Experimental and numerical analysis under axial and bending loading of hollow and foam filled A-profiles as stiffener concept for FRP structures for the aerospace industry

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1. Introduction to stiffened shells by using A-Former
2. Experimental analysis of hollow and foam-filled A-Former
3. Numerical analysis of hollow and foam-filled A-Former
4. Conclusion
5. Further Works
PMI filled A-formers:

Optimized method of stiffening FRC structures

• The most suitable and effective method for stiffening thin carbon/epoxy shells can be achieved by using A- or hat- profiles.

• PMI serves as a mandrel during the lay-up, but also as a structural member in the design of the component.

• This case history will demonstrate that PMI sandwich cores can be used for thickness – and weight – reduction of a shell element.
Introduction to stiffened shells by using A-former

Application: Pressure Bulkheads Airbus A340-500 / A340-600 / A380

- Material for stringer: ROHACELL 71 WF-HT used as mandrel
- Manufacturing process: autoclave co-curing

180°C (356°F) / 0.35MPa (50 psi) / 2hrs
Introduction to stiffened shells by using A-former

Application: Fuselage according the SOFI-concept

Fuselage
A-former
Window frame
Introduction to stiffened shells by using A-former

Application: Engine Cowling Airbus A320 / Bombardier BR710 / Gulfstream G550
Experimental analysis of hollow and foam-filled A-former

• Buckling occurs in the compression loaded areas before reaching the actual compression resistance.
• Improvement of buckling resistance of a shell can be achieved by stiffening profiles bonded to the shell.
• PMI - filled profile is stabilized by the structural performance of the core, and will maintain its geometry and its strength properties until the yield load.
• The main structural loadings for the core are tensile and compression perpendicular to the sidewalls of the profile.
Experimental analysis of hollow and foam-filled A-former

The paper of Heinz Ames and Dr. Manfred Rather, DORNIER evaluates the behavior of a hollow and foam-filled A- or hat-profile under static compression load, focusing on weight and cost optimization by implementing a more cost effective manufacturing method.

Test specimen:

- Flank angle: 25°
- Foam
- Fibre-glass reinforced resin

Dimensions:
- Flange: 84
- Flange thickness: 33
- Flange width: 17
- Flange height: 74
- Flange length: 22.5
- Flange angle: 13°
Experimental analysis of hollow and foam-filled A-former

**Material:**

Laminate: CF and S-GF-Prepreg (DoL186/177/63)
Core material: ROHACELL® 110 WF

**Lay-up of laminate:**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Angle</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFK</td>
<td>±45</td>
<td>0.1</td>
</tr>
<tr>
<td>CFK</td>
<td>0/90</td>
<td>0.2</td>
</tr>
<tr>
<td>SFK</td>
<td>±45</td>
<td>0.26</td>
</tr>
<tr>
<td>&quot;S&quot;</td>
<td>CFK</td>
<td>0/90</td>
</tr>
<tr>
<td>SFK</td>
<td>±45</td>
<td>0.26</td>
</tr>
<tr>
<td>CFK</td>
<td>0/90</td>
<td>0.2</td>
</tr>
<tr>
<td>GFK</td>
<td>±45</td>
<td>0.1</td>
</tr>
</tbody>
</table>

11-11-2014, SAMPE Brazil Conference, São Paulo, Brazil, Dr.-Ing. M. Alexander Roth
Experimental analysis of hollow and foam-filled A-former

Load-/strain-diagram of hollow A-former

- **Breakage** of part 43 kN
- **Buckling** 28 kN

Load [kN] vs. strain [10E-3]
Experimental analysis of hollow and foam-filled A-former

Load-/strain-diagram of PMI-filled A-former

→ Breaking load is increased up to + 41%
→ Stability is increased up to + 108%
Development of a full parametrical FE model with the aid of input-files and the ANSYS programming language (APDL)

- Geometry
- Material data
- Lay-up
- Boundary conditions (e.g. bearing, loading etc.)

