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WEBINAR
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ASOCIACIÓN ESPAÑOLA DE MATERIALES COMPUESTOS

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JOSE ALFONSO ARTERO

Universidad Carlos III de Madrid

Laminados de carbono/epoxi reforzados con materiales derivados del grafeno. Aplicación a estructuras aeronáuticas sometidas a impacto.

19 de Febrero de 2020, 16 horas. (Madrid, GMT +2)

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Laminados de carbono/epoxi reforzados con materiales derivados del grafeno. Aplicación a estructuras aeronáuticas sometidas a impacto

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ÍNDICE

1. GRUPO DE COMPORTAMIENTO DINÁMICO DE ESTRUCTURAS LIGERAS
2. PROYECTO GRAPHENE FLAGSHIP
3. IMPACTOS ALTA VELOCIDAD
4. IMPACTOS BAJA VELOCIDAD
5. TRABAJOS FUTUROS
6. CONCLUSIONES

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1.

GRUPO DE COMPORTAMIENTO DINÁMICO DE ESTRUCTURAS LIGERAS

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1. GRUPO DE COMPORTAMIENTO DINÁMICO DE ESTRUCTURAS LIGERAS

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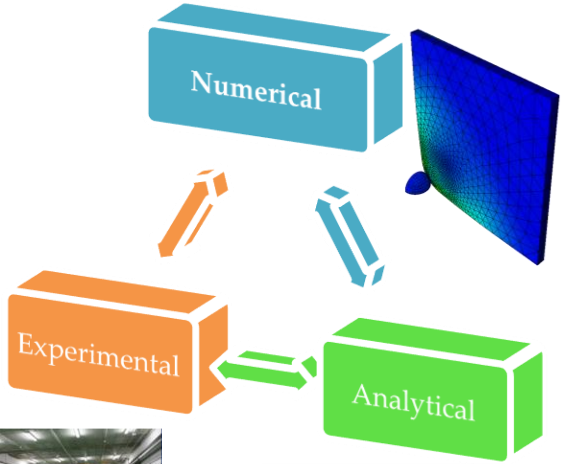
Estudiar y analizar el **comportamiento dinámico** de estructuras ligeras (**material compuesto**) para desarrollar protecciones eficiente y ligeras

1 CU, 3 PTU y 8 Doctorandos

Alta experiencia en la transferencia de teconología al sector industrial



$$\left(\frac{v_r}{v_i}\right)^2 = \frac{m_p}{\pi r^2 \mathrm{h} \cdot \rho_l + m_p} -$$

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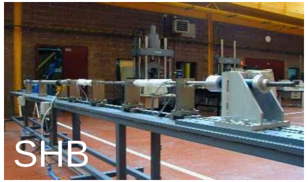
@Dynamics_uc3m

1. GRUPO DE COMPORTAMIENTO DINÁMICO DE ESTRUCTURAS LIGERAS

Máquinas universal de ensayos

- 6 máquinas servohidráulicas (10 a 1000 kN)
- Hornos y cámaras climáticas (-150 ºC a 1000 ºC)



Servohidráulica
Alta velocidad

Torre Caída

Comportamiento dinámico de materiales

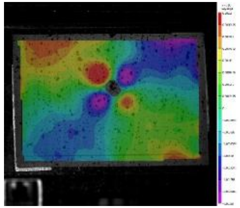
- 2 Barras Hopkinson (Tracción, compresión, flexión…)
- Servohidráulica Alta velocidad INSTRON (20 m/s)
- 3 Torres de caída (hasta 1800 J)
- 2 péndulos Charpy (hasta 300 J)

1. GRUPO DE COMPORTAMIENTO DINÁMICO DE ESTRUCTURAS LIGERAS

Cañones neumáticos

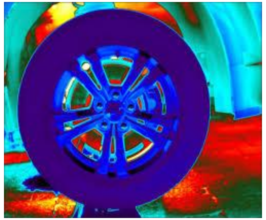
- Calibre 7.62 y 12.5 mm (He, Stargon)
- Calibre 25 mm (He)
- Calibre 60 mm (Aire, He)
- Calibre Cuadrado 50*50mm^2 & 120*120mm^2 (Aire)
- Calibre 200 mm (Aire)
- **Calibre 500 mm (Aire)**

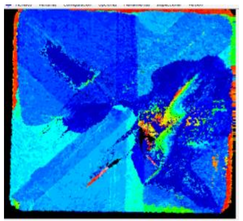
Alta velocidad



3D DIC

Termografía



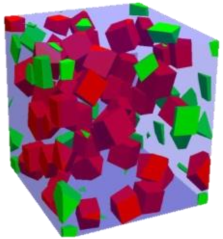


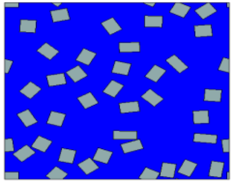
NDT TOF

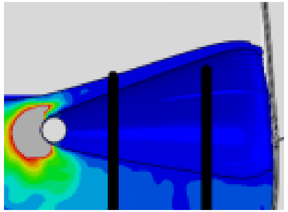
1. GRUPO DE COMPORTAMIENTO DINÁMICO DE ESTRUCTURAS LIGERAS

FEM

- ABAQUS/Explicit
- ABAQUS/Standard
- LS-DYNA







Artículos científicos

- >40 artículos en revistas de alta calidad (Q1-Q2)

Colaboraciones industriales

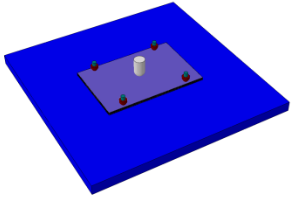
- AIRBUS Operations
- AIRBUS Military
- Industria de Turbopropulsores (ITP)
- AERNNOVA
- Dassault (France)

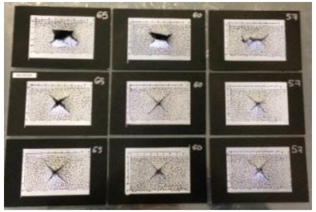
Proyectos competitivos

- 3 Nacionales, 3 regionales y 4 Europeos (H2020).

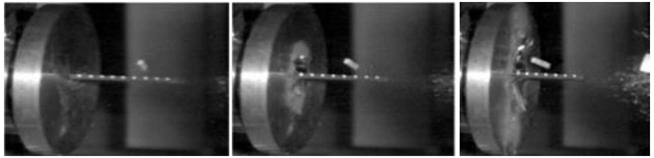
1. GRUPO DE COMPORTAMIENTO DINÁMICO DE ESTRUCTURAS LIGERAS

- **Impactos proyectiles metálicos de alta y baja velocidad contra laminados CFRP**

