RTM 4.0 – Quo Vadis?

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ADD-ITC, 25.11.2016

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Status of Today’s RTM Processes

Time:
- Injection and curing cycle (aircraft: 4-6hrs / automotive: longer than TP pressforming)
- Parts modification complex with respect to molds
- Time consuming preforming
- Time consuming post processing (e.g. trimming, edge sealing)

Cost:
- High mold costs (invar injection tools, aluminum preforming tools)
- Parts modification costly

Quality:
- No reproducible preform quality due to manual draping
- Offline NDT (long-lasting backtracking of defects to process parameters)

Process uncertainties:
- Process induced deformations (e.g. spring-in after curing)
- Incomplete cutting of filaments (ply cutting, fine trimming)
- Porosities after injection
RTM technology today

Source: Composite Germany 2016
Why RTM in the future?

**Lightweight Structures**
- Defined fibre orientation
- Maximum fibre volume content
- RTM offers best ratio weight saving /cost

**Specific Strength and Strain of Lightweight Materials**

- **UD CFK (60\% FVC) vs. SF GMT/LTF:** up to 30 times better specific strain
- **UD CFK (60\% FVC) vs. SF GMT/LTF:** up to 20 times better specific strength
Further Potentials of RTM Processes - Examples

- High production rates for small parts with high mechanical performance
- Faster binder activation
- Net shape preforming (no trimming, no edge sealing, no tool wearing etc.)

- Molds of cheaper material
- Modularity of molds (core/shell)
- Integration of parts and functions possible (inserts, electrical wires, SHM)

- Defined fiber volume content
- In-line quality assurance, deviation control and correction
- Avoid micro-fractures in final part due to net shape preforming

- Production of hybrid parts, multi-material-systems, e.g. hybrid sandwich
- Full automation possible
- Part – process interaction and automatic process correction possible
RTM – Transformation to next phase

RTM today
Achieved:
- Process chain demonstrated for parts with high production rates
- Automation of manual processes

But:
- Quasi static processes
- No active draping control
- Slow (manual) layer fixation
- Human based quality assurance
- Post processing required, e.g. part trimming
- ...

RTM 4.0?

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DLR Automated modular RTM Process Chain

RTM-Area

Preforming Area

Ply Preparation Area
DLR Automated modular RTM Process Chain

- Ply preparation
- Ply storage
- Picking-up
- Draping
- Binder activation
- Curing
- Injection
- Fine trimming
- Fibre angle detection
- IR consolidation

Process chain
Some DLR Solutions for RTM 4.0

- Automated net shape preforming
- Efficient binder activation
- Isothermal injection and curing

- Multi purpose molds
- Modularity of molds (core/shell)
- Function Integration

- Inline QA
  - Eddy current and 3D contour scan
  - Curing sensors

- In-situ assessment of structural properties
- Compensation of process induced deformations

- Adaptable production facility
- Process assessment
- Part-Process communication
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Preform-Trimming to Net-Shape

Net shape approach:
• preform shape ≡ part shape

Why net-shape?
• Reducing post processes, e.g. edge sealing
• Higher RTM process stability due to defined edges
• No influence on resin by machining

Cutting of dry fibre preform
• by ultrasonic knife
• by laser (future)

Piercing of pilot holes
Some DLR Solutions for RTM 4.0

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Efficient Binder Activation Systems

- Local activation of several plies
  - Electric resistance (Joule) principle
  - Required activation time: 0.3 sec

- Line activation of several plies
  - Electric resistance (Joule) principle
  - Activation time: 150 mm/sec

- Plane activation of full stack
  - Diaphragma-membrane-press with infrared field
  - Time: 15 min (depending on mold material)

RTM 4.0: NEW FEATURES
Some DLR Solutions for RTM 4.0

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Isothermal Injection and Curing

- **Approach:** (reduction of process time)
  - Isothermal processing
  - Higher injection temperature and lower resin viscosity
  - Post-processed tempering

- **Procedure:**
  - Injection time determination (viscosity / gel point)
  - Demolding time determination (vitrification / curing degree)
  - Control of mechanical properties and process induced part deformation

- **Result:**
  - Description of relation between time, temperature and mechanical performance allows optimal injection and curing timing
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Reduced Cost of Molds

- Multi purpose preforming mold
  - Integrate process of draping, consolidation and fine trimming in one mold
    - One mold instead of three
  - Moveable mold
  - Cheaper mold material

- Design of modular mold system
  - Basic mold + specialized mold

RTM 4.0: IMPROVEMENTS
Some DLR Solutions for RTM 4.0

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Function Integration

Example RTM Sandwich - Structure
- Multi use of core volume
- Acoustic and thermal isolation
- Integration of media guiding elements, e.g. wiring, sensors, local stiffeners, inserts, antennas etc.

