AERnnova engineering

AED

DAMTEX

Damage tolerance design for thin ply textile composites

R&T Department
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ACARE

Air Transport Net

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INTRODUCTION

- 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

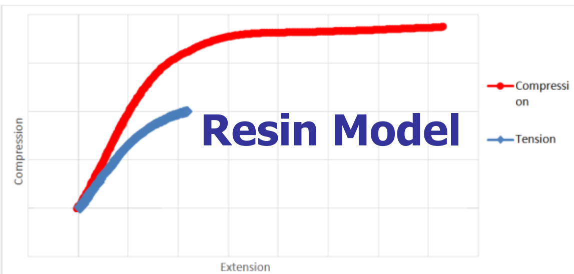
- Creation of methodology for TeXtreme material selection between different available ones
- Demonstration of feasibility of injecting industrial panels with RTM process of TeXtreme fabrics
- Comparison of obtained static and dynamic properties between current qualified OoA materials and TeXtreme ones. 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

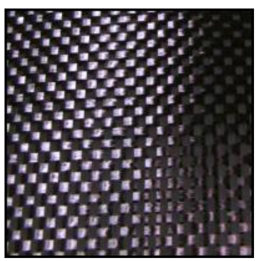
- INTRODUCTION. MESOSCOPIC MODEL FOR SELECTING MOST POTENTIAL FIBRE/RESIN COMBINATION
- MANUFACTURING PLAN FOR COUPON TESTS OBTENTION
- TEST PLAN OF CHARACTERIZATION

ÓPTIMAL RESIN+FIBRE COMBINATION

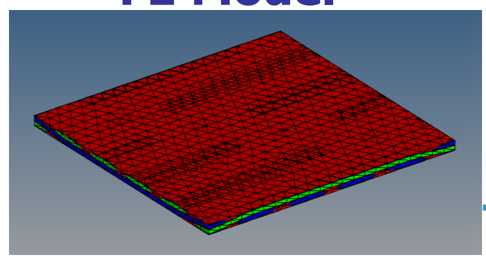
- Capabilty for predicting the final properties of a composite material knowing only the constituents (fibre and resin) properties and material textile arquitecture.

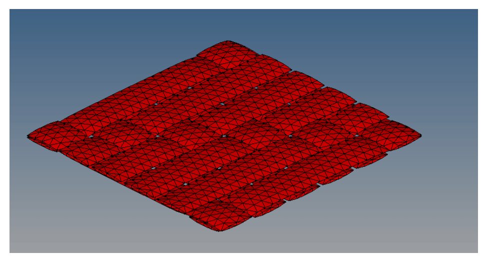


Textile Arquitecture

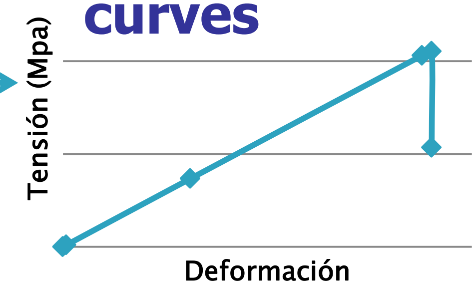


Mesoscopic FE Model





Data and characteristic curves



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.

ÓPTIMAL RESIN+FIBRE COMBINATION

- 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)

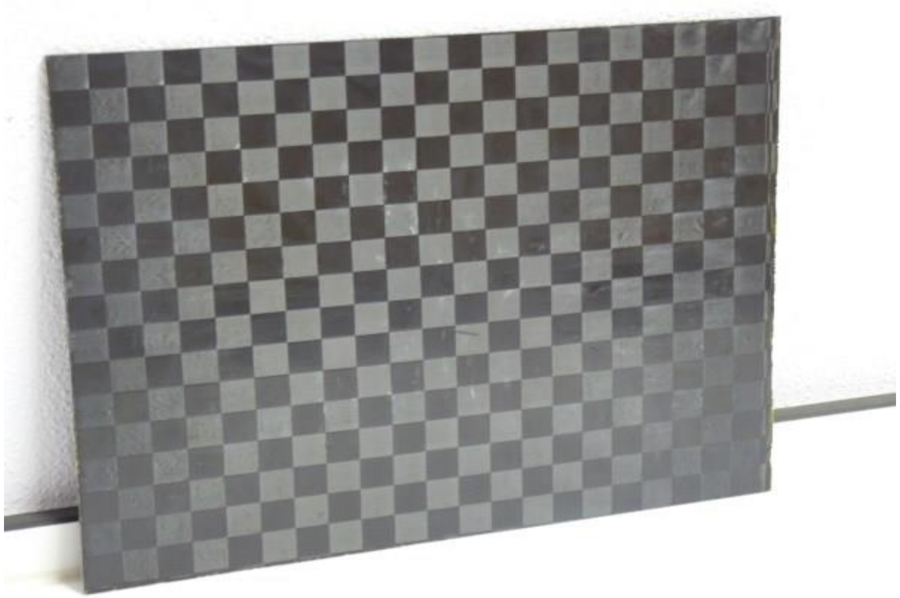
MANUFACTURING PLAN
PLY MATERIALS

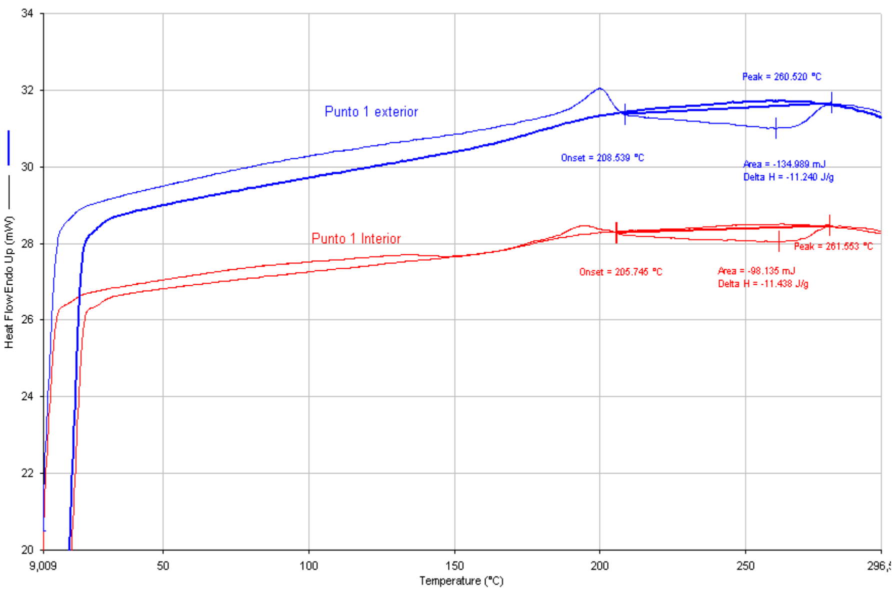
	TEXTREME® 80 gsm
Fibre type	HTS45 (12 K by yarn)
Fabric areal weight	80 gsm, plain weave with 20 mm yarn (ply thickness: 0.08 mm)
Resin	RTM6
Fibre volume fraction	Vf = 69%

	TEXTREME® 160 gsm
Fibre type	HTS45 (12 K by yarn)
Fabric areal weight	160 (plain weave with 20 mm yarn and ply thickness: 0.16 mm)
Resin	RTM6
Fibre volume fraction	Vf = 69%

MANUFACTURING TRIALS

- For 0º/90º laminates on 80gsm and 160gsm:
  - Good injections
  - Tg_{onset} > 205º (>195º is Airbus requirement)





