Technical services

2019

AMADE

ANALYSIS AND ADVANCED MATERIALS
FOR STRUCTURAL DESIGN

Universitat de Girona

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Lab Services

Simulation Services

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Lab Services

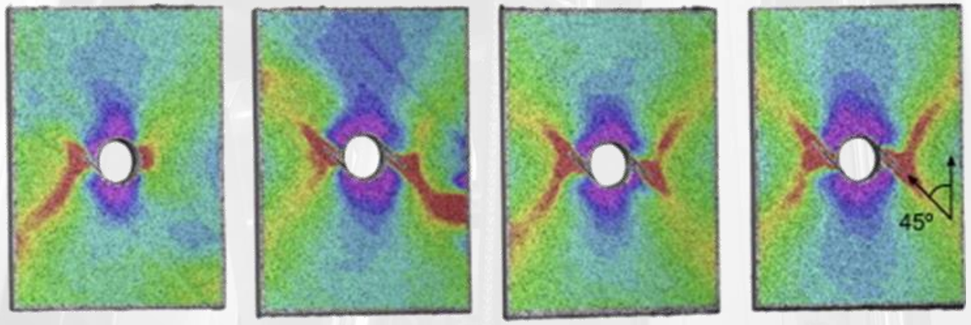
Testing capabilities

The mechanical testing lab is equipped to perform a wide variety of tests of coupons and small components, under static or fatigue loads, in different environmental conditions.

Load range	**50 N** to **300 kN**
Test temperature	**-55 °C** to **240 °C**
Test humidity	**10%** to **95%**
Test frequency	up to **20 Hz**

Lab equipment

- Universal testing machines,
  hydraulic (3x) and electromechanical (4x)
- Temperature and humidity testing chambers,
  for testing under controlled temperature and humidity conditions
- Drop weight testing tower,
  for low velocity impact tests
- Conditioning chambers and furnaces,
  controlled temperature and humidity
- Digital Image Correlation (DIC),
  contactless strain and displacement measurement
- Measurement equipment:
  - Long-distance travelling microscope for crack length monitoring
  - Strain gauge monitoring
  - Axial, biaxial, shear and COD extensometers
  - etc.



Vertical strains during cracking on a CFRP open hole laminate, measured by means of DIC

Accredited tests

AMADE is currently holding ISO 9001 certification for its quality management system and its mechanical testing lab is ISO 17025 and Nadcap accredited.

The standard ISO 17025 is the guidebook for the mechanical testing laboratory management.

ENAC ENSAYOS Nº 1015/LE1997

Nadcap NON-METALLIC MATERIALS TESTING

TÜVRheinland CERTIFIED
Management System ISO 9001:2008
www.tuv.com ID 9105057916

Nadcap accredited tests

Room temperature	Tensile
	In-plane shear
	Interlaminar shear
	Single lap shear
	Double lap shear
	Bending
Any temperature	DCB - G_{IC}
	ENF - G_{IIC}
	Flatwise tensile

ISO 17025 accredited tests

Room temperature	Tensile test	ASTM D3039M EN 2561
-55 °C to 120 °C	DCB - G_{IC}	ISO 15024 ISO 25217 AITM 1-0053 AITM 1-0005
	ENF - G_{IIC}	AITM 1-0006 EN 6034
	C-ELS - G_{IIC}	ISO 15114
	Mixed mode	ASTM D6671M

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Mechanical characterization tests

Composite materials

Tensile
- Tensile strength
- Young's modulus
- Poisson's ratio

ASTM D3039M | EN 2561
ASTM D638 | ISO 527-1 (Plastics)

Compression
- Compressive strength
- Young's modulus
- Poisson's ratio

prEN 2850B | ASTM D695 | ASTM D6641M
ISO604 | ASTMD695 (Plastics)

In-plane shear ±45°
- Shear strength
- Shear modulus

ASTM D3518M | AITM 1-0002 | EN 6031

Interlaminar shear (ILSS)
- Shear strength

EN 2563 | ASTM D2344M | ISO 14130

V-notched shear - Iosipescu
- Shear strength
- Shear modulus

ASTM D5379M

Bending
- Flexural strength
- Flexural modulus

EN 2562 | ISO 14125 | ASTM C393
ASTM D790 (Plastics)

Low velocity impact
- Absorbed energy
- Delaminated area
- Indentation depth

ASTM D7136M

Compression after impact
- CAI strength

ASTM D7137M | AITM 1-0010 | EN 6038

Quasi-static indentation
- Absorbed energy

ASTM D6264M

Open hole tensile
- Strength
- Notch factor

AITM 1-0007 | EN 6035 | ASTM D5676M

Open hole compression
- Strength
- Notch factor

AITM1-0008 | EN6036

Flatwise tensile
- Strength

AITM 1-0025

Mechanical characterization tests

Composite materials

Delamination: DCB - G_{IC}

Interlaminar fracture toughness (mode I)