**Static Load** \( F_{\text{max.}} = 1000 \text{ N per loading point} \)

- Analysis of the stiffness
- Analysis of the strength according Tsai-Wu Criteria

**Non-linear buckling analysis**

- One variant of an A-former
- Reduction of the laminate thickness of the foam-filled A-former to reach the same buckling behavior as the hollow variant

**Axial compression load analysis**

- One variant of hollow and foam-filled A-former
Numerical analysis of hollow and foam-filled A-former

Geometry of thin shell stabilized by PMI-foam-filled A-former

Rohacell® 71 WF-HT

inner belt of A-former
inner belt of A-former

web of A-former

outer belt of A-former

shell

thin shell/
inner shell

W_s
### Geometry of A-former:

<table>
<thead>
<tr>
<th></th>
<th>geometry</th>
<th>variant 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>width of A-former</td>
<td>$w_{\text{total}}$ / mm</td>
<td>120.00</td>
</tr>
<tr>
<td>width of inner belt</td>
<td>$w_{\text{if}}$ / mm</td>
<td>35.00</td>
</tr>
<tr>
<td>width of outer belt</td>
<td>$w_{\text{of}}$ / mm</td>
<td>25.00</td>
</tr>
<tr>
<td>total high</td>
<td>$h_{\text{total}}$ / mm</td>
<td>80.00</td>
</tr>
<tr>
<td>width of inner shell</td>
<td>$w_{\text{innershell}}$ / mm</td>
<td>240.00</td>
</tr>
<tr>
<td>length</td>
<td>$l$ / mm</td>
<td>720</td>
</tr>
</tbody>
</table>

### Laminate thickness and lay-up of A-former:

<table>
<thead>
<tr>
<th>laminate thickness [mm]</th>
<th>variant 1</th>
<th>Material (Fabric, Tape)</th>
<th>angle [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>inner belt of A-former</td>
<td>4.65</td>
<td>$((\pm F2/(T)<em>{3})</em>{2}/\pm F2/(T/T/\pm F2/ (T)<em>{3}/T/\pm F2)/((T)</em>{3}/\pm F2)_{2})$</td>
<td>$(\pm 45/(0)<em>{3})</em>{2}/\pm 45/(0/0/\pm 45/ (0)<em>{3}/0/\pm 45/((0)</em>{3}/\pm 45)_{2})$</td>
</tr>
<tr>
<td>outer belt of A-former</td>
<td>1.9</td>
<td>$(\pm F2)_{9}$</td>
<td>$(\pm 45)_{9}$</td>
</tr>
<tr>
<td>web of A-former</td>
<td>1.9</td>
<td>$(\pm F2)_{9}$</td>
<td>$(\pm 45)_{9}$</td>
</tr>
<tr>
<td>shell</td>
<td>2.422</td>
<td>$(\pm F2/(T)_{16}/\pm F2)$</td>
<td>$(\pm 45/(0)<em>{2}/(90)</em>{2}/(0)<em>{3}/\pm 45/ (0)</em>{3}/(90)<em>{2}/(0)</em>{2}/\pm 45)$</td>
</tr>
</tbody>
</table>
### Material properties

**Foam Core:** PMI foam: **Rohacell® 71 WF-HT**

- Elastic modulus: 105 MPa
- Poisson's ratio: 0.375

**Face sheets:** Carbon fibre reinforced plastics (CFRP)

<table>
<thead>
<tr>
<th></th>
<th>$E_{11}$</th>
<th>$E_{22}$</th>
<th>$E_{33}$</th>
<th>$G_{12}$</th>
<th>$G_{13}$</th>
<th>$G_{23}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HTA-977/2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabric</td>
<td>53423</td>
<td>53423</td>
<td>9100</td>
<td>5200</td>
<td>4200</td>
<td>4200</td>
</tr>
<tr>
<td>Tape</td>
<td>130000</td>
<td>8000</td>
<td>8000</td>
<td>5200</td>
<td>5000</td>
<td>3400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>$\nu_{12}$</th>
<th>$\nu_{23}$</th>
<th>$\nu_{13}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTA-977/2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Fabric</td>
<td>0.035</td>
<td>0.464</td>
<td>0.464</td>
</tr>
<tr>
<td>Tape</td>
<td>0.3</td>
<td>0.5</td>
<td>0.01846</td>
</tr>
</tbody>
</table>