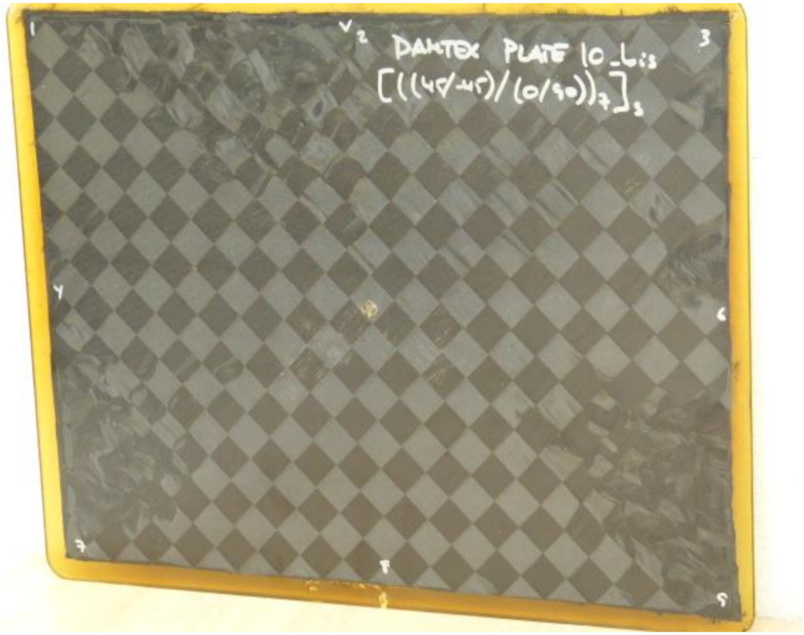
MANUFACTURING TRIALS

- For laminates with end ply at 45º/-45º:

Fibre wash-out on both 80 gsm and 160 gsm. Different strategies were used for minimising or avoiding this issue

Strategy 1

Strategy 2

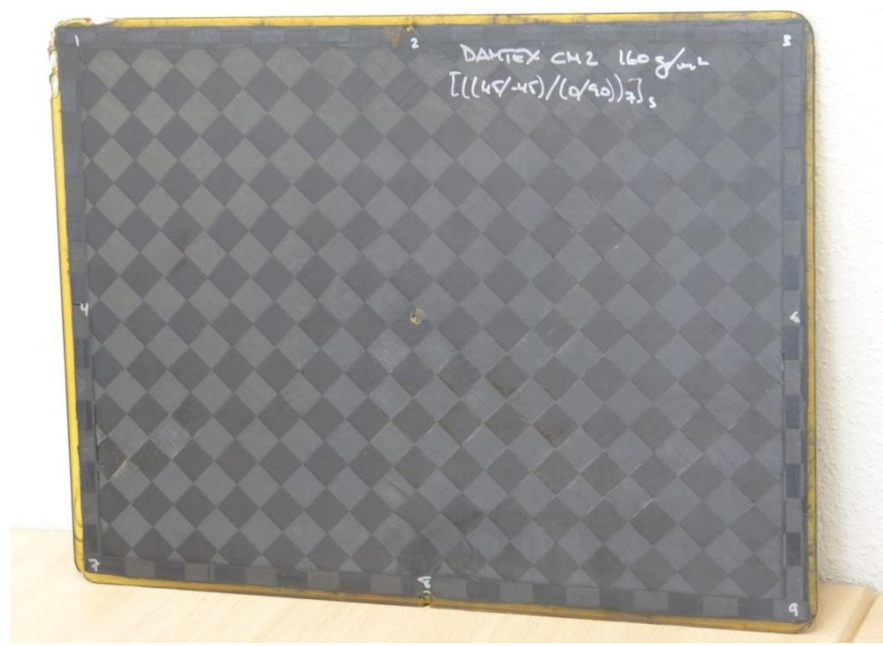


MANUFACTURING TRIALS

- After iterations and SICOMP recommendations a solution was found
- Fibre wash-out dissappeared on 80gsm laminate and was minimized on 160gms laminate

