Composite manufacturing in future lightweight design

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Lightweight structure research group:
- 6 senior faculty
- 2 research engineer
- 2 affiliated faculty
- 15 PhD students
- 2 Post Doc
- Research often in industrial collaboration
Composite manufacturing in future lightweight design

- Cost effective
- Using several different materials – and ensuring sustainability
- Deal with multifunctional materials and structures
Predictive technical cost modelling
- a modular approach

\[ C_{\text{tot}} = C_{\text{mtrl}} + \sum_{i=\text{step} \ i}^{i_{\text{end}}} C_i(A,C,n) \]

- \( C_{\text{mtrl}} \): Raw material cost
- \( C \): Part complexity
- \( A \): Part size
- \( n \): Annual manuf. volume

\[ C_{\text{mtrl}} = C_{kgw}(1 + r_{\text{scrap}}) \]

\[ C = f(\theta) \]

\[ I_\theta = \frac{L}{r} \]

\[ r_i = r_\theta C \]

\[ C_{\text{tooling}} = f(A) \]

\[ C_{\text{equipment}} = f(A) \]

\[ \# \text{ machines} = \frac{tn}{t_{\text{tot}}} \]

Cost effectiveness

1. Find the right level of automation for material, geometry and the production volume required

2. Learn the process window for that process

3. Ensure robust manufacturing and small geometrical tolerances to enable low cost assembly
Typical aerospace geometry

Scaled down geometry capturing industrial known wrinkling sensitive features such as:
- Ramp areas (Pad-ups)
- Recess areas (Joggles)
- Convex areas
Cost effective manufacturing of aerospace structural composite components

ATL/AFP placed flat

HDF Hot Drape Forming
Vrinkle free and robust manufacturing

45/-45 layup

0/90 layup

Vrinkle free and robust manufacturing

45/-45 layup

0/90 layup

45/-45/0/90 layup

Forming mechanisms and material characterisation

Inter-ply properties

Intra-ply properties


Modelling for robust forming

FE framework predicting:
• wrinkle development
• fibre angle deviations

Detailed material models developed

Pairing of plies can eliminate wrinkling

Samples manufactured with critical interfaces coupled together through consolidation

\[ [45/-45/0/90/90/0/-45/45]_{xs} \quad [45/-45/0/90/90/0/-45/45]_{xs} \]

Simulations used to identify critical interfaces


Robotized forming

Robotized manufacturing of aerospace composite spars

Forming of automotive composite components

Composites – Polestar 1 overview

- Lower body structure based on the Volvo SPA platform. The S90L shortened 520 mm.
- Upper body made from carbon fibre composite materials.
- Adhesive joining
Accurate fibre angles needed in crash simulations

Polestar 1 – crash test

Fulfilling Volvo’s crash worthiness requirements
Is high pressure forming a step towards out-of-autoclave curing?

- Rapid forming at <400 bar using Quintus press
- Saw different kinds of wrinkles and at other places
- Voids do not disappear since we close the evacuation channels
- For this material -NO

30% higher costs if poor fit

Technical cost modelling shows that shimming adds ~30% to the total part costs

Radius thinning and shape distortions are common

Radius thinning mainly occurs during HDF

“Heat as much as you need”: improved quality at 85% time reduction

- Heat flanges only (sliding area)
- Keep radius “cold”

→ 4% radius thinning compared to flat area
→ 7.5 minute HDF cycle for 64 ply laminate (8.4 mm)

Heat transfer modelling of different heating options confirm study


Automated production of spars in concave tools

Uncured thickness challenging when transferring laminate from convex to concave tool

Automated production of spars in concave tools

- Small gap and curved web forming tool best
Shape distortions and residual stresses

Improved FE modelling capability:
• Material compliance
• Moisture uptake in composite


The true shape of composite cure tools

Are cure tools out of composite material providing stress free composite components?