Example rearview mirror
- Integration of signal light and wiring in RTM part

[Source: A. Pototzky, DLR, FA]
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Inline Quality Assurance During Preforming

**Approach:**
- Reduction of NDT effort
- Process evaluation → online defect correction or part deletion

**Method: Eddy current measurement**
- Fibre angles of up to 6 layers simultaneously with 0,5° accuracy each
- Documentation of layup and patch positioning → digital LDS / correction?
- Detection of wrinkles, gaps, fuzzballs and undulations on hidden layers

**Method: 3D-contour scan**
- Determination of geometry and contour after net shape fine trimming
Inline Quality Assurance During Injection and Curing

**Approach:**
- No direct contact to part (mold integrated sensors)
- Easy mold integration (small sensors, cheap, reliable)

**Method: Ultrasound PZT sensors**
- Flow front monitoring
- Cure monitoring
  - Measure sound velocity for cure monitoring
  - Detect gelation and vitrification: Calibration by simultaneous measurement of ultrasound velocity in rheometer

**RTM 4.0: PART-PROCESS COMMUNICATION**
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- Part-Process communication
In-Situ Assessment of Structural Properties

Goal:
- Measurement → communication of geometric data to database → evaluation of structural properties → process adjustment if necessary
- Avoid rework and waste at an early manufacturing stage

Approach:
- Structural properties can be predicted and evaluated

Procedure:
- Online monitoring of fibre angle, waviness, gaps and overlaps
- Deriving surrogate models and database
- In-Situ comparison of as-design part (left) properties and as-build part (right) properties containing manufacturing-induced imperfections
- Automatic correction if possible – depending on process step
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Process-Induced Deformations

Phenomenological-numerical simulation (P-approach)

Volume model
Mid-surface model
FE shell model

Simulation parameter

Predicted distortions

PID compensated manufactured rib
Biased tool geometry
Inverted distortions

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Adaptable Production Facility

Status quo:
• RTM less attractive due to low quantity of equal parts in aeronautics

Goal:
• Make RTM more individual (number of parts)

Challenge:
• Individual parts production within serial RTM process

Approach for RTM 4.0:
• Usage of adaptable end-effector for part family (similar part geometry)
• Reduced mold costs with multi purpose molds (*already mentioned*)
Adaptable Endeffectors

Handling System
  • Separate control of each vacuum gripper

Draping endeffector
  • Inner flange and web height are flexible
  • Outer flange is fix
  • Individual controlled suction areas

Robot endeffector with different functions
  • Ultrasonic knife
  • Gripper for additional units
  • Position referencing system

RTM 4.0: NEW OPTIONS
Some DLR Solutions for RTM 4.0

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  - **Process assessment**
  - Part-Process communication
Process Assessment

Virtual plant
- Extension for any quantity
- Facilities and part flow optimization
- Process- and part cost and cyvle times

Real plant
- Technology demonstration
- Determination of cost
- Determination of cycle times

RTM 4.0: NEW OPTIONS
Productivity Forecast

Scenario analysis via process simulation:

- Evaluate impact of design changes on production line
- Line balancing of changed production process
- Identification of bottlenecks

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Part-Process Communication – an Outlook

Remote control of the facility via Internet
Communication between several facilities on different places

Inline digital life-data-sheet
Automatic documentation per part

Continuous improvement
of process parameters due to growing database
Conclusion

RTM 4.0

- Best process for lightweight structures at minimum cost
- Potential of function integration

Process – part interaction is improving in the direction of industry 4.0 by

- better sensors,
- more and more precise simulation and
- advanced automation capabilities.

Communication between part, process and environment enables

- process adjustment
- process optimization

Highly automated RTM process 4.0 is feasible and doffers

- Decreasing production rate and cost
- Higher process stability
- Increasing quality
- Increasing part flexibility
References

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THANKS FOR YOUR ATTENTION!