AITM 1-0005 | EN 6033 | ISO15024 | ASTM D5528

Delamination: ENF - G_{IIC}

Interlaminar fracture toughness (mode II)

AITM 1-0006 | EN 6034 | ASTM D7905

Delamination: C-ELS - G_{IIC}

Interlaminar fracture toughness (mode II)

ISO 15114

Delamination: MMB - G_{C}

Interlaminar fracture toughness (mixed mode)

ASTM D6671M

Bonded joints

DCB - G_{IC}

Mode I fracture toughness

AITM 1-0053 | ISO25217

C-ELS - G_{IIC}

Mode II fracture toughness

AITM 1-0068 | *Internal procedure*

Single/double lap shear

Lap shear strength

AITM1-0019 | ASTM D5656, D1002, D3165

Mechanical characterization tests

State-of-the-art tests

Compact Tension (CT) and Compression (CC)
- Translaminar fracture toughness
- Translaminar cohesive law

Internal procedure

Double Edge Notch Tensile and Compression
- Translaminar fracture toughness
- Notched strength

Internal procedure

Translaminar fracture toughness

Fatigue tensile test
- Fatigue strength
- S-N curves

ASTM D3479

DCB - Mode I fatigue
- Crack onset curve
- Crack growth rate curve
- Fatigue threshold

ASTM D6115 | *Internal procedure*

ENF - Mode II fatigue
- Crack onset curve
- Crack growth rate curve
- Fatigue threshold

Internal procedure

MMB - Mixed mode fatigue
- Crack onset curve
- Crack growth rate curve
- Fatigue threshold

Internal procedure

Fatigue

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Mechanical characterization tests

State-of-the-art tests

DCB - J integral

- Mode I fracture toughness
- R curve

Internal procedure

ENF - J integral

- Mode II fracture toughness
- R curve

Internal procedure

MMB - J integral

- Mixed mode fracture toughness
- R curve

Internal procedure

Cohesive law measurement

- Mode I, II and mixed-mode cohesive laws

Internal procedure

Cohesive laws of bonded joints

Dissimilar DCB - G_{IC}

- Mode I fracture toughness

Internal procedure

Dissimilar MMB 100% - G_{IIC}

- Mode II fracture toughness

Internal procedure

Dissimilar MMB - G_C

- Mixed mode fracture toughness

Internal procedure

Dissimilar material joints

Mechanical characterization tests

On-going research

Tensile tests at high strain rates

Dynamic strength and Young's modulus

Interlaminar tests at high strain rates

Dynamic interlaminar fracture toughness G_{IC}

Draping characterization

Mechanical properties for the simulation of composites draping process

Other tests

We perform multitude of tailor-made tests for our customers.

Let us know your needs !

Other standards & tests

testlab.amade@udg.edu
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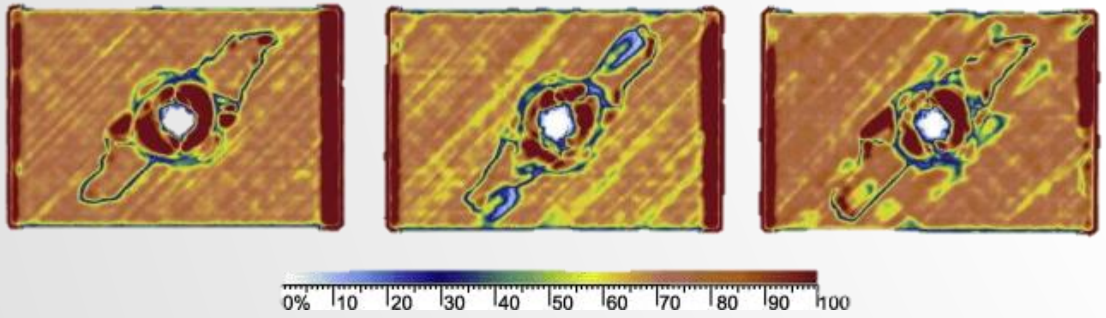
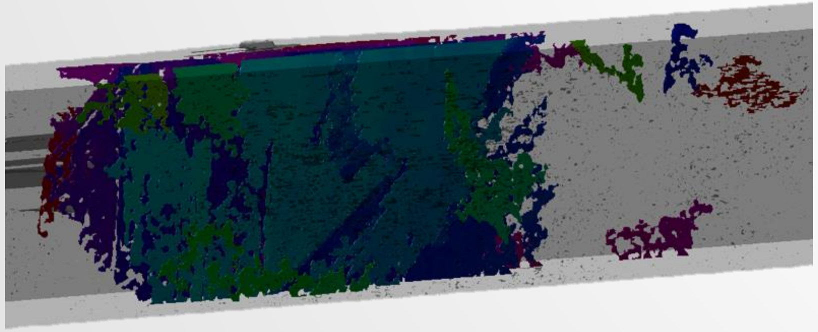
Non-destructive inspection

