AED

DAMTEX
Damage tolerance design for thin ply textile composites

R&T Department
AERNNOVA Engineering Division Madrid

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Air-TN DAMTEX Project began in October 2013

Kick Off Meeting in Illescas facilities of AERNNOVA Composites in October/2013. End at September 2015

Bilateral project between Sweden and Spain

Consortium description:

- Industrial Partners:
  - AERNNOVA (Spain)
  - Oxeon AB (Sweden)

- Research Partners:
  - SICOMP (Sweden). Proposal Leader
  - AMADE UdG (Spain). Outsourced by AERNNOVA
OBJECTIVES

- Creation of methodology for TeXtreme material selection between different available ones
- Demonstration of feasibility of injecting industrial panels with RTM process of TeXtreme fabrics
- Comparison of obtained static and dynamic properties between current qualified OoA materials and TeXtreme ones. Improvements
- Creation of methodology for selection of interfaces number to be modelled for correlating efficiently the impact damage
- Drop Tower Weight simulation accuracy and affordability
SPANISH TASKS

- INTRODUCTION. MESOSCOPIC MODEL FOR SELECTING MOST POTENTIAL FIBRE/RESIN COMBINATION

- MANUFACTURING PLAN FOR COUPON TESTS OBTENTION

- TEST PLAN OF CHARACTERIZATION
ÓPTIMAL RESIN+FIBRE COMBINATION

- Capability for predicting the final properties of a composite material knowing only the constituents (fibre and resin) properties and material textile architecture.

These predictions helped to minimize the material test campaigns reducing the number of materials to be tested in the design phase, and getting big savings in material and involved costs.
Materials selected for its use in aeronautics:

- Resin RTM6 from Hexcel Composites
- Carbon Fibre Fabric TeXtreme® PW HTS45 80 gsm
- Carbon Fibre Fabric TeXtreme®PW HTS45 160 gsm

The reasons are:

- Certified manufacturing process for aeronautic use
- Lower ply thickness (25% lower than current fabrics)
- Increased Mechanical Properties
- Increased Damage Tolerance (To Be Demonstrated)
### MANUFACTURING PLAN
PLY MATERIALS

<table>
<thead>
<tr>
<th>Fabric Type</th>
<th>TEXTREME® 80 gsm</th>
<th>TEXTREME® 160 gsm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre type</td>
<td>HTS45 (12 K by yarn)</td>
<td>HTS45 (12 K by yarn)</td>
</tr>
<tr>
<td>Fabric areal weight</td>
<td>80 gsm, plain weave with 20 mm yarn (ply thickness: 0.08 mm)</td>
<td>160 (plain weave with 20 mm yarn and ply thickness: 0.16 mm)</td>
</tr>
<tr>
<td>Resin</td>
<td>RTM6</td>
<td>RTM6</td>
</tr>
<tr>
<td>Fibre volume fraction</td>
<td>Vf = 69%</td>
<td>Vf = 69%</td>
</tr>
</tbody>
</table>
For 0º/90º laminates on 80gsm and 160gsm:

- Good injections
- $T_{g_{onset}} > 205º$ (>195º is Airbus requirement)
For laminates with end ply at 45°/-45°:

Fibre wash-out on both 80 gsm and 160 gsm. Different strategies were used for minimising or avoiding this issue.
After iterations and SICOMP recommendations a solution was found.

Fibre wash-out disappeared on 80gsm laminate and was minimized on 160gms laminate.
PLATE 1: TEXTREME 80gsm / RTM6
PLATE CM1: TEXTREME 80gsm / RTM6
PLATE 12: TEXTREME 160gsm / RTM6

<table>
<thead>
<tr>
<th>MANUFACTURED PLATE</th>
<th>C-SCAN</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Manufactured Plate" /></td>
<td><img src="image2.png" alt="C-Scan" /></td>
</tr>
</tbody>
</table>
PLATE CM2: TEXTREME 160gsm / RTM6
Material characterization: elastic properties and strength

- Tension
- Compression
- In-Plane Shear
- Iosipescu
- Shear Strength (10° off-axis tensile test)

TEXTREM® 80 gsm
Material characterization: fracture toughness

- Compact Tension (CT)
- Compact Compression (CC)
- Mixed-mode Bending (MMB)
- Double Cantilever Beam (DCB)
- Calibrated-End Loaded Split (C-ELS)
- Double Edge Notched under Tensile loading (DENT)
- Double Edge Notched under Compression loading (DENC)

TEXTREM® 80 gsm
Small demonstrator tests: impact + CAI/TAI/fractography; static indentation

- Static indentation test with the same boundary conditions used for the impact test
- Static indentation test using a rigid base support