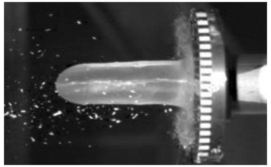




- **Impactos de alta velocidad de proyectiles de CFRP**

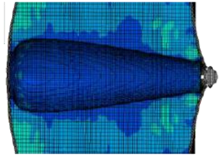


- **Impactos de “Soft projectiles” (Substitutivo pájaro e hielo)**

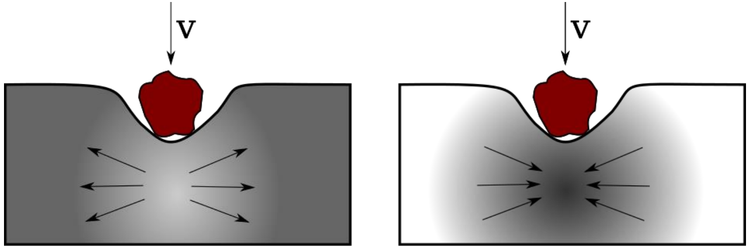


1. GRUPO DE COMPORTAMIENTO DINÁMICO DE ESTRUCTURAS LIGERAS

- **Interacción Fluido Estructura (HRAM)**



- **Desarollo de protecciones auxéticas**



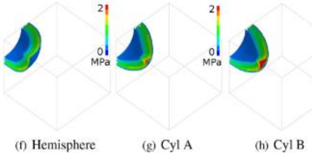
Comportamiento no auxético

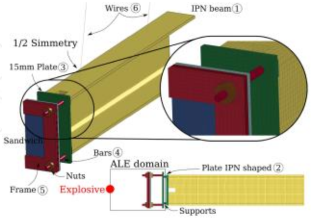
Comportamiento auxético

- **Caracterización dinámica de materiales (SPHB)**

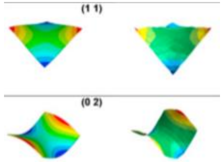
1. GRUPO DE COMPORTAMIENTO DINÁMICO DE ESTRUCTURAS LIGERAS

- **Estructuras de material compuesto sometido a explosiones**

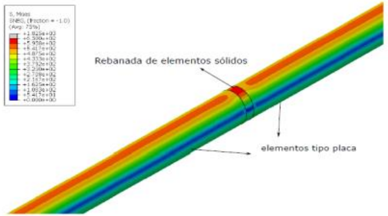


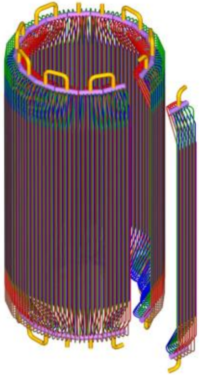


- **Monitorización de salud estructural en laminados**



- **Análisis termomecánico de receptores solares**

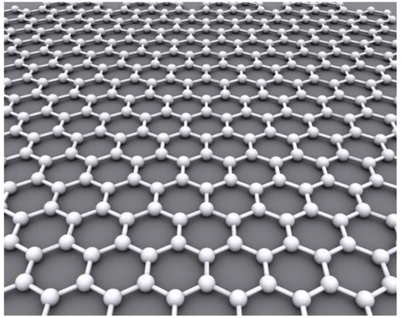


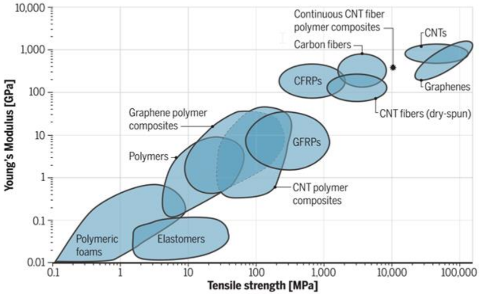


2.

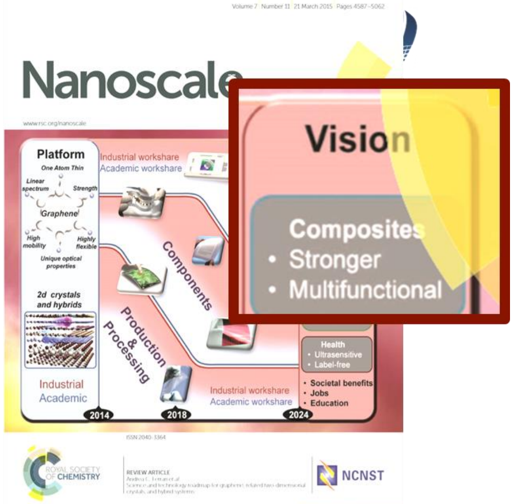
PROYECTO GRAPHENE FLAGSHIP

2. PROYECTO GRAPHENE FLAGSHIP





Ian A Kinlock, Science, 2018



GRAPHENE FLAGSHIP

2013-2023

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2. PROYECTO GRAPHENE FLAGSHIP

GRAPHENE FLAGSHIP

CORE 1 (2014-2017)

GRUPO ANTOLIN

AERnnova

AIRBUS

WP 15 Production

uc3m

GRAPHENE FLAGSHIP

Project ▾ Material ▾ Industry ▾ News ▾ Events ▾ Graphene Week 2019 ▾

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Graphene Flagship > News > The Leading Edge: Graphene Flagship leads the way in graphene composites for aerospace applications

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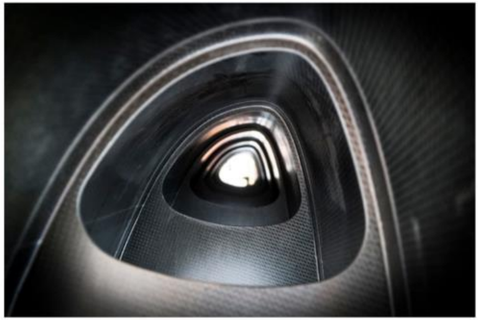
Newsletter
Graphene Flagship in the Media

The Leading Edge: Graphene Flagship leads the way in graphene composites for aerospace applications

By: Siân Fogden (Graphene Flagship)



Graphene Flagship partners Aernnova, Grupo Antolin-Ingenieria and Airbus produced a leading edge for an Airbus A350 horizontal tail plane using graphene. The leading edge is the part of the airplane wing or tail plane that first contacts the air. It must possess excellent mechanical and thermal properties. Graphene increases the mechanical properties of the leading edge, enabling to make it thinner, decreasing its weight, while maintaining its functions. This results in significant fuel saving, with consequent costs and emissions reduction over an aircraft lifetime.

AIRBUS

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An Airbus takes off or lands every 1.2 seconds!!

7,725
Commercial Aircraft backlog

400+
Operators

81k
Employees

€48bn
Annual revenue, restated IFRS 15

20,382
Aircraft sold

37,000+
Daily flights

12,657
Delivered

Airbus is an **international pioneer** in aerospace industry

WORLDWIDE LEADER in designing, manufacturing & delivering AEROSPACE PRODUCTS, services and solutions to customers on a global scale. A commercial aircraft manufacturer with two other Divisions - Defence & Space and Helicopters - largest aeronautics & space company in EUROPE

Participation in Graphene Flagship: Airbus Commercial - Spain

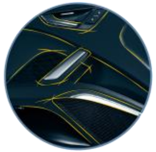
FOUNDED IN 1986	6 COUNTRIES
100% PRIVATE	14 LOCATIONS
+ $ 1 BILLION REV	+ 21 CUSTOMERS
+ 5500 EMPLOYEES	+ 18 MILLION ENGINEERING HOURS

A World-Class Supplier of Integrated Aerostructures, Components and Engineering Services through Four Business Segments

Overheads & Trunk Trim BU

- Modular headliner
- Substrate
- Sunvisors
- Lighted headliner
- Trunk Trim

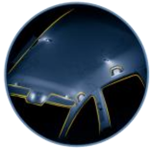
Number 1 Worldwide



Doors & Hard Trim BU

- Carrier solutions
- Door panels
- Window regulators
- Mechanisms

Multi-Technological Offer



Lighting BU

- Complete solutions
- Interior:
  Functional
  Mood lighting
- Exterior

Leading ambient lighting supplier

Cockpits & Consoles BU

- Cockpits
- Instrument panels
- Central console

We Improve Life on Board

Materials & Processes

Focused mainly on weight reduction to minimize CO_2 emissions and the use of green materials (recyclable/recycled)

