About the Feasibility of Thermoplastic Composite Fan Structures

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Company: DLR Institute of Structures and Design in Stuttgart (Germany)
*Rolls Royce Deutschland (RRD) in Dahlewitz (Germany)

Presenter: F. Kocian

Authors: Frank Kocian, Björn Drees, *Olaf Lenk
General Remarks

Different Design Approaches

1. Titanium / CFRP Material Combination

2. Overall Thermoplastic OGV Design

• Manufacturing of a Thermoplastic Vane

• Cost Assessment

• Conclusion

Topic of SP 4.2:
Structural OGV – combining aerodynamic and structural features
General Remarks

Why using thermoplastic UD CF-PEEK material?

- Material is well known in aerospace application
- Comprehensive material variants available in Europe
- Excellent mechanical properties
- Excellent chemical resistance
- Low moisture pick up with negligible impact on material performance
- Potential for alternative joining technologies and reparability
- No waste with a view to recycling capability
- Processes can be automated with a view to high quantities
Titanium / CFRP Material Combination

**Advantages:**
- Conventional metallic welding technique applicable
- High inherent stiffness of the joint
- Practicable with a view to simple manufacturing
- Variants for attachment possible

**Disadvantages:**
- Not easy to remove from full component in case of welded joint
- Hybrid joint still need to be tested intensively

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Static Test of Metal to Composite Joint
(Contributed from SP 3.3)

Results of Tested Hybrid Specimens

Double Lap Shear ASTM D3528

- APC-2/AS4
- APC-2/IM7

Temperature [°C]
Strength [MPa]

Variables:
- $T_1 = 1.6$ mm
- $T_2 = 3.2$ mm
- A = Test Splines
- B = Area in Test Grips
- C = Shear areas
Mass Specific Strain Energy in Joining Area

- 2nd Mode Testing
- Comparison of strain energy in joining area due to different stiffness and mass of specimen
- Double lap joint reaches nearly the mass specific strain energy level of pure titanium

1.00E+04 1.00E+05 1.00E+06 1.00E+07 cycles

mass specific strain energy

[J/kg]

- ▲ titanium
- ◆ single lap
- ▲ single lap from individual plies
- ◆ double lap
- ○ inverted double lap (CFRP clamped)
Impact Tests on HCF Specimen

- Impact velocity from 104 to 151 m/s
- Impactor (galantine) mass ranges from 25 to 33 gr
- Energy ranges from 139 J to 306 J
- No failure occurred due to 0.9% strain within CFRP material
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Composite OGV with Titanium Inner Casing and Mounting Brackets

- Mounting brackets (Titanium)
- Outer box (CF-PEEK)
- Outer vane extensions (CF-PEEK)
- Inner box (CF-PEEK)
- Vane
- Inner vane extensions
- Rear flange ring (CF-PEEK)
- Front flange ring (CF-PEEK)
Composite OGV with Titanium Inner Casing and Mounting Bracket

Main characteristics:

- Endless fibre reinforced vane with integrated load introduction
- Uninterrupted fibre structure between the two OGV flanges
- Usage of high inherent in plane stiffness of the vane between the flanges to avoid additional circumferential ribs
- Welded short/long fibre stiffened elements are used to increase the frequency of first vane bending mode
- There is the possibility to arrange several vanes to a cluster
- Exchanging a single vane or a cluster of vanes for repair can be guaranteed
- Cost-effective manufacturing
- No additional joining fittings
- Load introduction for mounting can be done directly in elongated vanes
- Problems of tolerance are solved
- Acoustic liner can be integrated in stiffening boxes
Composite OGV with Titanium Inner Casing and Mounting Bracket

CFRP vane with integrated load introduction

welding line

interesting point: torsion loaded vane extensions due to bending moment of the vane

short/long fibre reinforced stiffening boxes

Titanium

CF-PEEK

CF-PEEK short/long fibre

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Verification of Vane Extensions
Experimental Results

- Cross section in the middle of specimen
  9 mm x 30 mm
- Material APC2 AS4 – quasi isotropic lay-up
- Crack appears in the middle of specimen as expected
- Plastic deformation can be observed as from 70 Nm
### Bearing Strength of CF-PEEK