TEXTREM 80 gsm

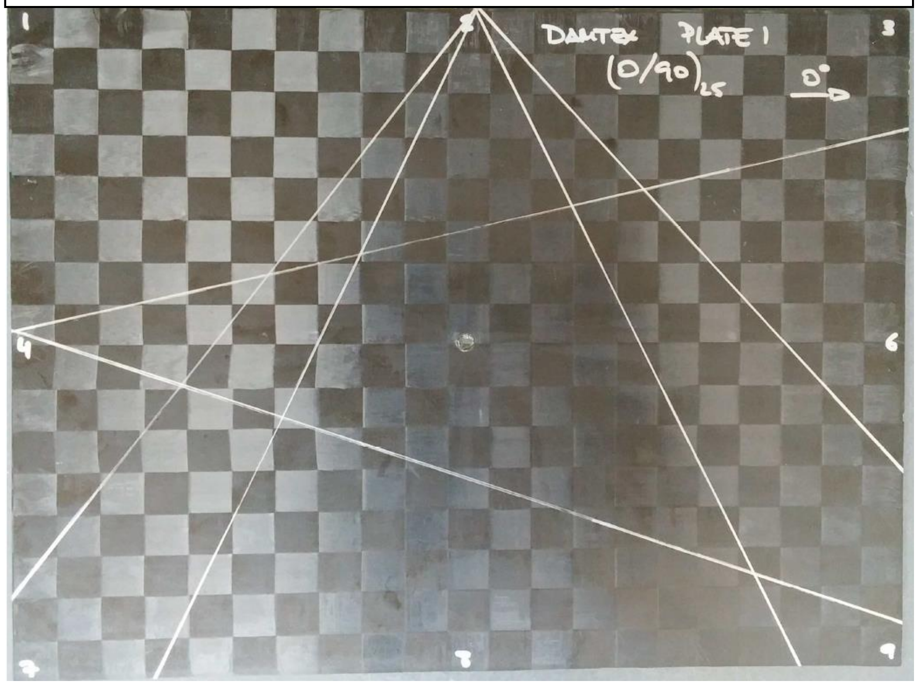
TEXTREM 160 gsm

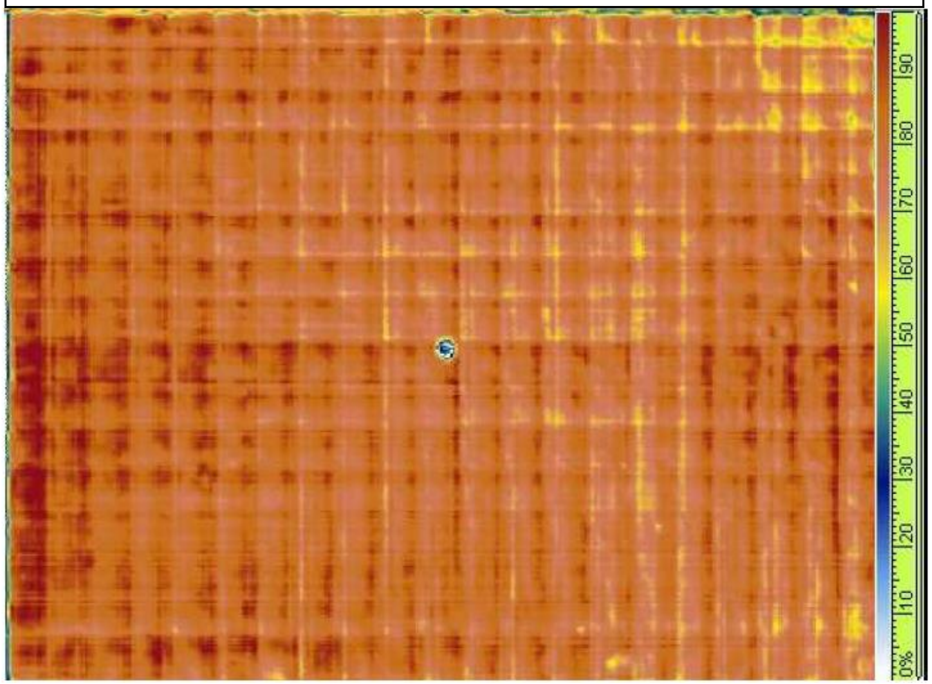


MANUFACTURED SAMPLES

➤PLATE 1: TEXTREME 80gsm / RTM6

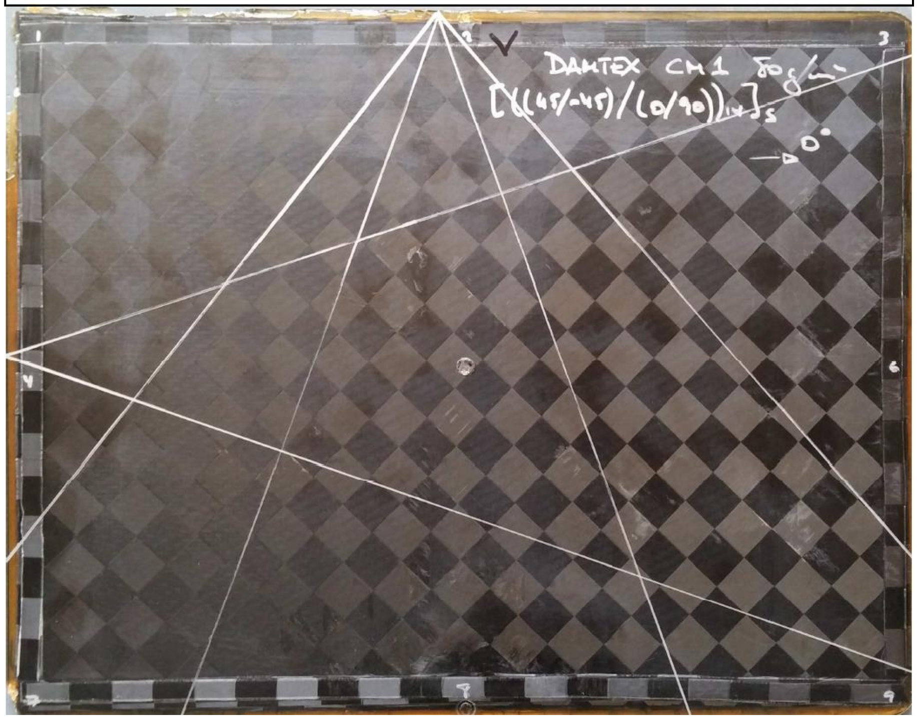
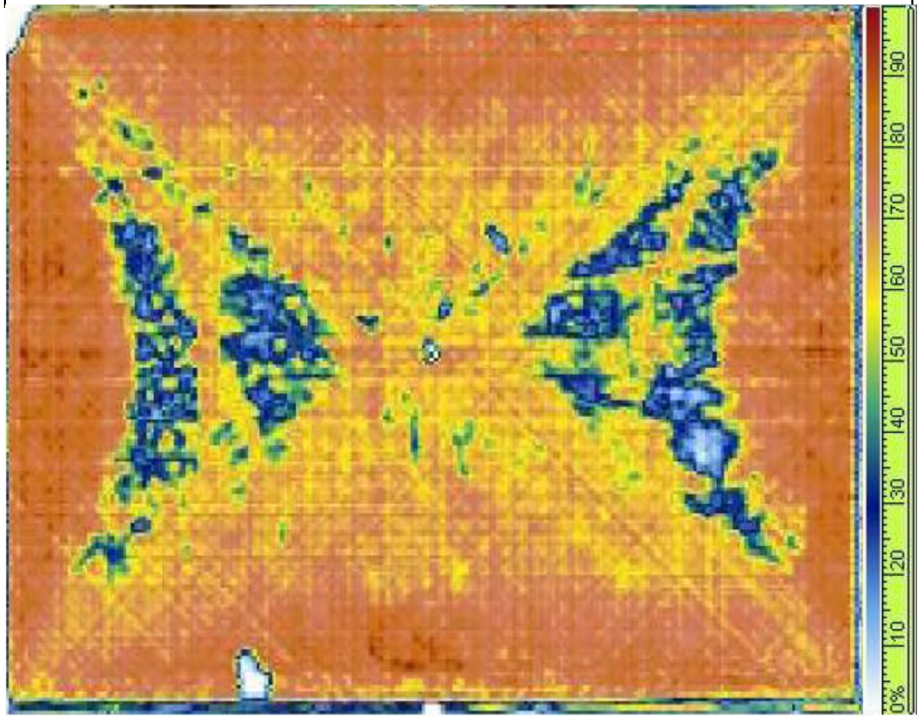
MANUFACTURED PLATE	C-SCAN





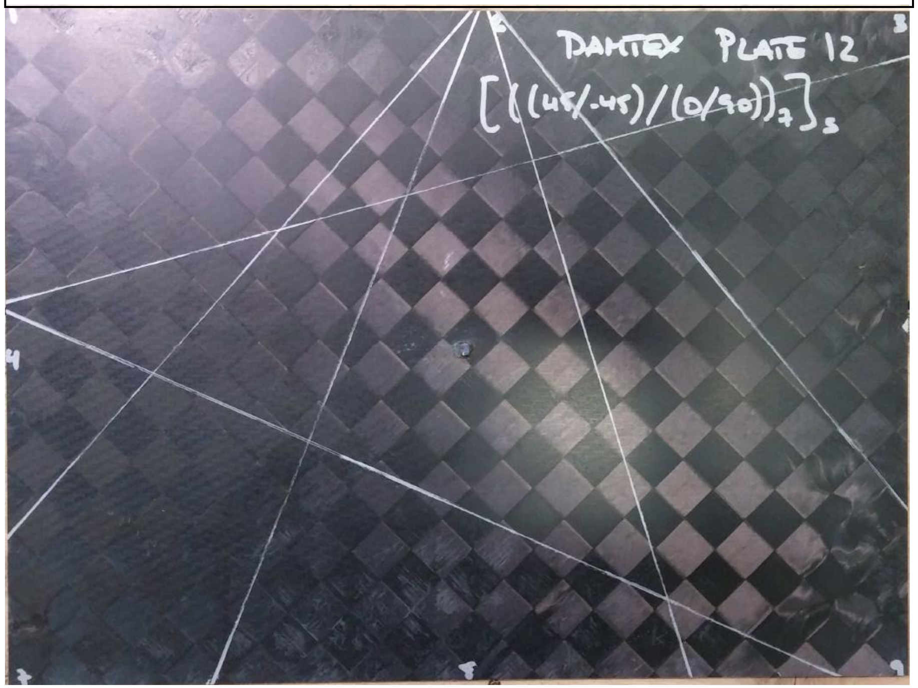
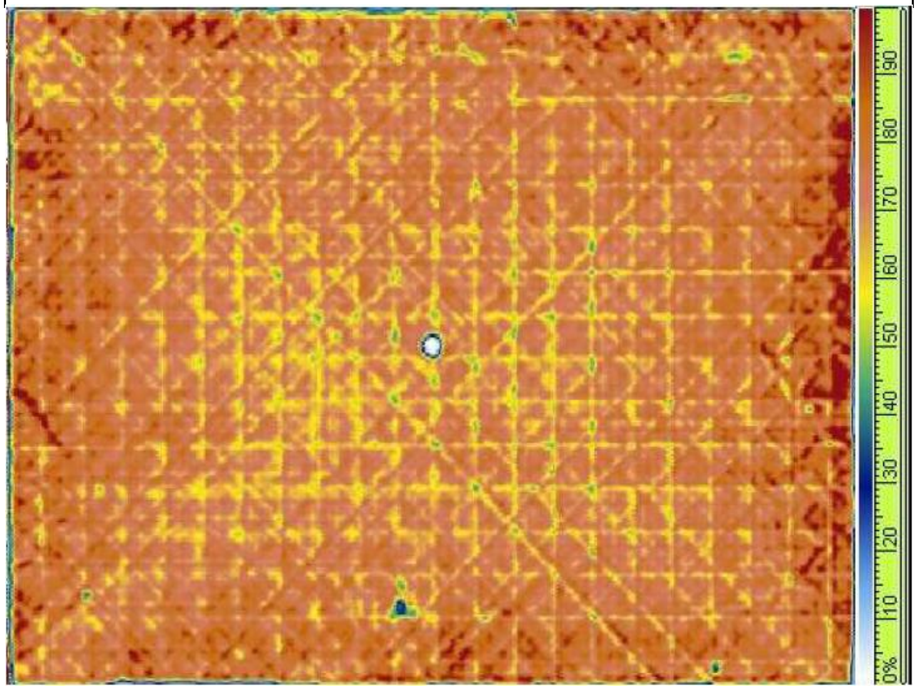
MANUFACTURED SAMPLES