Industrial flexibility

Innovative processes to produce different functions. Adapting to meet evolving market demands with minimum investment

Smart Interiors

Supporting our customers' brand strategy is key to end user experience and perceived quality based on customization

We are where the cars are manufactured

More than 150 facilities and 25 Technical Commercial Offices

30,646
Employees

106
Nationalities

Grupo Antolin is present in 9 of the top 10 best selling cars in the world

2. PROYECTO GRAPHENE FLAGSHIP

HORIZON 2020

GRAPHENE FLAGSHIP

CORE 2 (2017-2020)

uc3m AIRBUS GRUPO ANTOLIN AERnnova

Fabricación Grafeno	Fabricación laminado	Ensayos caracterización e impacto	Producción
GRUPO ANTOLIN, uc3m	AERnnova	uc3m, AIRBUS	AIRBUS, GRUPO ANTOLIN, AERnnova

2. PROYECTO GRAPHENE FLAGSHIP

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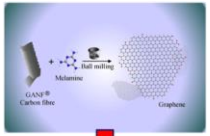
HORIZON 2020

GRAPHENE FLAGSHIP

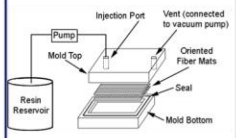
CORE 2 (2017-2020)

uc3m AIRBUS GRUPO ANTOLIN AERnnova

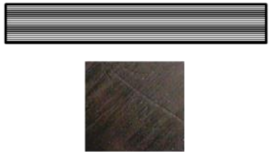
Producción grafeno



RTM



Composite con grafeno <2%

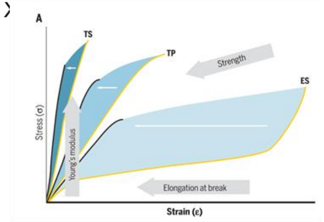


Acciones:

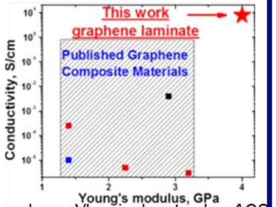
- Impactos baja velocidad laminado (Torre caída + CAI)
- Impactos alta velocidad (gelatin 160gr) sobre estructura simplificada.
- Impactos alta velocidad (gelatin 160gr) sobre estructura representativa
- Caracterización resina y laminado: Compresión, DCB, ILSS, SHPB…

2. PROYECTO GRAPHENE FLAGSHIP

Rigidez y resistencia: Grafeno X ≈ 10GPa vs FC
)

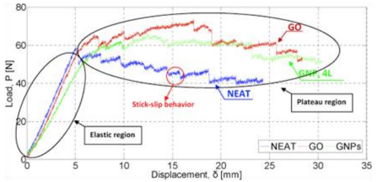


I. Kinloch, *Science* (2018)



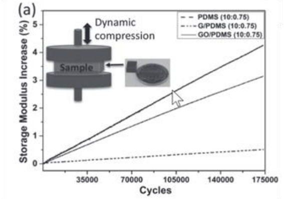
Ivan Vlassiouk et al., *ACS Appl. Mater. Interfaces* (2015)

G_{IC}: Mejoras del 50%



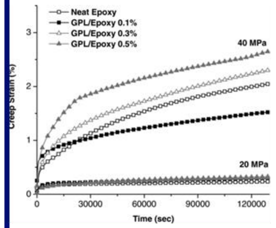
C Kostagiannakopoulou et al., *Compos Sci Technol* (2015)

Fatiga: Efecto de



L Cao et al., *Small* (2012)

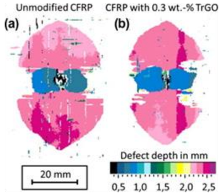
Fluencia:



A. Zandiatashbar et al., *Small*, (2012)

N Koratkar et al., *Appl. Phys. Lett.*, (2005)

Impacto: Se reduce el área delaminada

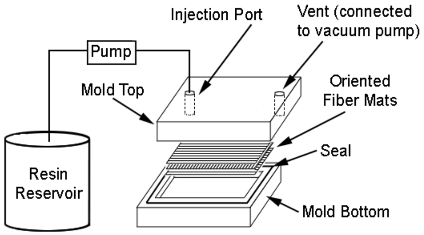


E. Mannov et al., *Compos Sci Technol* (2013)

2. PROYECTO GRAPHENE FLAGSHIP

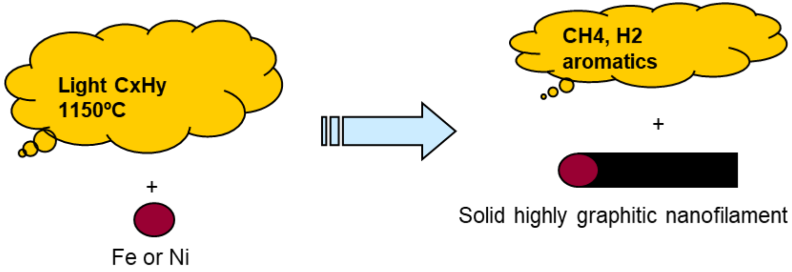
Proceso de producción nanofilamentos

Injetex fibres 5HS + Hexcel resin



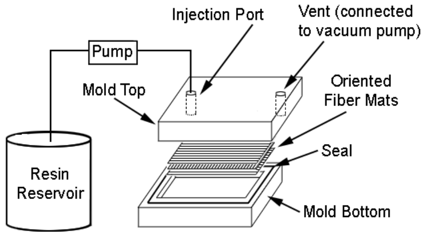
Resin Transfer Moduling

- Producción por CVD que comienza con catalísis metálica.
- Temperatura: ≅ 1150ºC