The true shape of composite cure tools

Backering structure results in tool deformation which influences the forming shape.

Large tooling stresses reduces its durability.

Grankäll, T., Hallander, P., Petersson, M., Åkermo, “The true shape of composite cure tools”
3D-reinforcement in T-joints for improved integrity and reliability

3D woven fillets
- thermally stable
- durable
- enables automated and robust manufacturing

Composite manufacturing in future lightweight design

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Framework for weight and cost optimisation

Optimize $f(x)$

Parametric FE

Stiffness response ($u / \Theta$)

Stop criteria met?

Yes

CAD script

Cost estimation

kg, €

No

Production costs
Case Study

Find minimum cost from optimised topology and available materials/manufacturing methods.
Towards a multi-material approach

Hagnell, M.K., Kumaraswamy, S., Nyman, T., Åkermo, M., “From aviation to automotive - a study on material selection and its implication on cost and weight efficient structural composite and sandwich designs” Heliyon, 6 (3) (2020)
Design for sustainability

- Minimize energy consumption or CO₂ footprint
- Cost and CO₂ goes hand in hand
- Recycled aerospace carbon/epoxy has economical and mechanical potential for recycling
- Multi-material and bio-material solutions are cost effective, but how do we recycle?

Hagnell, M.K., Kumaraswamy, S., Nyman, T., Åkermo, M.., “From aviation to automotive - a study on material selection and its implication on cost and weight efficient structural composite and sandwich designs” Heliyon, 6 (3) (2020)
SrPET composite stiffened by overmoulding

Single-polymer composite

SrPET wind deflector

37% weight reduction with SrPET

27% lower part costs with SrPET


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Multifunctional materials - beyond smart....

Smart Materials (Multifunctional Structures)
Implanting of secondary materials or devices within a parent to imbue additional functionality...

Multifunctional Materials
Constituents synergistically and holistically perform two very different roles....


The Li-ion battery

Positive electrode

Polymer-matrix?

Negative electrode

Carbon fibres?

Johannisson et al, Compos Sci Technol, 162, 2018
**Carbon fibres as electrodes**

<table>
<thead>
<tr>
<th>Carbon fiber</th>
<th>Capacity (mAh g⁻¹)</th>
<th>1C</th>
<th>0.5C</th>
<th>0.2C</th>
<th>0.1C</th>
</tr>
</thead>
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<tr>
<td>T800 sized</td>
<td></td>
<td>130</td>
<td>180</td>
<td>234</td>
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<tr>
<td>IMS65 sized</td>
<td></td>
<td>80</td>
<td>137</td>
<td>171</td>
<td>236</td>
</tr>
</tbody>
</table>

Theoretical maximum: 372 mAhg⁻¹

We can use carbon fibres as battery electrodes

We can make solid polymer electrolyte matrices
Need for electrification of future vehicles

Structural batteries a possible enabler?

\[ \text{Mechanical structure, } m_s \] \quad \text{Rechargeable battery pack, } m_b \quad \text{Structural battery, } m_{sb} \\
\text{with } m_{sb} < m_s + m_b

1500 kg Structure + systems

600 kg Batteries

+  

Car: 1500 kg Structure + systems

Plane: 600 kg Batteries

KTH Royal Institute of Technology
Potential mass savings – ranging from 5 to 65%
Multifunctional materials -more?

Carbon fibres are excellent battery electrodes
Carbon fibres are piezo-electrochemical
  • Sensing capability (fast)
Carbon fibres expand
  • Actuation capability (slow)
Piezo-electrochemical effect
  • Energy harvesting capability (needs to be explored further)

Johannisson et al, PNAS, 117, 2020
Vision

“A composite material that carries load, stores electrical energy, senses its own state, morphs and harvests energy”
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Youtube link for inspiration

“Why You Should Be Excited About This Battery Breakthrough From Sweden!”
https://www.youtube.com/watch?v=qeFxqg3B4RA
Thank you!