➤PLATE CM1: TEXTREME 80gsm / RTM6

MANUFACTURED PLATE	C-SCAN
	

MANUFACTURED SAMPLES

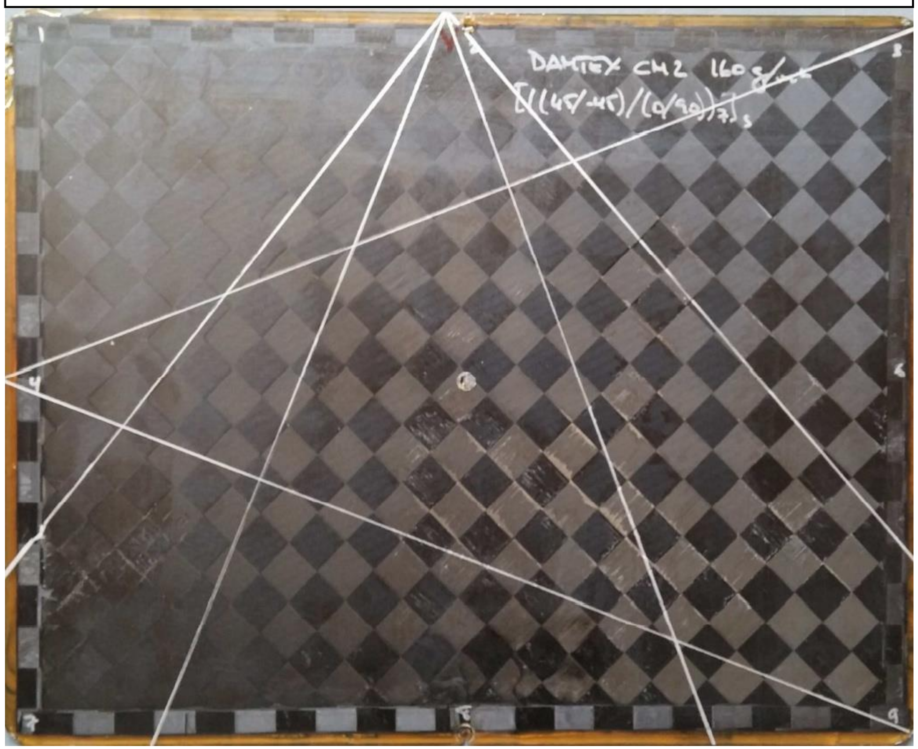
➤PLATE 12: TEXTREME 160gsm / RTM6

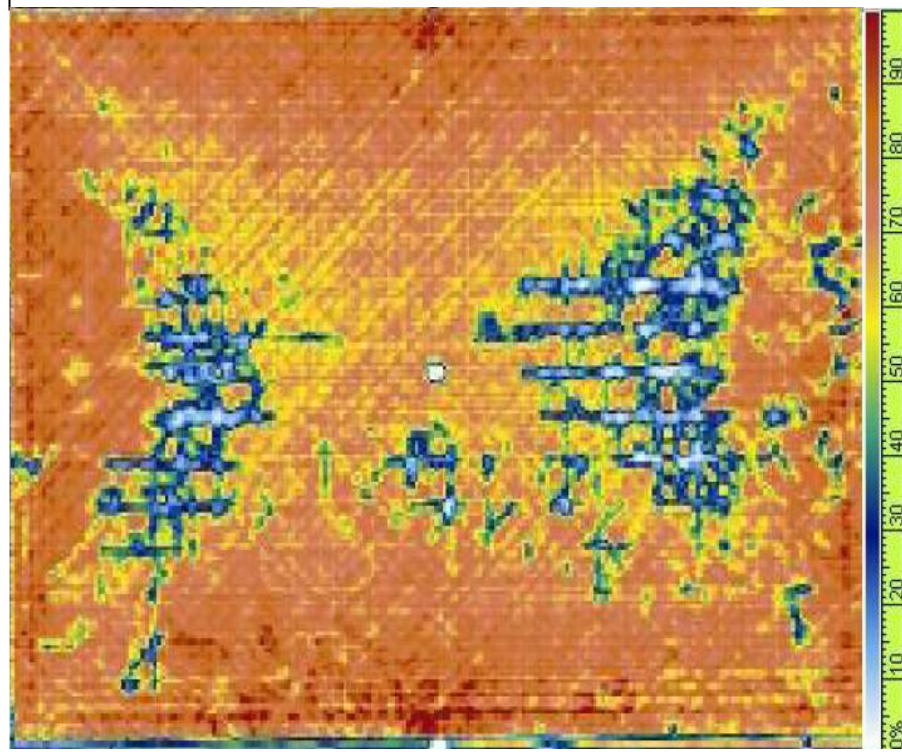
MANUFACTURED PLATE	C-SCAN
	

MANUFACTURED SAMPLES

➤PLATE CM2: TEXTREME 160gsm / RTM6

MANUFACTURED PLATE	C-SCAN





TEST PLAN

Material characterization: elastic properties and strength

- Tension
- Compresion
- In-Plane Shear
- Iosipescu
- Shear Strength (10º off-axis tensile test)

TEXTREME® 80 gsm

TEST PLAN

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)