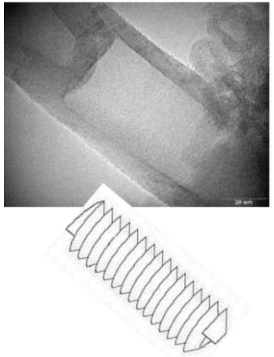


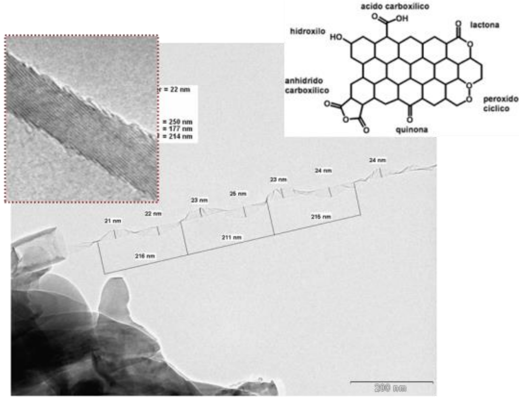
Proceso de producción nanofilamentos

Injetex fibres 5HS + Hexcel resin



Resin Transfer Moduling

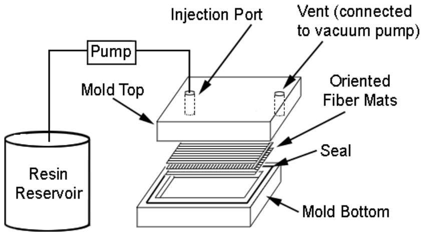




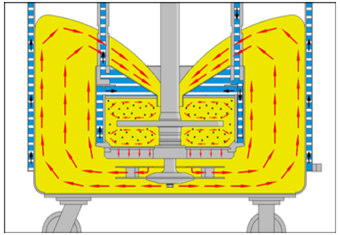
2. PROYECTO GRAPHENE FLAGSHIP

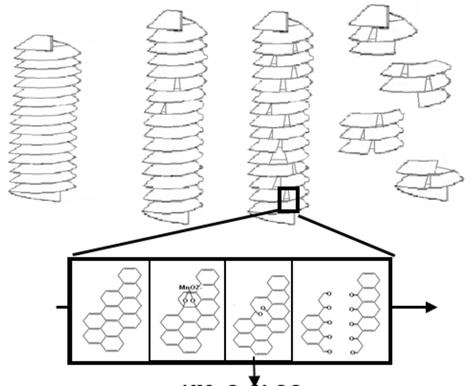
Proceso de producción nanofilamentos

Injetex fibres 5HS + Hexcel resin



Resin Transfer Moduling





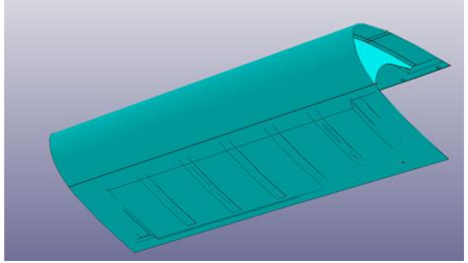
3.

IMPACTOS ALTA VELOCIDAD

3. IMPACTOS ALTA VELOCIDAD

Procedimiento de ensayo

60mm Cañón de aire

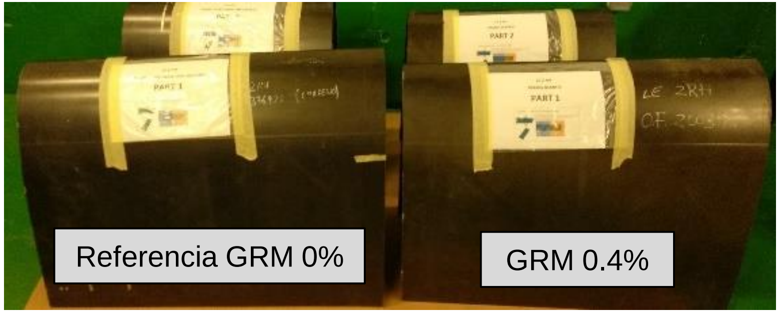


Cada borde de ataque se ha dividido en 2:
- Parte A para **impactos entre costillas**
- Parte B para **impactos en la costilla**

Substituto de pájaro (gelatina) 163g & esfera acero 30mm

Procedimiento de ensayo

60mm Cañón de aire



Cada borde de ataque se ha dividido en 2:

- Parte A para **impactos entre costillas**
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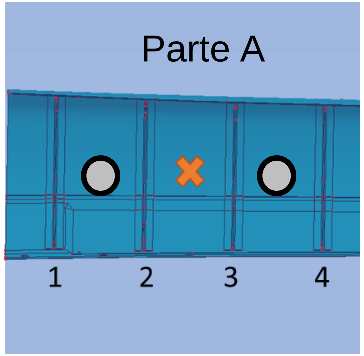
Substituto de pájaro (gelatina) 163g & esfera acero 30mm