A, B and C-Scan,

for ultrasound inspection of internal material damage

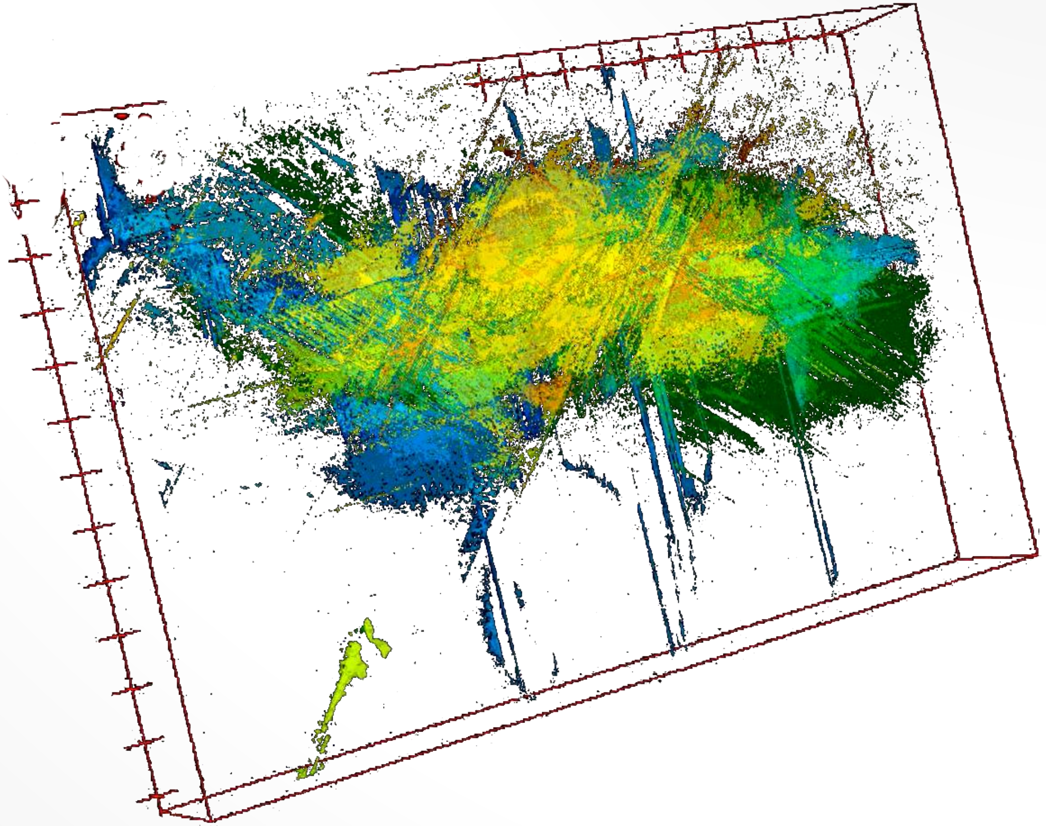


Impact damage (delaminations) in CFRP laminates



X-ray tomography,

3D X-ray images of the microstructure and internal damage



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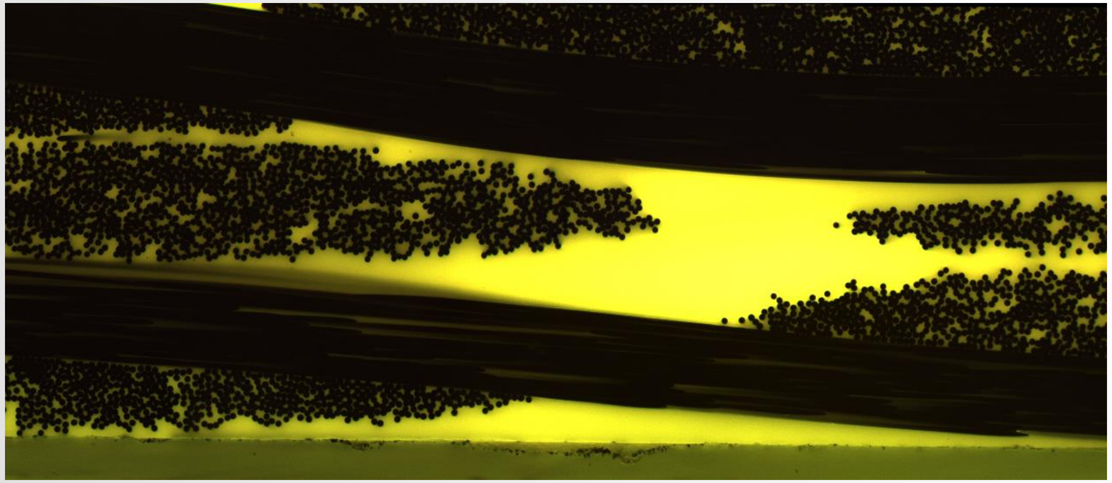
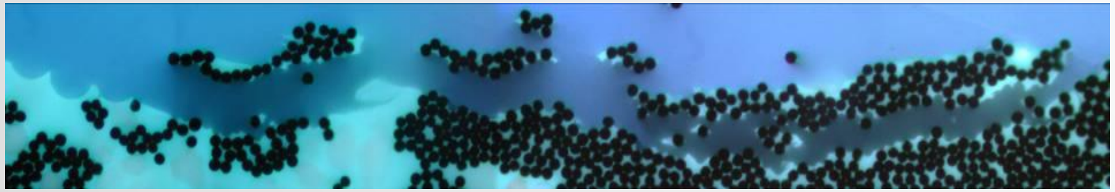
Microstructural inspection

Optical Fluorescence Microscopy,
detailed failure mode identification

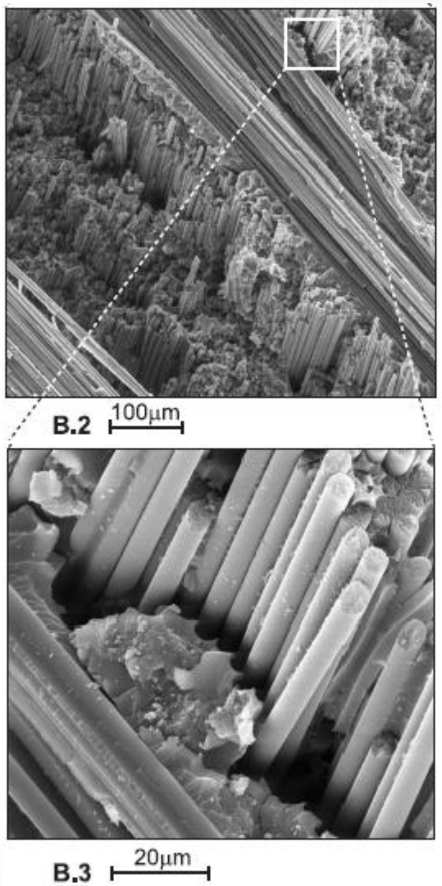


Cross section of a woven CFRP laminate



Cross section of a delaminated UD CFRP laminate

Scanning Electron Microscopy (SEM),
detailed failure mode identification



SEM image of a fractured cross ply CFRP laminate
L. Marín, PhD thesis, 2015

Thermomechanical lab

Differential Scanning Calorimetry (DSC)

Glass transition temperature	AITM 3-0002 | ASTM E1356 | ISO 11357-2
Melting / Crystallization	AITM 3-0027 | ASTM D3417, E793, E794 | ISO 11357-3
Extent of cure	AITM 3-0002, 3-0008 | ISO 11357-5
Thermal conductivity	ASTM E1952
Specific heat capacity	ASTM E1269 | ISO 11357-4

Thermogravimetric Analysis (TGA)