TEXTREME® 80 gsm

TEST PLAN

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

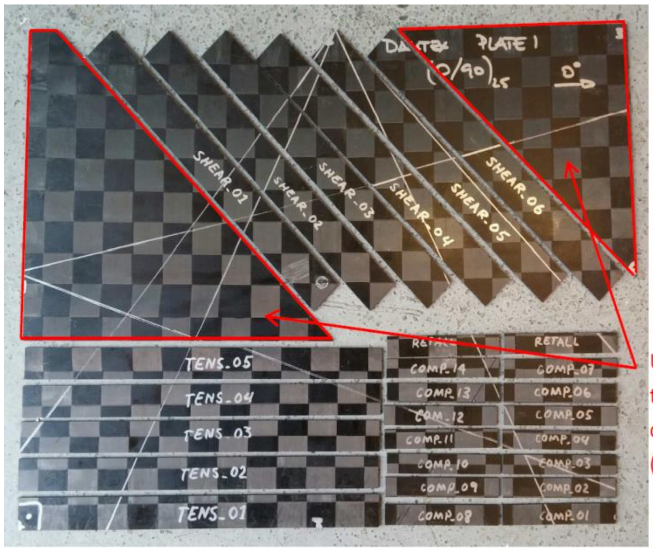
TEXTREME® 80 gsm

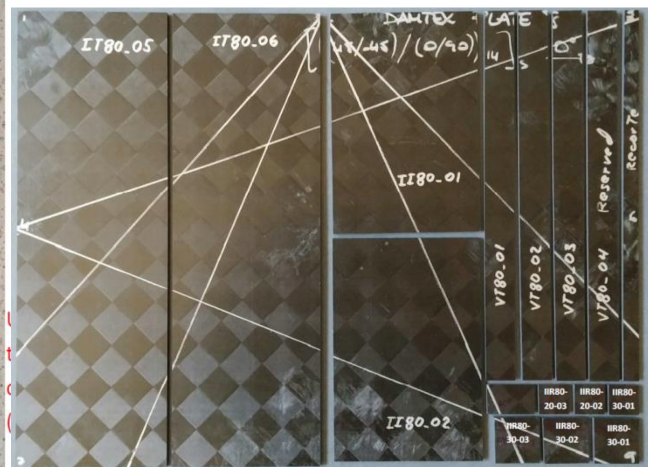
TEXTREME® 160 gsm

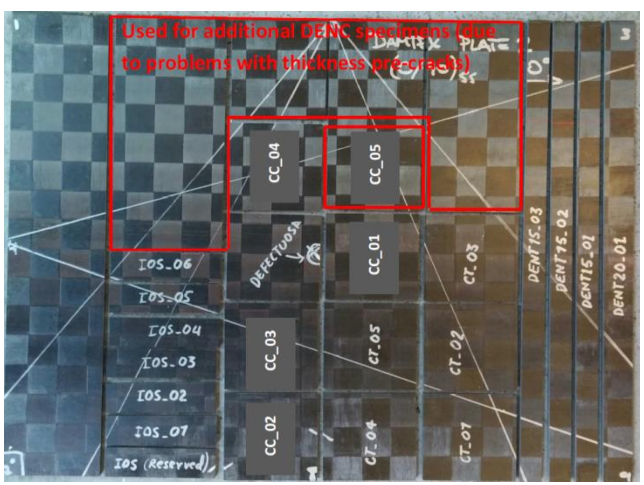
TEST PLAN: PLATES AND COUPONS

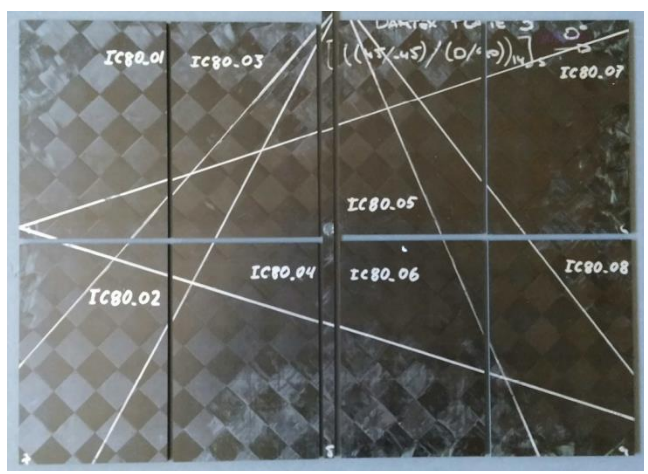
TEXTREME® 80 gsm

- More than 200 coupons tested





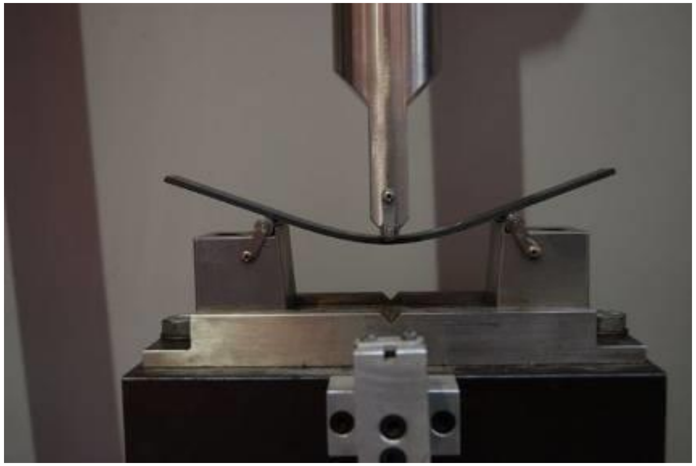




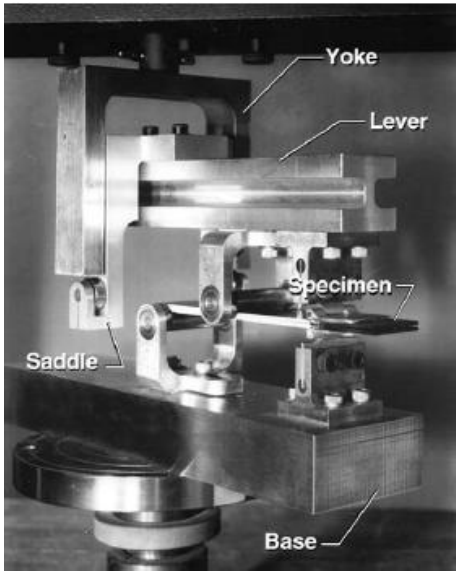
TEST PLAN

- **INTERLAMINAR QUASI-STATIC CHARACTERIZATION TEST RESULTS**
- **INTRALAMINAR QUASI-STATIC CHARACTERIZATION TEST RESULTS**
- **DROP WEIGHT TOWER, CAI and TAI TEST RESULTS**