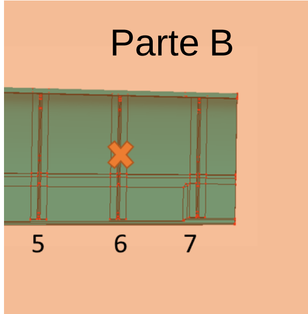
3. IMPACTOS ALTA VELOCIDAD

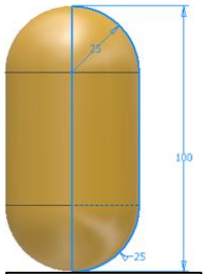


Impacto gelatina

Esfera acero

Impacto gelatina



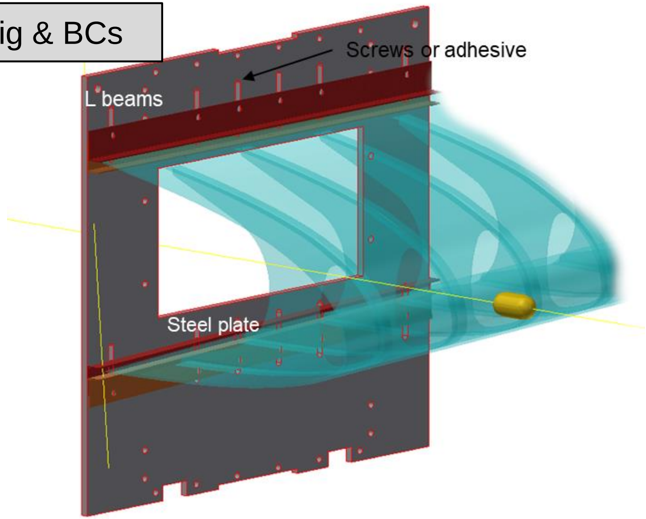


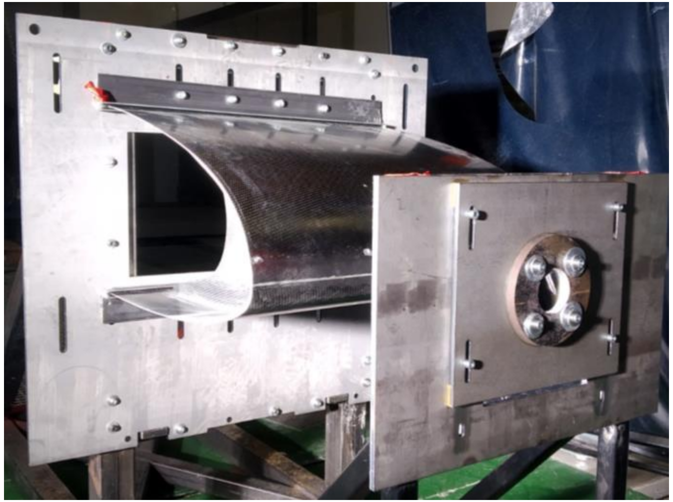
Gelatine 163g

Esfera acero 30mm

3. IMPACTOS ALTA VELOCIDAD

Rig & BCs

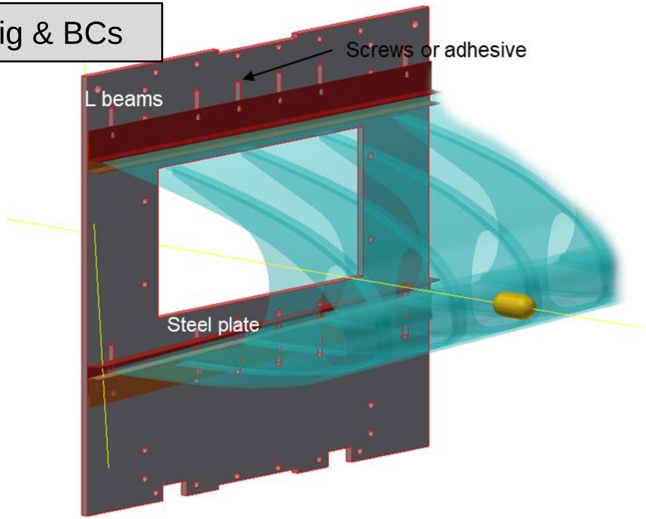


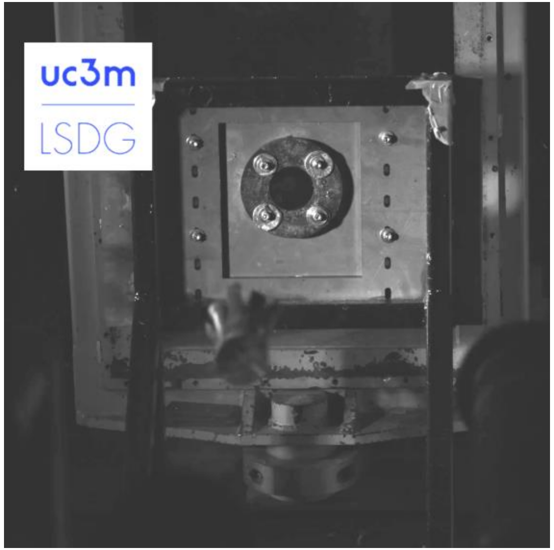


Velocidad impacto **180m/s**

3. IMPACTOS ALTA VELOCIDAD

Rig & BCs

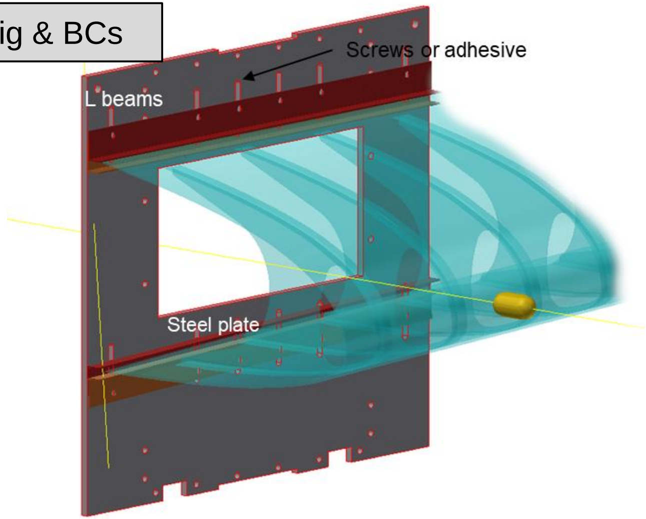




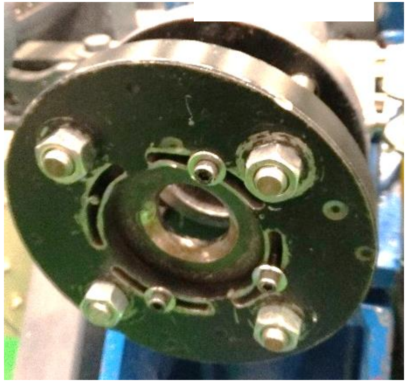
uc3m

3. IMPACTOS ALTA VELOCIDAD

Rig & BCs

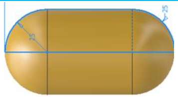


Esfera acero 30mm

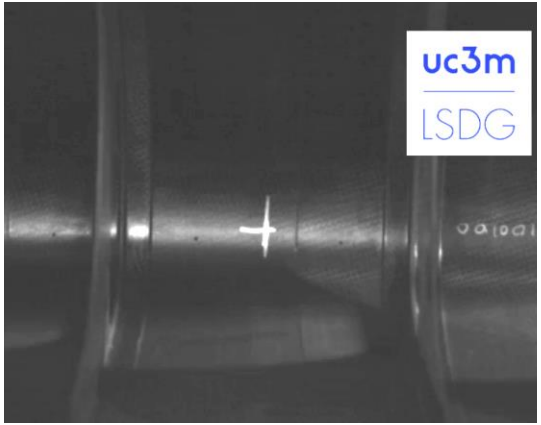


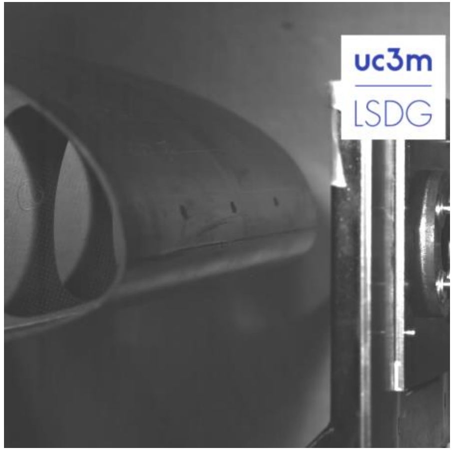
Para Sabot

3. IMPACTOS ALTA VELOCIDAD



- **GRM 0% Parte A**

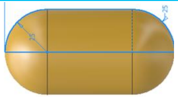


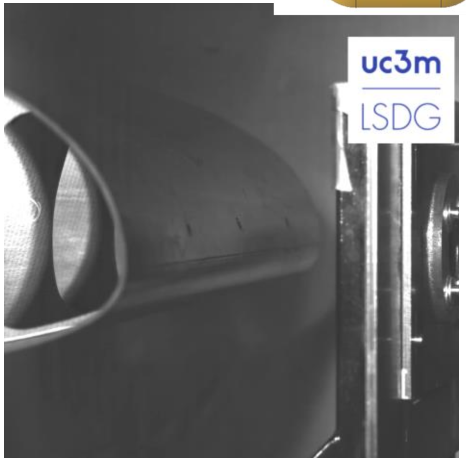


uc3m

3. IMPACTOS ALTA VELOCIDAD

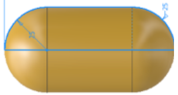
- **GRM 0.4% Parte A**

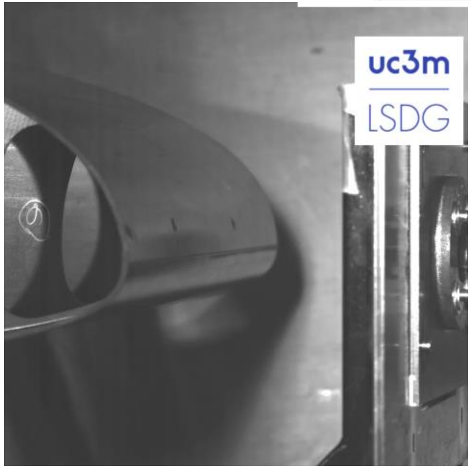




3. IMPACTOS ALTA VELOCIDAD

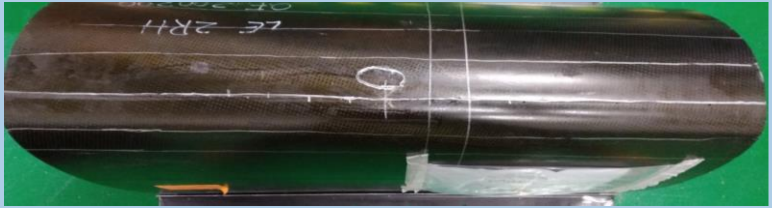
- **GRM 0.4% Parte B**



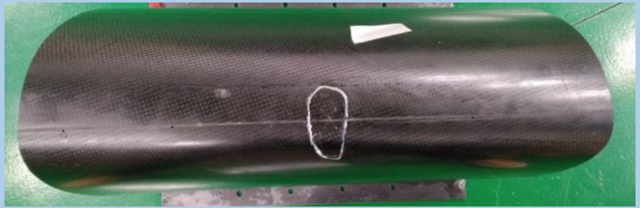


4. IMPACTOS ALTA VELOCIDAD

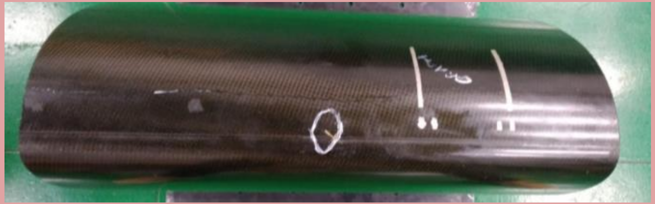
GRM 0% Parte A



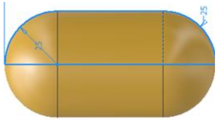