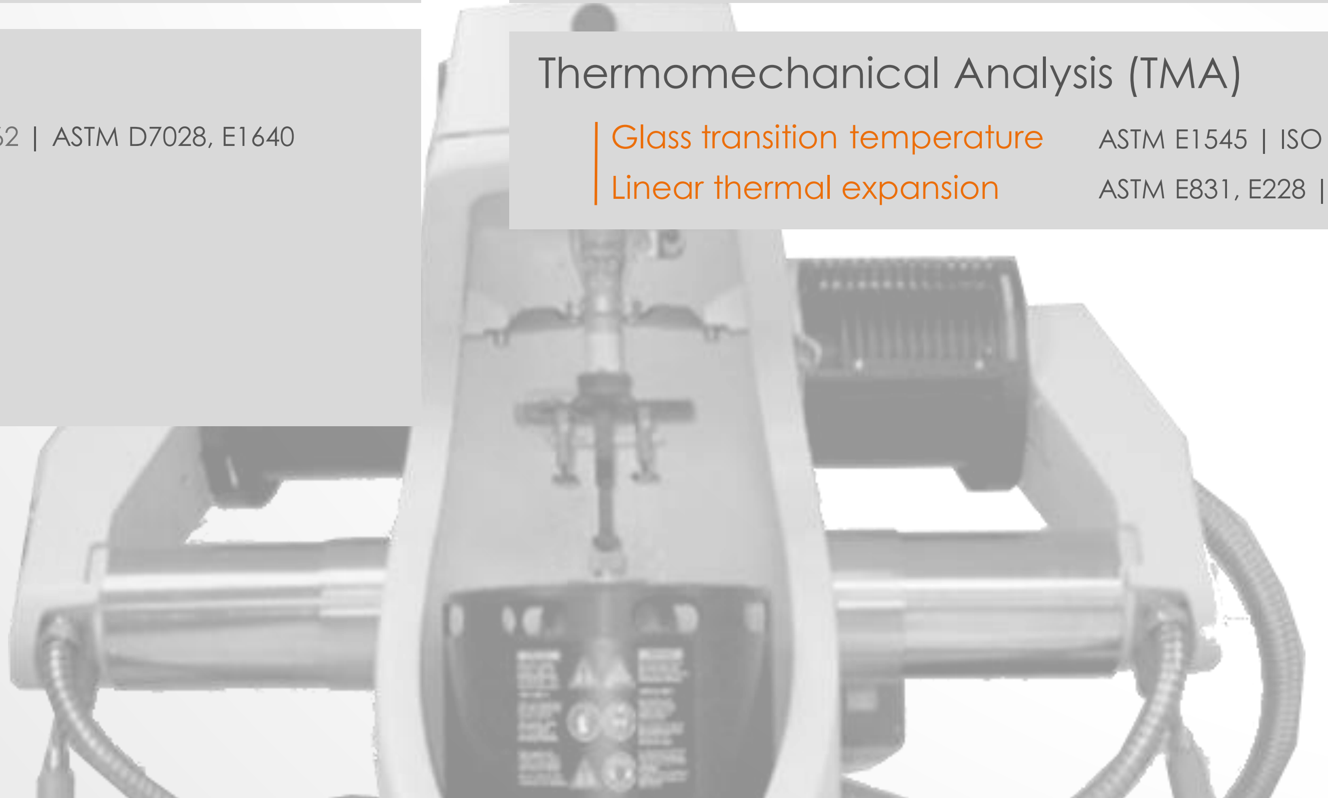
Degradation	ISO 11358
Loss on dry	ASTM E1868
Compositional analysis	ASTM E1131 | ISO 11358
Degradation kinetics	*Internal procedure*

Dynamic Mechanical Analysis (DMA)

Glass transition temperature	AITM 1-0003 | EN6062 | ASTM D7028, E1640
Dynamic mechanical props	
(in tension)	ASTM D5026-01
(three-point bending)	ASTM D5023-01
(dual cantilever beam)	ASTM D5418-01
Master curve (stiffness vs time)	*Internal procedure*

Thermomechanical Analysis (TMA)

Glass transition temperature	ASTM E1545 | ISO 11359-2
Linear thermal expansion	ASTM E831, E228 | ISO 11359-2



