Robustness analysis to show controllable springback

Inverse vector approach
AutoForm Compensator
LS-DYNA Compensator

x-axis [mm]
y-axis [mm]
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 behavior of AHSS is of course a relevant topic, but controllable with appropriate compensation techniques.
- The Q&P Steel fulfills the requirements and demands for the target series production by conventional deep forming technologies.
- Hence no additional methods and technologies are necessary.
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

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

![Diagram of metal forming process with labels for die, punch, and blank holder]
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.
hybrid metal-composite
Fast curing of hybrid aluminum-composite joints

Motivation:
• Cost efficient and lightweight hybrid CMS design
• Reduced CO₂-footprint
• Joining process suitable for mass production required

Goals for joining method:
• Short curing time
• Cohesive failure
• Sufficient strength level
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)
Innovative hybrid metal-composite thermoforming process

Motivation

- 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*

Sandwich layouts

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

<table>
<thead>
<tr>
<th>Case</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AA5182 tk. 0.5mm</td>
<td>GFRP tk. 1mm</td>
<td>AA5182 tk. 0.5mm</td>
</tr>
<tr>
<td>2</td>
<td>AA5182 tk. 0.5mm</td>
<td>GFRP tk. 1mm</td>
<td>AA5182 tk. 0.5mm</td>
</tr>
<tr>
<td>3</td>
<td>AA5182 tk. 0.5mm</td>
<td>GFRP tk. 1mm</td>
<td>/</td>
</tr>
<tr>
<td>3</td>
<td>AA5182 tk. 0.5mm</td>
<td>GFRP tk. 1mm</td>
<td>/</td>
</tr>
</tbody>
</table>
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
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

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Total thickness [mm]</th>
<th>Density [g/cm³]</th>
<th>Flexural Modulus [GPa]</th>
<th>Specific flexural modulus [10⁶ m²/s²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure aluminum blank</td>
<td>2.2</td>
<td>2.7</td>
<td>69</td>
<td>25.56</td>
</tr>
<tr>
<td>Hybrid blank</td>
<td>2.2</td>
<td>2.14</td>
<td>58.87</td>
<td>27.51</td>
</tr>
</tbody>
</table>
Innovative hybrid metal-composite thermoforming process
Hybrid thermoforming of GFRP and AA5182

**V-shaped tools**
- Simple 2D drawing process
- Optical evaluation on void formation

![Image of V-shaped tools](image)

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

![Diagram showing process variables and outcomes](image)
Innovative hybrid metal-composite thermoforming process
Process development for demonstrator validation

- Thermoforming process equipment

- Electric oven
- 800 t single effect hydraulic press
- Pc for real time temperature display

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

**Example of temperature measurement**

**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

**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
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 aluminum 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

Water injection machine

Water injection

Water removal

Mold

Software & Hardware

Pressure valve

Water injector
Improved thermoplastic composite manufacturing process validation

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

<table>
<thead>
<tr>
<th>WEIGHT (gr)</th>
<th>CAD</th>
<th>VIRTUAL (Process simulation)</th>
<th>REAL (Prototype process)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR floor full plastic part</td>
<td>3,451*</td>
<td>3,185</td>
<td>3,430 ✓</td>
</tr>
</tbody>
</table>

* Considering theoretical constant thickness of inner hollow structure
**Improved thermoplastic composite manufacturing process 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.
**Improved thermoplastic composite manufacturing process 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.
**Improved thermoplastic composite manufacturing process**

**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
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, ...)