GRM 0% Parte B



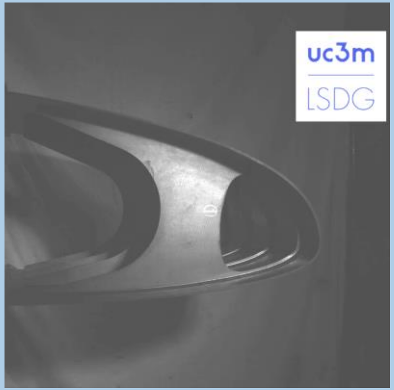
GRM 0.4% Parte A

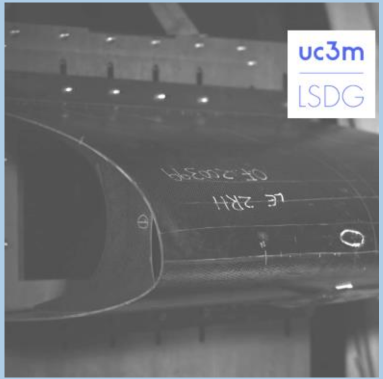


GRM 0.4% Parte B

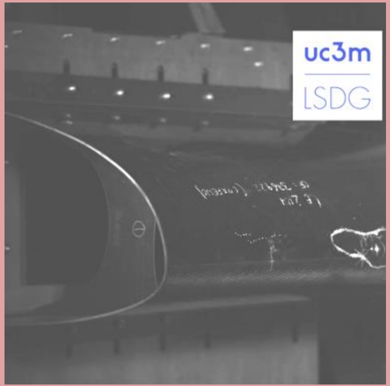


GRM 0% Parte A





GRM 0.4% Parte A



3. IMPACTOS ALTA VELOCIDAD

GRM 0% Parte A

E_{abs}=20.1%

GRM 0.4% Parte A

E_{abs}=21.6%

4.

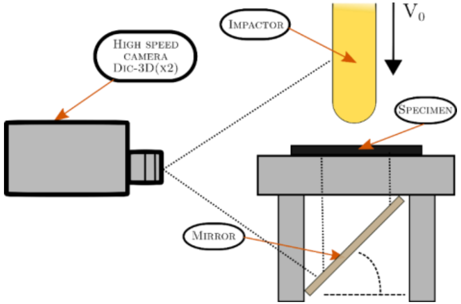
IMPACTOS BAJA VELOCIDAD

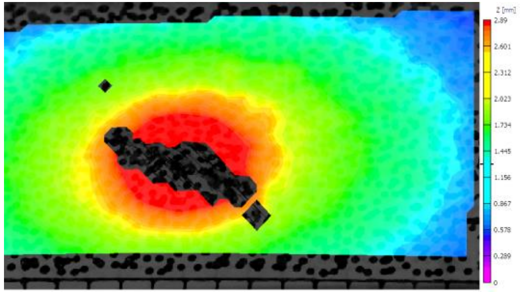
- **Torre de caída**

Instron-Ceast
Factovis 6875

ASTM D7136

150x100





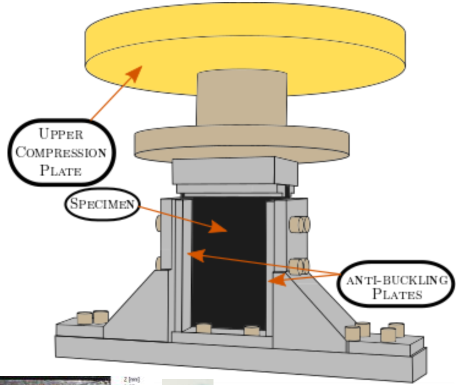
4. IMPACTOS BAJA VELOCIDAD

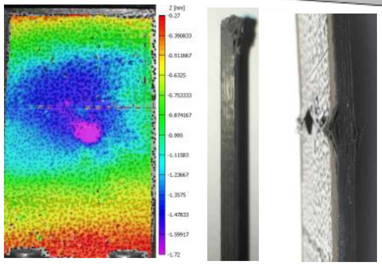
- **CAI**

Instron Ceast 8802

ASTM D7137

150x100





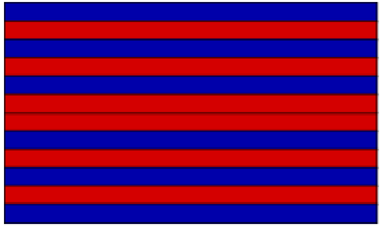
4. IMPACTOS BAJA VELOCIDAD

Decidir material

- Reference CFRP
- CFRP + GRMCORE1 (GANF)
- CFRP + GRMCORE2 (GAtam)

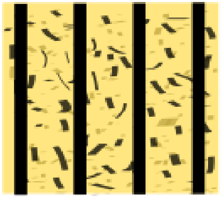
Injetex fibres 5HS + Hexcel resin

$[((\pm45)/(0/90))_3]_S$

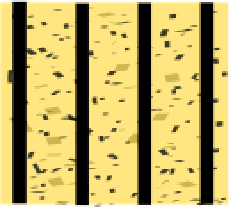


Measured property	Unit	GANF	GAtam	GANFg
FIBRE DIAMETER (TEM)	nm	20 - 80	20-80	20-80
PURITY (TGA)	%	>85	>80	>99
APPARENT DENSITY	g/cc	~ 0.06	~ 0.08	~ 0.08
SPECIFIC SURFACE AREA (BET N_2)	m^2/g	100-170	70-140	80-120
GRAPHITIZATION DEGREE (XRD)	%	≈70	≈60	≈90
ELECTRICAL RESISTIVITY	Ω·m	$1 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-4}$