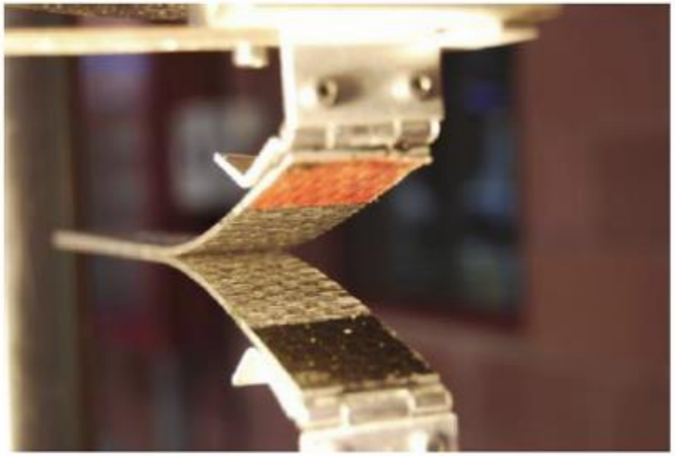
Gic, G2c, MMB FRACTURE ENERGIES TESTS



ENF test



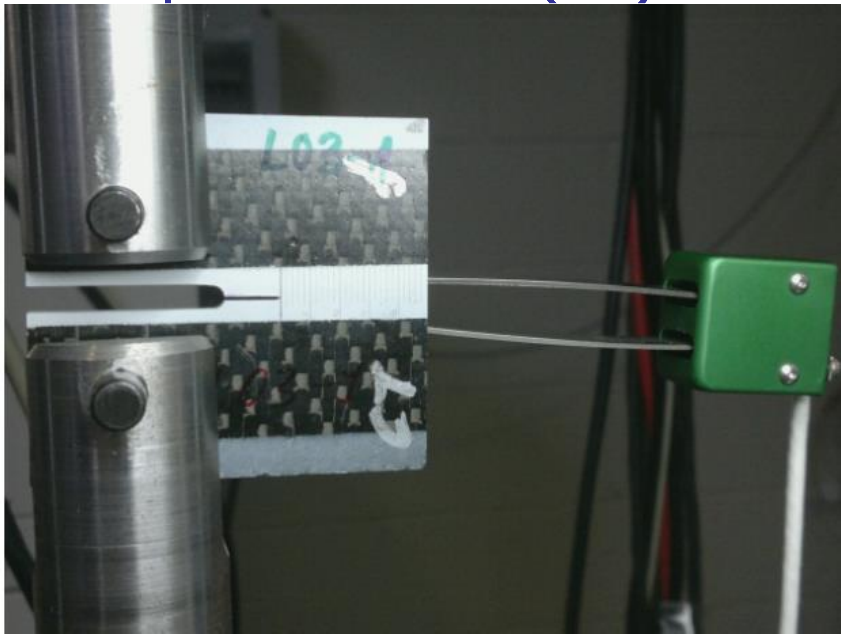
MMB test

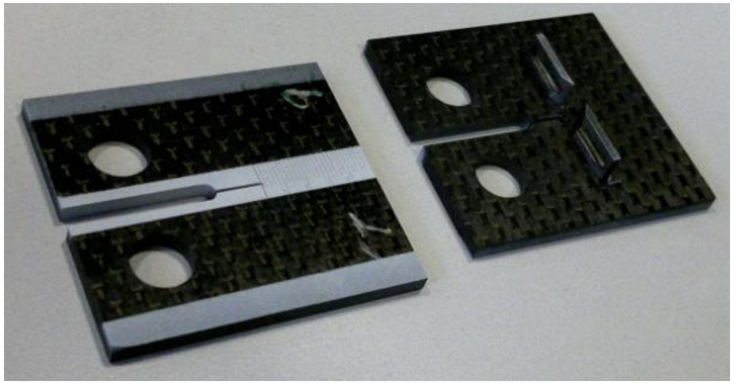


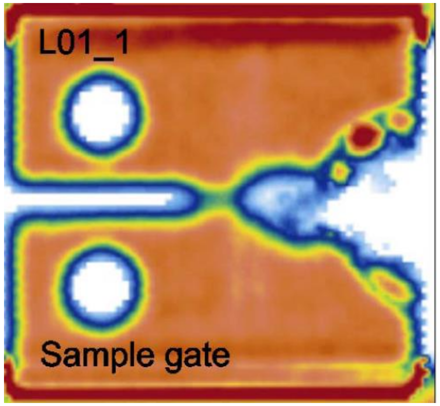
DCB test

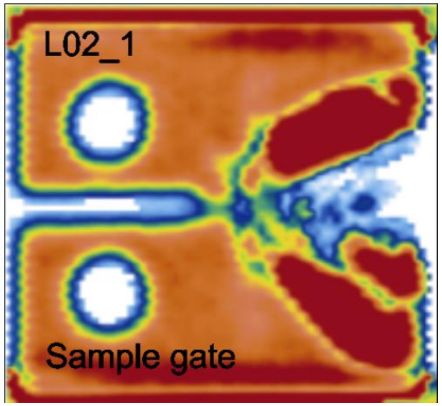
INTRALAMINAR FRACTURE ENERGY TESTS

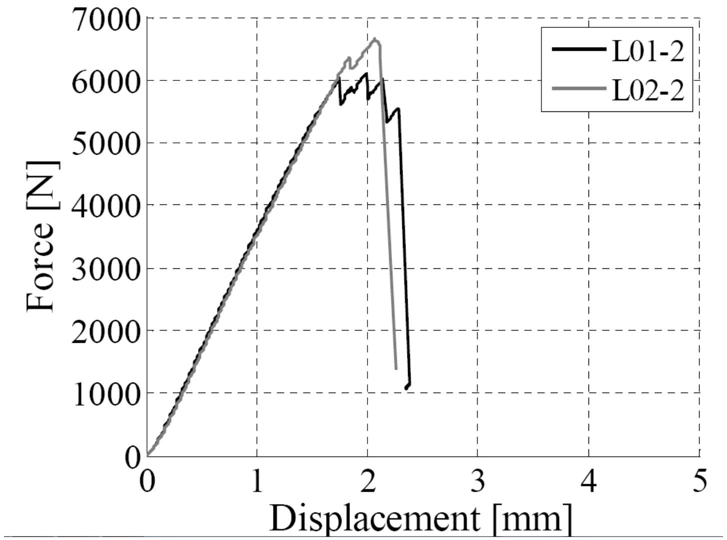
- Compact Tension (CT):





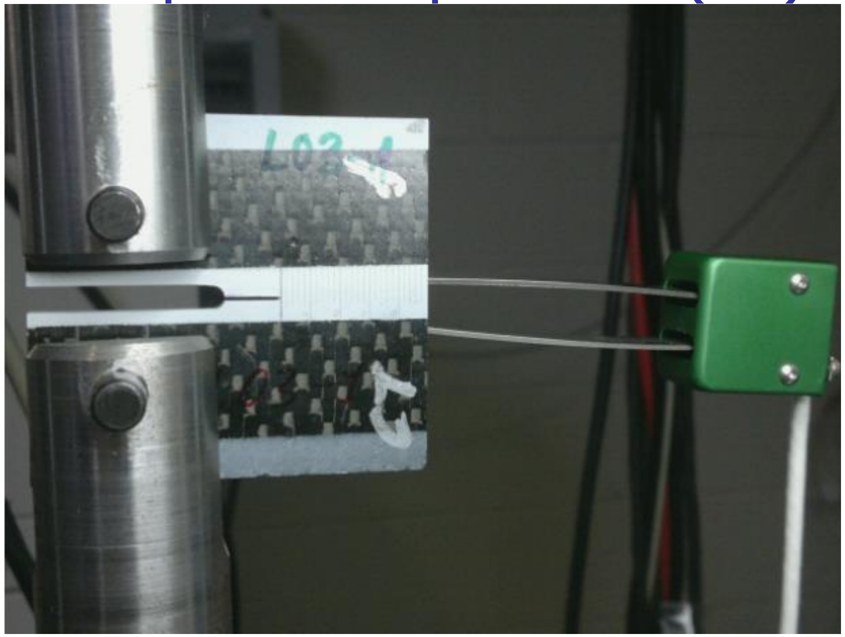


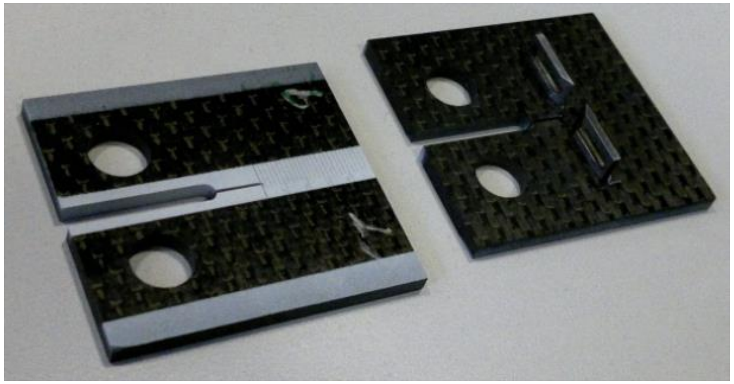


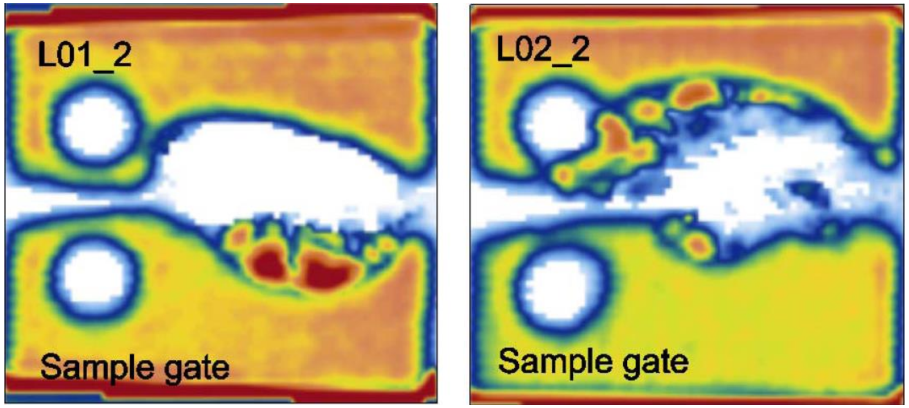


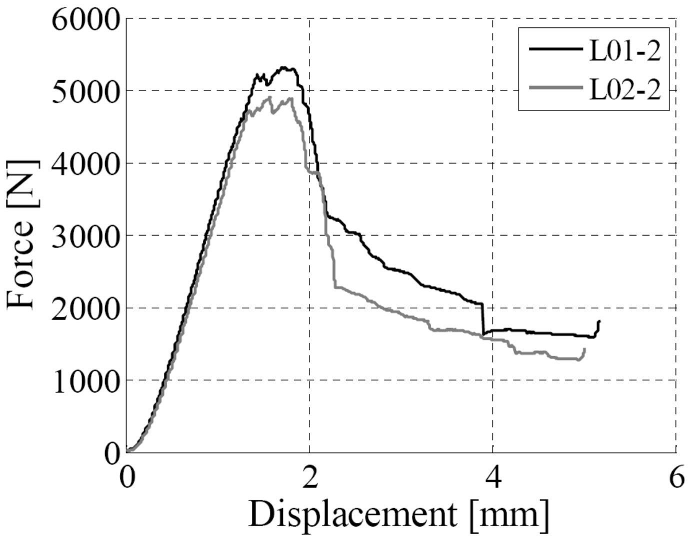
INTRALAMINAR FRACTURE ENERGY TESTS

- Compact Compression (CC):









TEST RESULTS SUMMARY. IMPROVEMENTS

Summary: elastic properties and strengths

Property		Value	Comparison vs G0926 Hexcel Composites (AIMS 05-04-009)
E_{11T} ; (E_{22T})	[GPa]		+ 6 %
E_{11C} ; (E_{22C})	[GPa]		≈
G_{12}	[GPa]		- 15 %
ν_{12}			+ 31.3 %
X_T	[MPa]		+ 30 %
X_C	[MPa]		+ 12%
S_L	[MPa]		- 20 %

TEST RESULTS SUMMARY. IMPROVEMENTS

Summary: interlaminar fracture toughness

Property	Value	G0926	Comparison
G_{IC} [J/m²]			↓
$G_{MM\ 25\%}$ [J/m²]			↓
$G_{MM\ 50\%}$ [J/m²]			↓
$G_{MM\ 75\%}$ [J/m²]			↓
G_{IIC} [J/m²]			↓