Index 1: direction of load; 2: direction of contraction
Used element-types

- the laminate is represented by element-type SHELL 99 and the core by SOLID 95
Numerical analysis of hollow and foam-filled A-former

Load case and boundary conditions

Front view of load case

Side view of load case

Load case:
4-point bending
Analysis of the stiffness

Load case:

Variant 1

- Hollow A-former
- Foam-filled A-former

percentage increase:

2.8%
### Analysis of the strength according to Tsai-Wu criteria

<table>
<thead>
<tr>
<th>Variant</th>
<th>Inner belt of A-former</th>
<th>Web of A-former</th>
<th>Outer belt of A-former &amp; thin shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.7</td>
<td>13.6</td>
<td>1.2</td>
</tr>
</tbody>
</table>

→ Improvements are especially achieved in the web of the A-former.
Increased buckling load up to 69% in the web area of the A-formers by using a PMI-foam to stabilize the thin face sheet.
Non-linear buckling analysis: Load-/strain diagram of A-former variant 1/inner shell

-> Increased buckling load up to 10% in the area of the thin shell.
Non-linear buckling analysis

<table>
<thead>
<tr>
<th>Variant 1</th>
<th>buckling load in the web of the A-former [kN]</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hollow</td>
<td>foam-filled</td>
<td>Percentage increase [%]</td>
</tr>
<tr>
<td>web</td>
<td>28.9</td>
<td>49.0</td>
<td>69.6</td>
</tr>
<tr>
<td>inner shell</td>
<td>31.7</td>
<td>34.9</td>
<td>10.1</td>
</tr>
</tbody>
</table>

→Increased buckling load up to 69% in the web area and 10% in the inner shell.
Analysis of a complete stiffened thin shell by using a hollow and a foam-filled A-former according to geometry of variant 1

![Graph showing buckling load in the web vs. reduction of the face sheet thickness of the A-Former.](image)

- **Reduction of the face sheet thickness of the A-Former [%]**
- **Buckling load in the web [kN]**

- Critical buckling load of the PMI-foam-filled A-former
- Critical buckling load of the hollow A-former
- Linear trend line
Findings:

-> Reduction of the laminate thickness of the A-former up to 17% (= 2 layers)
-> Weight reduction of the complete structure up to 9% in comparison to a foam-filled A-former, where the stabilizing effect due to the foam core is not taken into account.
Numerical analysis of hollow and foam-filled A-former

Analysis of axial compression loading

Variants

- hollow A-former
- PMI foam-filled A-former

Load Case
Axial compression load analysis

- Increased buckling load up to 16%.

**Load [kN]**
- Hollow A-former: 47.3
- PMI foam-filled A-former: 54.8
Results of the experimental analysis (Dornier investigation)

- Strength and durability of a carbon epoxy shell can be significantly improved by using an A–former stabilized by a structural ROHACELL® core.

- The ROHACELL® - stabilized structure greatly out-performs the hollow stiffener by far, because the failure caused by stability is moved almost to the yield strength.

- This makes it possible to design the stiffened profile with minimized wall thickness resulting in a significant weight reduction.

- The achievable level of optimization depends on the actual design / geometry of the stiffened profile.

- Breaking load is increased up to 41%

- Stability is increased up to 108%
Advantages by using an foam-filled A-former:

- Structural and mechanical advantages regarding buckling effects
- Good laminate quality, good reproduction of the geometry of the A-hat, no dimpling effects, reduced process steps

Findings:

- Increased stiffness up to 5%
- Increased strength up to 18%
- Stabilizing effect of the thin face sheets of the A-former especially in the area of the web due to rigid foam core → Increased buckling load up to 69%
- Due to the stabilizing effect it's possible to reduce the thickness of the A former up to 17% or 2 layers, i. e. decreased weight of the whole structure up to 9%
Conclusion

Final Result:

- The stabilizing effect of the thin face sheets as a result of the foam core have to be taken into account to reduced the **lamine thickness**, **the weight**, as well as the **production costs** and **production time** of foam-filled A-formers.

Further works:

- Experimental testing of foam-filled and hollow A-formers under 4-point-bending and axial compression loading.
- Validation of the numerical results with the aid of the experimental tests.
Thank you very much for your Attention!!!

ROHACELL®
Making Your WORLD lighter