GANF

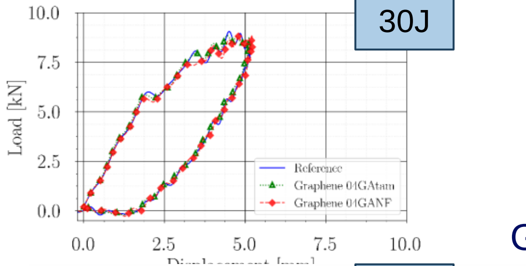


GAtam

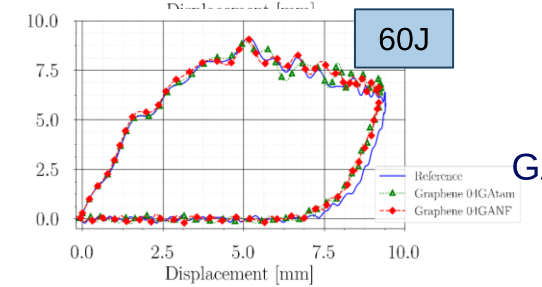


4. IMPACTOS BAJA VELOCIDAD

30J

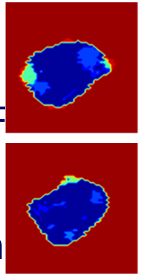


60J



30J

GANF



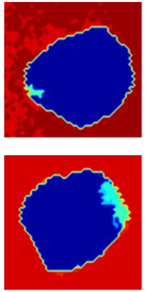
598

GAtam

552

60J

GANF

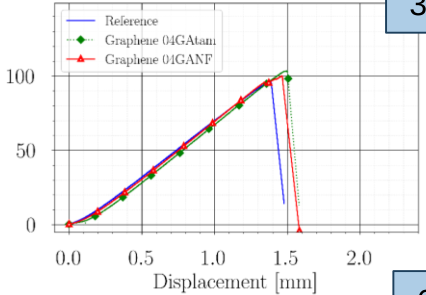


860

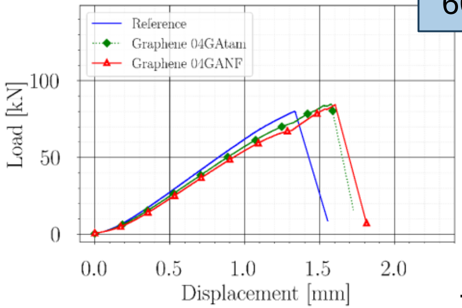
GAtam

866

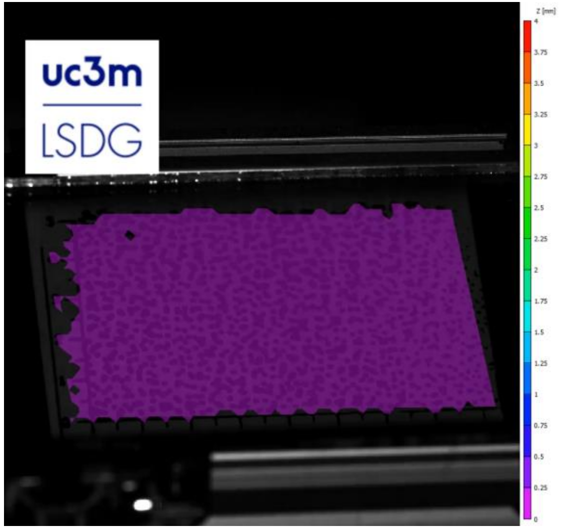
30J

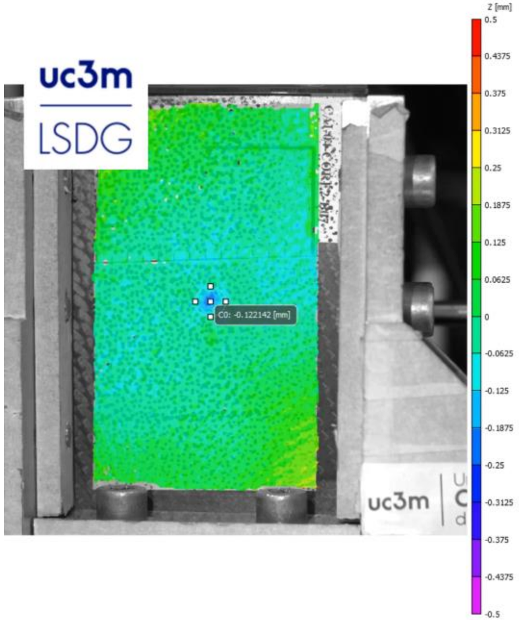


60J

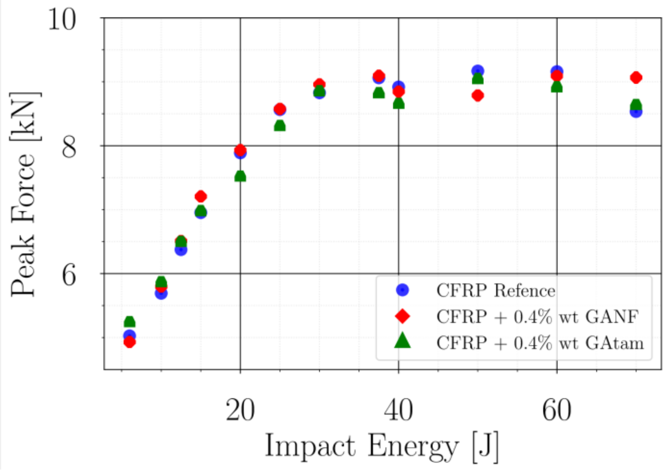


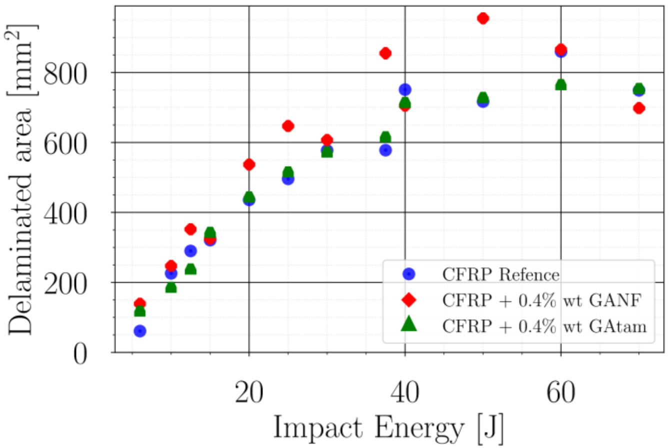
- **CAI**


uc3m
LSDG
Z [mm]
4
3.75
3.5
3.25
3
2.75
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0

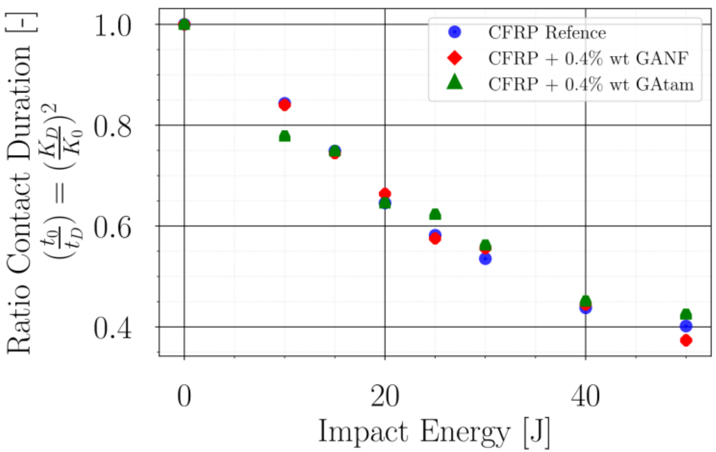

uc3m
LSDG
C0: -0.122142 [mm]
Z [mm]
0.5
0.4375
0.375
0.3125
0.25
0.1875
0.125
0.0625
0
-0.0625
-0.125
-0.1875
-0.25
-0.3125
-0.375
-0.4375
-0.5

