Composites forming simulations in LS-Dyna using the material law 249
0. Agenda

Presentation content

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II. Material models for composites part forming

III. Material characterization

IV. Composites forming application

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I. Introduction

Faurecia: Leader in automotive equipment

- 34 Countries
- €20.7 Billion of total sales
- 103,000 Employees
- 330 Sites
- 489 Patents filed in 2015
- 6,000 Engineers and technicians
- 30 R&D centers
- 610 Programs in development

#1 Worldwide
#3 Worldwide
#1 Worldwide
#1 Worldwide
#1 Worldwide
I. Introduction

Faurecia Composite Technologies

- **350 Employees**
  - Structural parts
    - Body in white, beam reinforcements
    - Crash resistance, stiffness
    - Luxury & Premium, mass market, trucks, EV

- **2 Composite plants**
  - Semi-structural parts
    - Large 3D parts, closures and panels
    - Function integration, acoustics / NVH
    - Luxury & Premium, mass market, trucks

- **3 R&D + D&D centers**
  - A Class
    - Visible parts, closures
    - Painted or exposed carbon
    - Luxury & Premium, trucks

- **3 Countries**
  - Faurecia competence center
    - Seat structures
    - Cross Car Beams
    - Heat shields
I. Introduction

Composites forming of continuous fiber plies

- Major step of two promising processes for a mass market composite parts production

<table>
<thead>
<tr>
<th>Thermoforming</th>
<th>RTM</th>
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</thead>
<tbody>
<tr>
<td>Forming of organsheets</td>
<td>Dry fabric preforming</td>
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</tbody>
</table>

- Advantages
  - Short cycle times
  - High repeatability allowing automation
I. Introduction

Composites forming of continuous fiber plies – Drawbacks

- **Defect intensive**
  - Fiber wrinkling
  - Inter-ply fiber wrinkling
  - Fiber thinning
  
  Gazo-Hanna, E. et al. (2009) in JNC 16, AMAC

- **Waste intensive**
  - Increased process and material cost
  - Complex recycling

- **Important influence on mechanical part properties**

**Process simulation fundamental**
II. Material models for composites part forming

Composites forming simulation: FCT- vision

- Expertise domain (physics, mathematics, IT, product, process, materials …)
  - Garbage in – garbage out
- Important number of software codes and material models on the market
  - Different levels of maturity and usability
- Main material model selection criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Kinematic draping</th>
<th>Elastic / Viscoplastic material models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>Only for simple kinematics (problematic especially for complex parts)</td>
<td>Most important defects can be detected</td>
</tr>
<tr>
<td>Availability</td>
<td>CATIA, Quick-Form, etc.</td>
<td>PAM-Form, LS-Dyna, RADIOSS, etc.</td>
</tr>
<tr>
<td>Computation time</td>
<td>Very fast evaluation</td>
<td>Computational time intensive</td>
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<tr>
<td>Considered physics</td>
<td>Largely simplified physics (e.g. no thermal considerations)</td>
<td>Comprehensive process simulation possible</td>
</tr>
<tr>
<td>Material characterization</td>
<td>Some non-physical parameters</td>
<td>Some non-physical parameters</td>
</tr>
</tbody>
</table>
II. Material models for composites part forming

One-step forming

- Comparison of 2 commercial software codes: LS-Dyna (MAT 34) and RADIOSS (Mat 58)
  - Comparable results
  - However differences in the details and the usability
- Inter-ply wrinkling prediction in multi-ply simulation
II. Material models for composites part forming

Multi-stamp-forming

- Material model behavior in complex situations
  - Numerical instabilities due to not considered physical phenomena
    - Convergence errors
    - Reduced prediction precision
  - Important computation times
  - Superposition with a second material layer necessary to consider matrix behavior

- LS-Dyna Mat 249:
  - Recently developed material law
  - Specifically developed for composite part forming
    - Independent fiber - matrix behavior in the same material law
III. Material characterization

Material characterization

- Specific characterizations of the matrix and the fiber material

- Friction coefficients
  - Consideration in the *CONTACT Keyword
  - Traction of a mass over the composite ply
  - Differentiation between
    - Ply - ply contact
    - Ply - mold contact
  - Non-negligible influence on the material forming behavior

- Fiber material parameters of Mat 249 – direct characterization
  - Young modulus → E.g.: Tensile test, bias extension test
  - Shear behavior → E.g.: Bias extension test, picture frame test
III. Material characterization

Material characterization – Non-physical input values

- Direct input into material law not possible
- Mat 249: Bending stiffness
  - Can be determined by the local integration point position
- Characterization approach
  - Numerical reconstruction of the DIN cantilever test
  - Optimization cycle in LS-Opt

Integration point position variation
Dr. T. Klöppel, 2016, New material model *MAT_249 for thermoplastic pre-pregs and dry fabrics

Specific characterization protocols for non-physical parameters
IV. Composites forming application

Dry fabric preforming with the Fraunhofer ICT

- **Preform stamping for the RTM process**
  - High influence on local permeabilities and thickness (dry zones, wrinkles…)
  - Mandatory to consider during RTM filling simulation

- **3 Materials**
  - Plain weave, Twill (2/2), NCF
  - Different forming behavior

- **Forming press at the Fraunhofer ICT**
  - 3 independent forming stamps
  - Multiple possible gripper positions
  - Optimization of the forming kinematics
  - Wrinkles elimination

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Independent forming stamps
Prof. F. Henning et al., 1st International Composites Congress (ICC) - 2015
“Cost-efficient Preforming as leading process step to achieve a holistic and profitable RTM product development”
IV. Composites forming application

Dry fabrics forming simulation

- High grade of correlation for all three materials
- Independent of the forming sequence
- Detection of wrinkles for the interior plies
  - Detection very difficult for the real part

Forming with Mat 249
IV. Composites forming application

Dry fabrics forming sequence optimization

- **Simulation driven optimization**
  - Manual variation of the stamp displacement curves
  - Manual analysis of the wrinkle number and location for all plies
  - All wrinkles eliminated for two materials but not the NCF fiber material

- **Validation of the simulation results by physical trials**

Wrinkles elimination via simulation / optimization reduces part development cost and time
V. Conclusions

Outlook

- Important influence of forming sequence on final mechanical part properties

  Mechanical part simulation using mapping of fiber orientations and wrinkles

- Application on other formed composite parts
  - One-shot process for visible parts
V. Conclusions

Take-away

- Simulation and optimization: a key to reduce Cost, Weight & Time
- Forming is an essential part of the complete composites product-process chain
  - Application in main automotive processes
    - RTM – preforming of dry fabrics
    - Thermoforming of organosheets
  - Managing the forming kinematics
    - Guarantee and optimize the mechanical properties of the final part
    - Enable advanced process combinations
- Main reasons for a successful industrial application of a material model
  - Exhaustive representation of all main defects and physics
  - Reasonable computational effort
  - Easy material law characterization and availability of characterization protocols
Technical perfection; automotive passion