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Simulation Services

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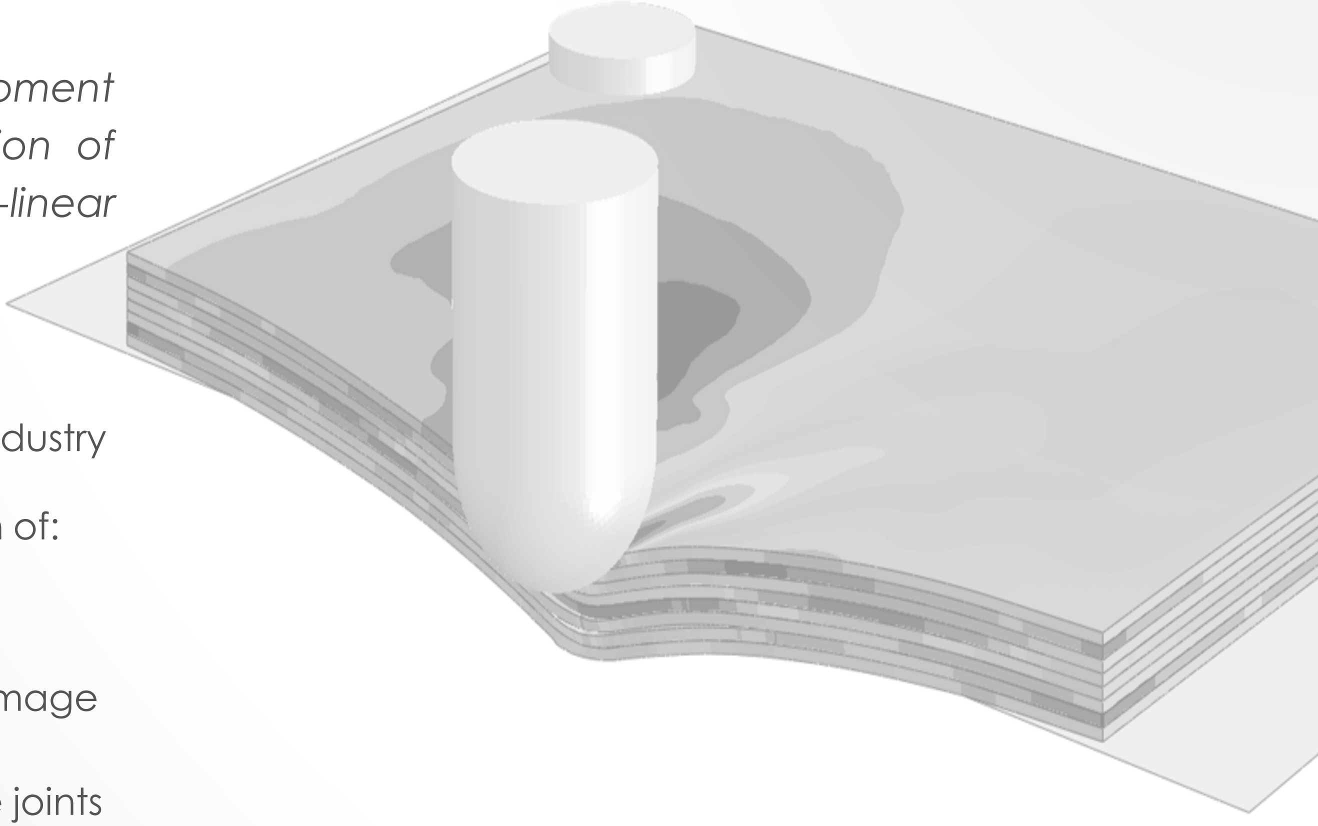
Simulation services

AMADE's research pursues the industry-oriented development of material constitutive models for the reliable simulation of composite materials, bonded joints and, in general, non-linear anisotropic materials. We offer the following services:



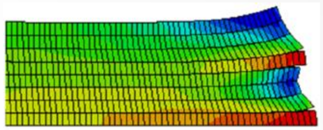
- Expert advising on the simulation of composite materials
- Guidelines for the use of advanced material models in industry
- Robust and reliable constitutive models for the simulation of:
  - Damage evolution in composite materials
    Intralaminar damage model
  - Static and fatigue delamination | Adhesive joints damage
    Interlaminar damage model: cohesive zone model
  - Impact events on composite materials and adhesive joints
    Intra and interlaminar damage models
- Development of tailor-made material models
- Customized training at companies facilities

Constitutive models

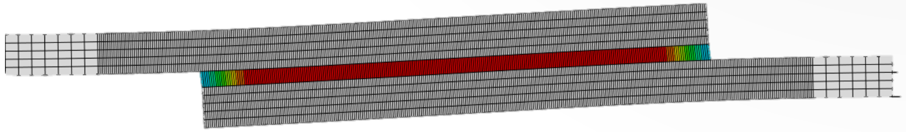
Cohesive zone model

Cohesive zone models allow the modeling of damage at predefined interfaces. They accurately reproduce the fracture process zone and can account for both damage initiation and propagation. The main features of AMADE's cohesive zone model are:

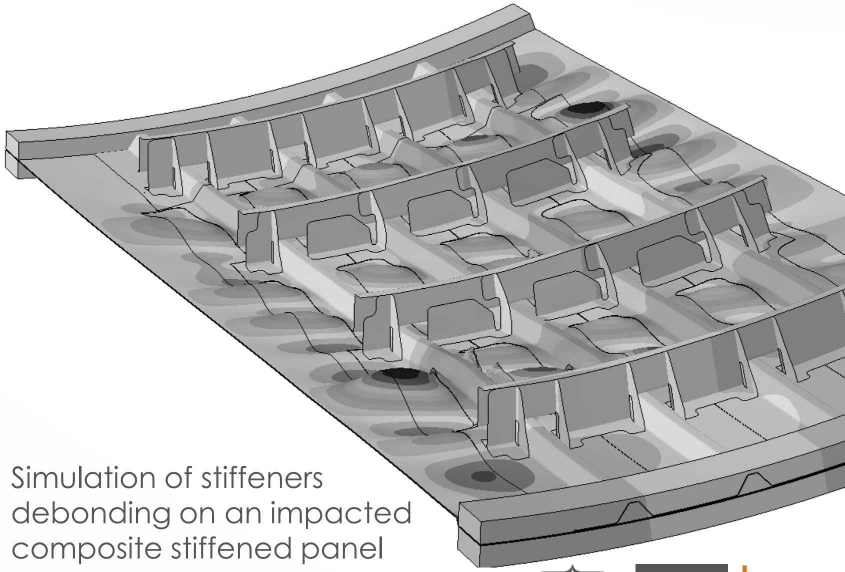
- Modelling of interlaminar damage: delamination and adhesive joints
- Static, fatigue and impact loads
- Consistent mixed-mode behavior
- Strategies to use with coarse meshes: reduced computational time
- Implemented and working on Abaqus Standard and Explicit
  User subroutines: UEL | UMAT | UINTER | VUMAT | VUINTER | VUINTERACTION
- Available to be implemented in other FE software
- Physically measurable material properties



Prediction of free-edge delaminations on a CFRP laminate using cohesive elements



Simulation of a lap adhesive joint with cohesive elements



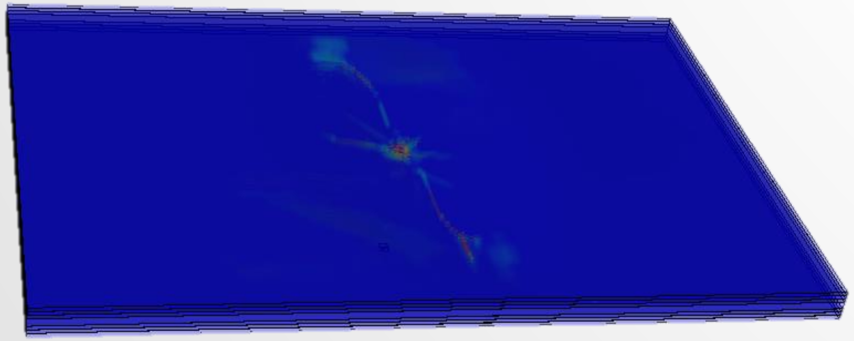
Simulation of stiffeners debonding on an impacted composite stiffened panel

Constitutive models

Intralaminar damage model

Thermodynamically consistent damage model for the simulation of progressive intralaminar damage mechanisms in composite materials. The main features of the model are:

- Modelling of intralaminar matrix and fiber progressive damage
- Damage activation functions based on LaRC failure criteria
- Objectivity of the model is ensured using Bažant's Crack Band Model
- Physically based degradation
  The tensile degradation of the fiber is described by two softening branches: linear (fiber bridging) and exponential (fiber pull-out)
- Large element size allowed
  by virtue of automatic strength reduction whilst keeping the fracture energy



Simulation of damage evolution in a Compression After Impact (CAI) test

Unidirectional composite laminates

- Available for shell and 3D solid finite elements
- Implemented on Abaqus Standard and Explicit
  User subroutines: UMAT | VUMAT
- Implemented on LS-DYNA
  Material model "MAT_262: Laminated Fracture Daimler Camanho"
- Available to be implemented in other FE software

Woven composite laminates

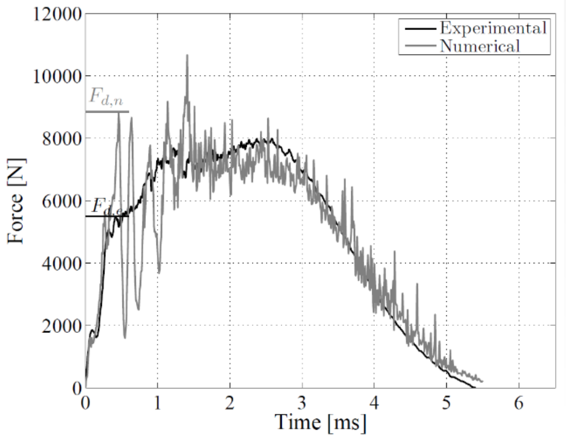
- Available for shell finite elements
- Implemented on Abaqus Explicit
  User subroutine: VUMAT
- Available to be implemented in other FE software

Constitutive models

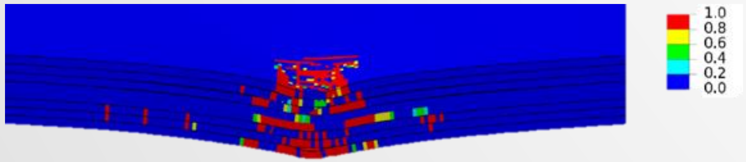
Simulation of impact events

Impact events are a design limitation in most structural elements. Combining AMADE's inter and interlaminar damage models implemented in explicit finite element codes, impact events in composite materials can be reliably simulated.