#### Results of Tests

<table>
<thead>
<tr>
<th>W/D / t / e/D</th>
<th>$\sigma_{\text{max}}$ [N/mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 / 4 / 3</td>
<td>1074.47</td>
</tr>
<tr>
<td>4 / 4 / 3</td>
<td>1125.19</td>
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<tr>
<td>5 / 4 / 3</td>
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<td>6 / 4 / 3</td>
<td>1106.07</td>
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<td>6 / 9 / 3</td>
<td>830.21</td>
</tr>
</tbody>
</table>

- Highest stress value for W/D = 5
- Lower maximum stress for thicker specimen at constant W/D = 6 ratio

![Failure mode for W/D=4](image1)

![Failure mode for W/D=5](image2)
Bearing Strength of CFRP
Comparison of CF/RTM6 and CF/PEEK Specimens

![Bar chart showing stress vs. W/D and e/D for CF/PEEK and CF/RTM6 specimens.](image-url)
Resistance Welding as a Basis for Assembling

**CF prepreg as resistive element**
+ no additional material
+ acceptable strength
- leakage current possible
- insufficient process reliability
- fibers may blow

**VA-mesh as resistor with PEEK matrix**
+ high process reliability
+ acceptable strength
+ easy to manufacture
- leakage current possible
- additional material remains in structure

**VA-mesh as resistor with GF-PEEK**
+ high process reliability
+ no leakage current
+ no corrosion problems
+ acceptable strength
+ constant melt on
- additional material remains in structure

*figure: Hou, M.*
Resistance Welding as a Basis for Assembling - Shear Test
(Partly contributed from DLR Internal Projects)

Generals
- welding size: 200mm x 40mm
- specimen preparation and testing according to ASTM D1002 and QVA-Z10-46-9

Advantages
- no fringe effects in the test area
- larger welding areas
Shear Strength of Welded Joint

The image shows a bar graph comparing the tensile shear strength of different materials, including welded, pure PEEK, heating element, and inter laminar. The graph indicates a trend of increasing strength from left to right across the categories.

Consolidated references and welded specimen are indicated with icons.
**Weight Estimation of Different Design Approaches**

**Comparison**

- **Metal structure**
- **Hybrid structure with metallic inner and outer casing**
- **Full composite structure with metallic inner casing**

Legend:
- **outer load introduction**
- **outer ring structure**
- **vane**
- **inner casing**
Manufacturing of a Thermoplastic Vane
Variant I with Thin Plates

- Provision of thin plates
- Forming of thin plates
- Cutting of thin formed plates
- Cleaning and surface preparation of pre cuts
- Stacking of pre cuts within a mould
- Consolidation of the vane
- Final milling of edges and drilling of holes
Manufacturing of a Thermoplastic Vane
Variant II with Thick Plates

- Provision of thick plates
- Forming of plates
- Cutting and milling of formed plates
- Cleaning of milled pre cuts
- Stacking of pre cuts within a mould
- Consolidation of the vane
- Final milling of edges and drilling of holes
Manufacturing Facility for Production of thermoplastic Vane

- transport unit where the plates are mounted
- infrared heat field
- heatable press

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Manufacturing of prototype variant I

- Positioning of single layers has been done by laser projection – Optimisation by using simple centring bolts

- Additional matrix material was added in terms of piecewise foil – Need to be replaced by coating technology

- Geometry of vane need to be adapted to material characteristics – minor change of vane geometry respectively change of ply thickness is necessary to reduce manufacturing complexity
Consolidated Blade in the Open Press
Final Vane for Test

- Two vanes were manufactured up to now
- Final processing step consists of machining leading and trailing edge respectively clamping areas of the vane
- Processing of the vane geometry was the fundament of cost estimation together with RRD
Cost Assessment Variant I

- Estimated costs are competitive to existing design alternatives (statement RRD)
- Cost assessment based on measured time during production of prototype and detailed analysis of procedures
- Optimization of manufacturing processes were taken into account too
- handling systems need to be integrated in an automated manufacturing process

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- Provision of the thin plates
- Forming of plates
- Cutting of the thin formed plates
- Cleaning and surface preparation on pre cuts
- Stacking of pre cuts within a mould
- Consolidation of the vane
- Milling of the vane edges
Cost Assessment Variant II

- Cost assessment based on experience of variant I
- Variant II offers further cost reduction potential of 17% with a view to reduced stacking effort
Conclusion

• Technical feasibility of thermoplastic fan structures could be demonstrated

• Further optimisation with view to automation is necessary to reach maximum cost effectiveness

• Technological potential offers possibility of new design concepts