Similar values to a UD tape

Not so good interlaminar fracture toughness as current materials

TEST RESULTS SUMMARY. IMPROVEMENTS

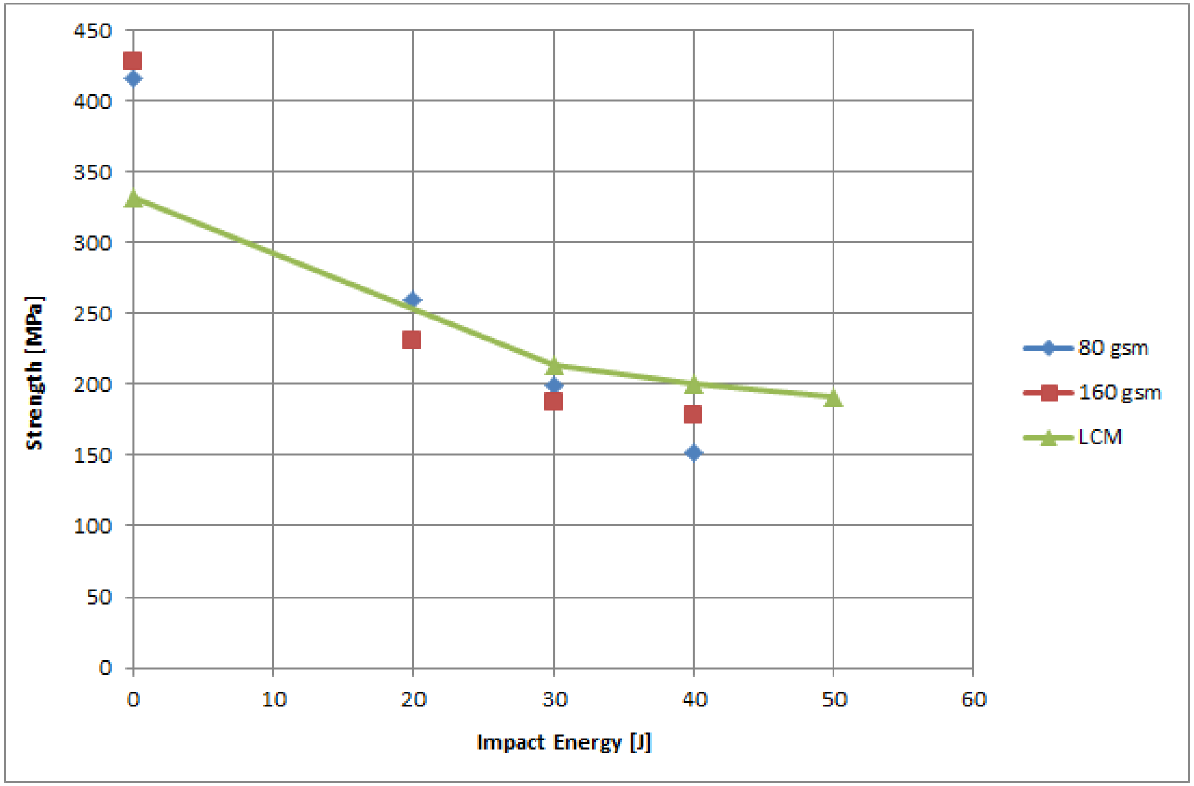
Summary: interlaminar fracture toughness

Property	Value	G0926	Comparison
G_{IC} [J/m²]			↑
$G_{MM\ 25\%}$ [J/m²]			↑
$G_{MM\ 50\%}$ [J/m²]			↑
$G_{MM\ 75\%}$ [J/m²]			↑
G_{IIC} [J/m²]			↓

Solution to interlaminar lower fracture toughness:

Thermoplastic veil applied to each TeXtreme 80 gsm ply

CAI TEST RESULTS SUMMARY. IMPROVEMENTS



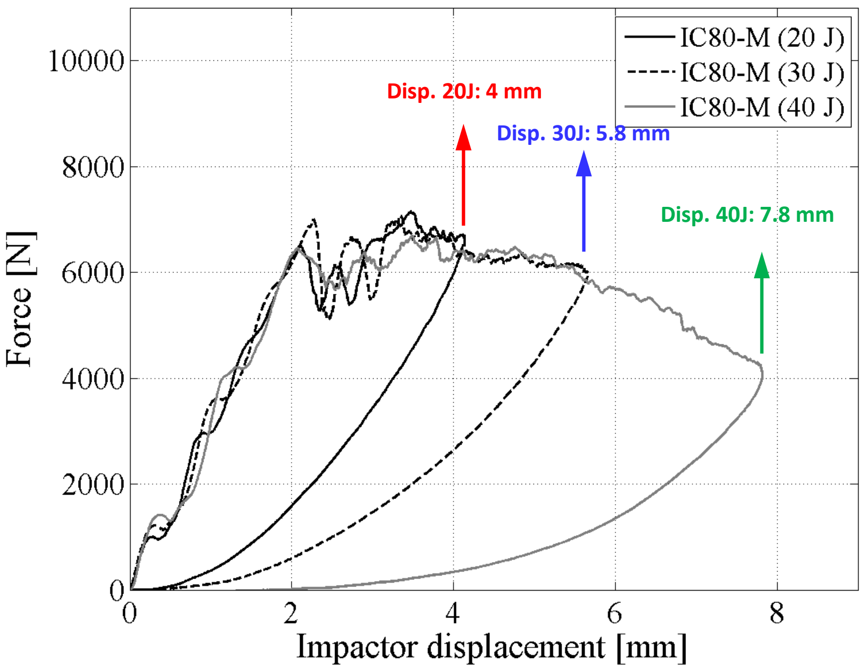
TeXtreme 80 gsm material has better no-damage (pristine) behaviour and similar damage tolerance values at low energy than currently used fabrics. These values will be increased if the thermoplastic binder is used. ONGOING WORK

Drop WeightTower Impact and Compression After Impact (CAI) Results

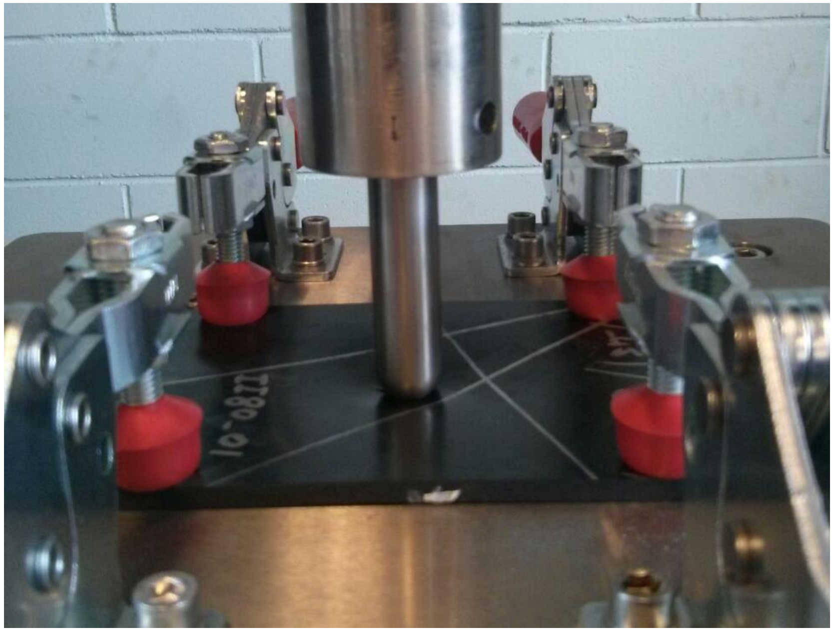
The big problem for an efficient model in a layup of 55 plies, is to consider the lowest number of interfaces for delamination that represents enough accuracy.