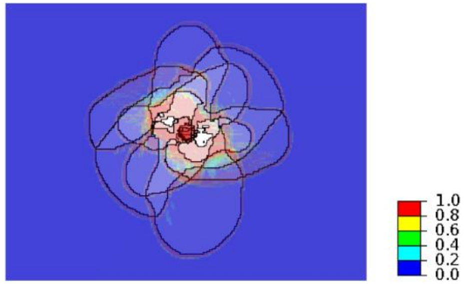
- Reliable simulation of impact-induced damage
  good correlation in both damage extension and load-displacement response
- Modelling strategies for improved computational time
- Implemented and working on Abaqus Explicit
  User subroutines: VUMAT | VUINTER | VUINTERACTION
- Available to be implemented in other FE software



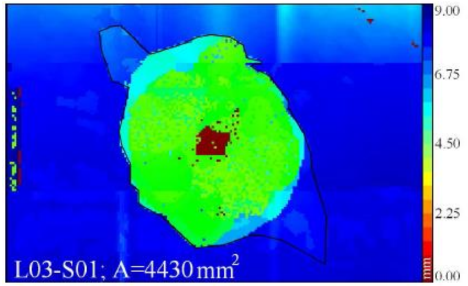
Load vs time during an impact event: experimental data and numerical prediction



Simulation, intralaminar damage



Simulation, delaminations



Experimental (C-Scan), delaminations

Material properties identification

The material models developed in AMADE rely on physically measurable material properties that can be obtained in our test lab, mostly by means of standardized tests.

Some guidelines on the required material properties and how to measure them are given >

Composite material elastic properties

E_{11}	Young's modulus, fiber direction	Tensile test, fiber direction
E_{22} E_{33}	Young's moduli, transverse direction	Tensile test, transverse direction
G_{12} G_{13}	In-plane shear moduli	In-plane shear ±45º | Iosipescu tests
G_{23}	Transverse shear modulus	*Resin shear modulus* | Iosipescu test
ν_{12} ν_{13}	In-plane Poisson's ratios	Tensile test
ν_{23}	Transverse Poisson's ratio	*Computed (transversal isotropy plane)*

Composite material strength properties

X_T	Tensile strength, fiber direction	Tensile test, fiber direction
X_C	Compressive strength, fiber direction	Compression test, fiber direction
Y_T	Tensile strength, transverse direction	Tensile test, transverse direction
Y_C	Compressive strength, transv. direction	Compression test, transverse direction
S_L	Shear strength	In-plane shear ±45º | Iosipescu tests

Material properties identification

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Cohesive model material properties

$\mathcal{G}_{Ic}$	Fracture toughness, mode I	DCB test
$\mathcal{G}_{IIc}$	Fracture toughness, mode II	ENF or C-ELS tests
$\mathcal{G}_{c}$	Fracture toughnesses, mixed mode	MMB test
σ_n^{max}	Interlaminar strength, mode I	Tensile test / ILTS test (bulk matrix / adhesive)
σ_f^{max}	Interlaminar strength, mode II	Interlaminar shear (ILSS) test (bulk matrix / adhesive)

Intralaminar model material properties

$\mathcal{G}_{XT}$	Fiber fracture toughness, tensile	Compact tension or Double edge notch tensile
$\mathcal{G}_{XC}$	Fiber fracture toughness, compression	Compact compr. or Double edge notch compr.
$\mathcal{G}_{YT}$	Matrix fracture toughness, tensile same as $\mathcal{G}_{Ic}$ from the cohesive model	DCB test
$\mathcal{G}_{YC}$	Matrix fracture toughness, compression	*Computed:* $\mathcal{G}_{YC} = \mathcal{G}_{SL} / \cos(53)$
$\mathcal{G}_{SL}$	Matrix fracture toughness, shear same as $\mathcal{G}_{IIc}$ from the cohesive model	ENF or C-ELS tests

Strength properties *(see previous page)*

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