TEXTREM® 80 gsm

TEXTREM® 160 gsm
More than 200 coupons tested
TEST PLAN

- INTERLAMINAR QUASI-STATIC CHARACTERIZATION TEST RESULTS
- INTRALAMINAR QUASI-STATIC CHARACTERIZATION TEST RESULTS
- DROP WEIGHT TOWER, CAI and TAI TEST RESULTS
Gic, G2c, MMB FRACTURE ENERGY TESTS

ENF test

DCB test

MMB test
Compact Tension (CT):

![Compact Tension Test Samples and Graph](image-url)
Compact Compression (CC):

Sample gate

Sample gate

Force [N]

Displacement [mm]
## TEST RESULTS SUMMARY. IMPROVEMENTS

**Summary:** elastic properties and strengths

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Comparison vs G0926 Hexcel Composites (AIMS 05-04-009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{11T} ; (E_{22T})$ [GPa]</td>
<td>+ 6 %</td>
<td></td>
</tr>
<tr>
<td>$E_{11C} ; (E_{22C})$ [GPa]</td>
<td>$\approx$</td>
<td></td>
</tr>
<tr>
<td>$G_{12}$ [GPa]</td>
<td>- 15 %</td>
<td></td>
</tr>
<tr>
<td>$\nu_{12}$</td>
<td>+ 31.3 %</td>
<td></td>
</tr>
<tr>
<td>$X_T$ [MPa]</td>
<td>+ 30 %</td>
<td></td>
</tr>
<tr>
<td>$X_C$ [MPa]</td>
<td>+ 12%</td>
<td></td>
</tr>
<tr>
<td>$S_L$ [MPa]</td>
<td>- 20 %</td>
<td></td>
</tr>
</tbody>
</table>
## TEST RESULTS SUMMARY. IMPROVEMENTS

**Summary: interlaminar fracture toughness**

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<th>Comparison</th>
</tr>
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<tbody>
<tr>
<td>$G_{IC}$</td>
<td>[J/m²]</td>
<td></td>
<td>↓</td>
</tr>
<tr>
<td>$G_{MM 25%}$</td>
<td>[J/m²]</td>
<td></td>
<td>↓</td>
</tr>
<tr>
<td>$G_{MM 50%}$</td>
<td>[J/m²]</td>
<td></td>
<td>↓</td>
</tr>
<tr>
<td>$G_{MM 75%}$</td>
<td>[J/m²]</td>
<td></td>
<td>↓</td>
</tr>
<tr>
<td>$G_{IIIC}$</td>
<td>[J/m²]</td>
<td></td>
<td>↓</td>
</tr>
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Similar values to a UD tape

Not so good interlaminar fracture toughness as current materials
## TEST RESULTS SUMMARY. IMPROVEMENTS

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**Solution to interlaminar lower fracture toughness:**

Thermoplastic veil applied to each TeXtreme 80 gsm ply
TeXtreme 80 gsm material has better no-damage (pristine) behaviour and similar damage tolerance values at low energy than currently used fabrics. These values will be increased if the thermoplastic binder is used. ONGOING WORK
The big problem for an efficient model in a layup of 55 plies, is to consider the lowest number of interfaces for delamination that represents enough accuracy.

Impact tests

Indentation tests
Consideration of sublaminates:

SEM inspections from indented specimens

LOCALIZED NUMBER OF DELAMINATIONS. HOW MANY WE SHOULD CONSIDER??

It seems that with 5 or 6 equally spaced delaminations is enough.
Consideration of sublaminates:

SEM inspections from indented specimens

LOCALIZED NUMBER OF DELAMINATIONS. HOW MANY WE SHOULD CONSIDER??

It seems that with 5 or 6 equally spaced delaminations is enough.

Shell + SFM model perfectly capture delamination initiation and propagation in Mode I, II and MMB

VUMAT subroutine developed by AMADE for fabric materials has been used for the intralaminar behaviour. (1)

(1) A continuum constitutive model for the simulation of fabric-reinforced composites

E. Martin-Santos, P. Maimí, E. V. Gonzalez, P. Cruz
CONCLUSIONS AND LESSONS LEARNT

- Manufacturing knowledge in how carrying out successful RTM injections with TeXtreme fabrics with aeronautics qualified resins has been obtained.

- Improvements in intralaminar behavior respect state-of-the-art fabrics has been demonstrated.

- After introducing thermoplastic binder, similar or even better interlaminar behavior respect to current fabrics has been also demonstrated.

- Similar Compression After Impact (CAI) behaviour than current ones also demonstrated. Improvement expected if TP binder is used.

- Good correlations obtained between simulations and experiments of drop weight tower impacts with low number of interfaces, making simulation time affordable.