	Specimen No.	Max. disp.
1	II80_02	3.5
2	II80_03	2.8
3	II80_04	2
4	II80_05	4
5	II80_06	4
6	II80_07	5.8
7	II80_08	5.8
8	II80_09	7.8
9	II80_10	7.8
10	II80_01	8.5

Impact tests



Indentation tests



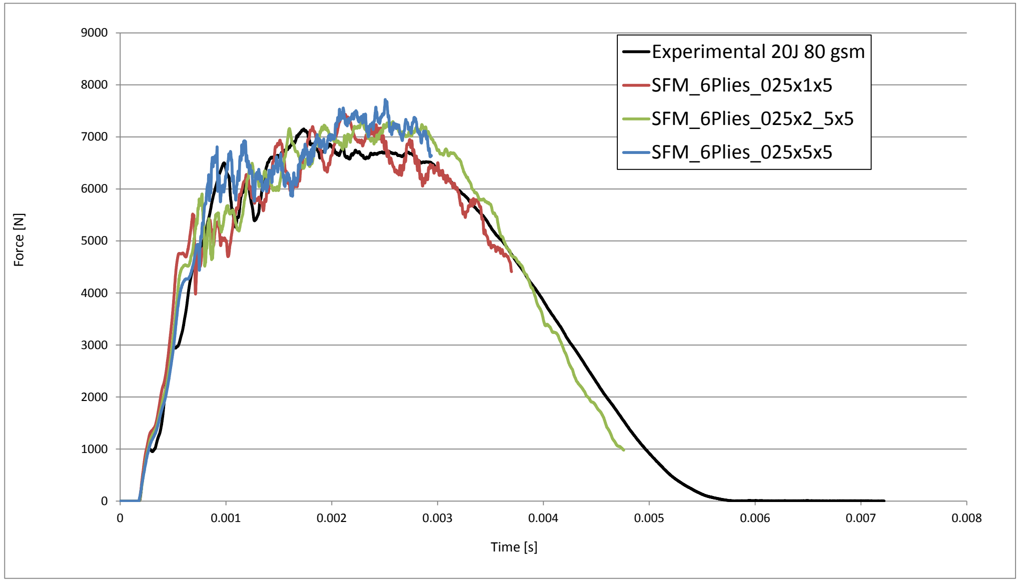
Simulation of Drop Weight Tower

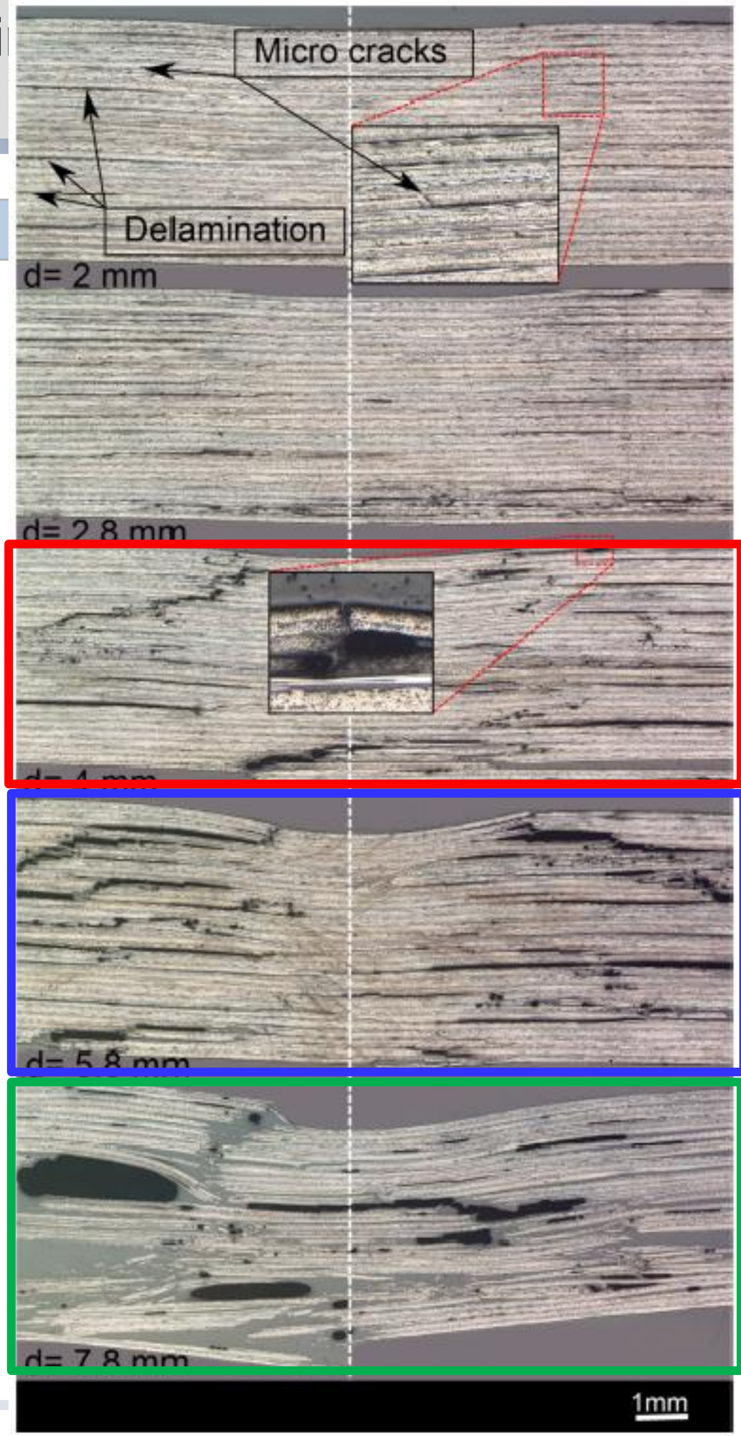
Consideration of sublaminates:

SEM inspections from indented specimens

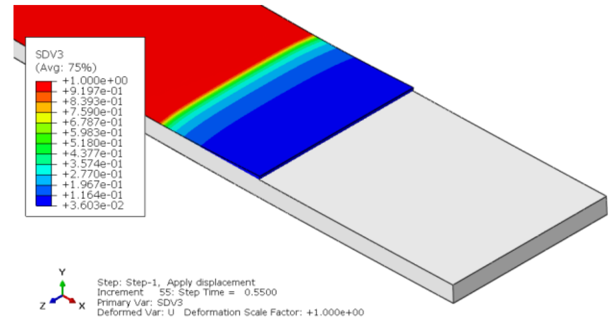
LOCALIZED NUMBER OF DELAMINATIONS. HOW MANY WE SHOULD CONSIDER??

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





Simulation of Drop Weight Tower



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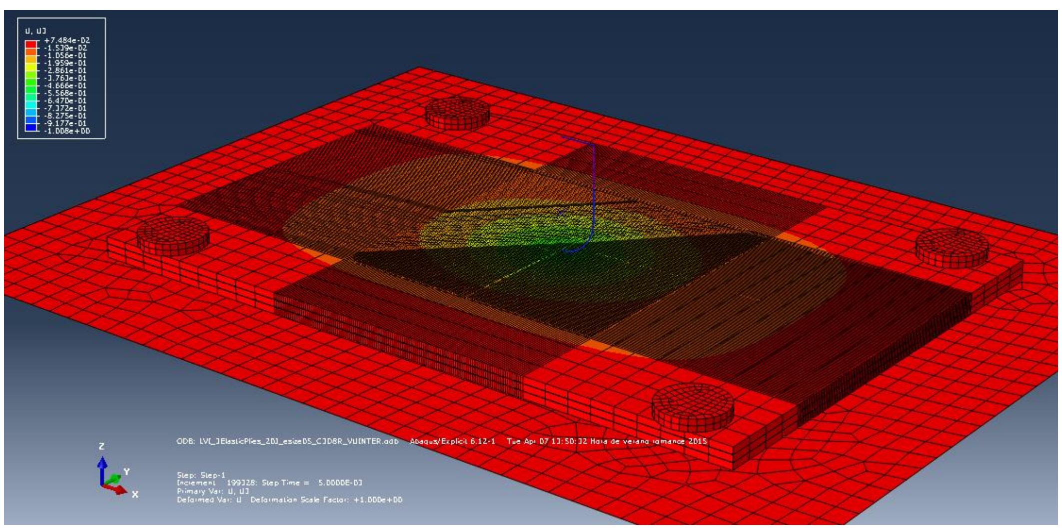

Shell + SFM model perfectly capture delamination initiation and propagation in Mode I, II and MMB

VUMAT suborutine 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