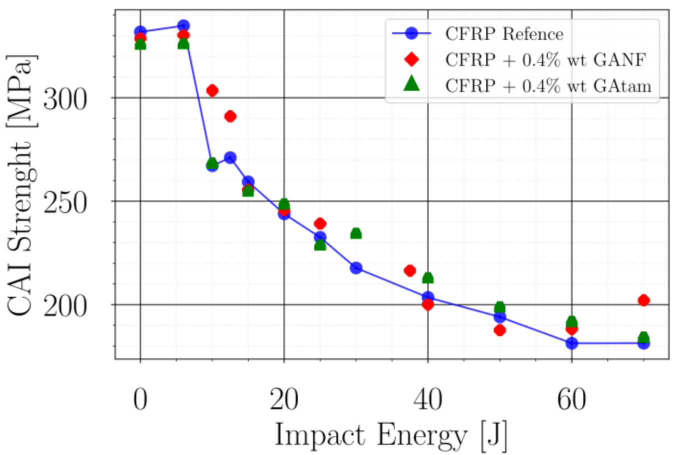
4. IMPACTOS BAJA VELOCIDAD





4. IMPACTOS BAJA VELOCIDAD





CFRP + GRMCORE2 (GAtam) es seleccionado con un 2.3% de mejora en CAI

4. IMPACTOS BAJA VELOCIDAD

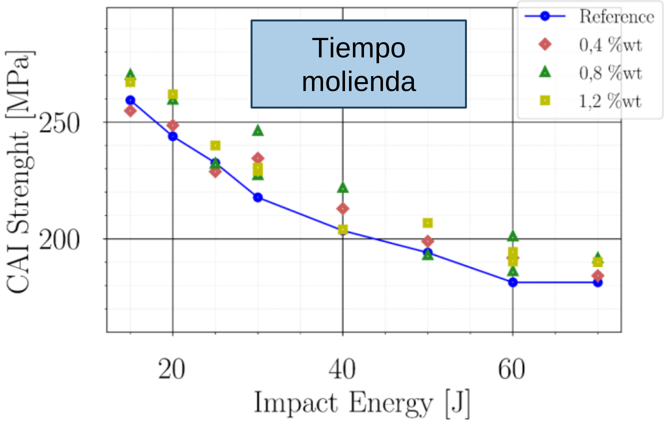
Decidir material

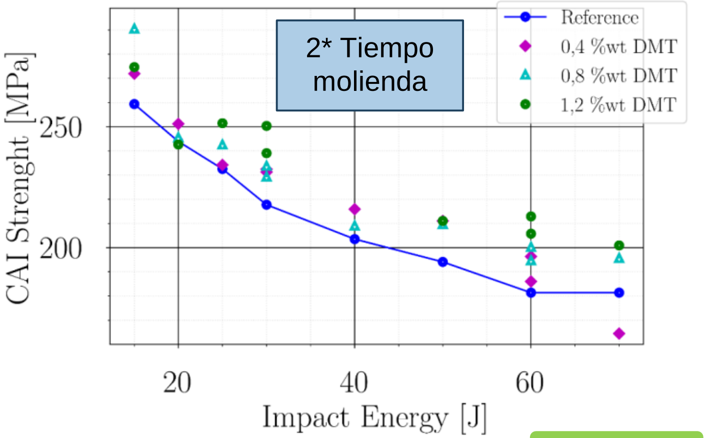
- Reference CFRP
- CFRP + GRMCORE1 (GANF)
- CFRP + GRMCORE2 (GAtam)

Decidir %GRM y tiempo de molienda

CFRP + 0,4%GRMCORE2 (GAtam)	CFRP + 0,4%GRMCORE2 (GAtam)*2Milling
CFRP + 0,8%GRMCORE2 (GAtam)	CFRP + 0,8%GRMCORE2 (GAtam) *2Milling
CFRP + 1,2%GRMCORE2 (GAtam)	CFRP + 1,2%GRMCORE2 (GAtam) *2Milling

4. IMPACTOS BAJA VELOCIDAD





	Graphene 0,4% 1*TM	Graphene 0,8% 1*TM	Graphene 1,2% 1*TM	Graphene 0,4% 2*TM	Graphene 0,8% 2*TM	Graphene 1,2% 2*TM
Mejora media(%)	2.30	5.54	4.85	5.24	6.54	9.30

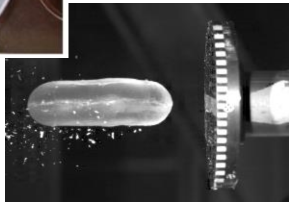
5.

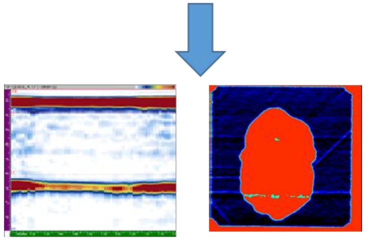
TRABAJOS FUTUROS

5. TRABAJOS FUTUROS

Procedimiento de ensayo: Placas planas

60mm Cañón de aire





Substituto de pájaro (gelatina) 163g & 81.5g

5 velocidades * 2 repeticiones

5. TRABAJOS FUTUROS

- **Caracterización estática**

Tracción, compresión y cortadura
ASTM D638-14, D695-15 y D5379-M98

Tenacidad a la fractura
ASTM D5045

- **Caracterización a alta velocidad de deformación**

Split Hopkinson Pressure bars

Probetas RTM6 para SPHB (Izq: Grafeno izq, Der: sin grafeno)

FIDAMC

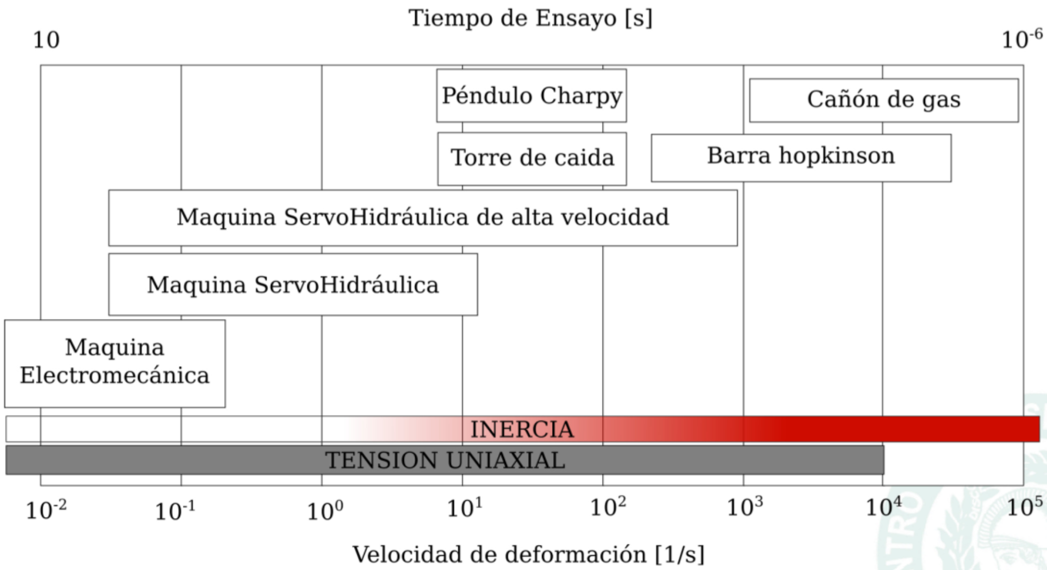
Placas de Resina neta y resina + Grafeno

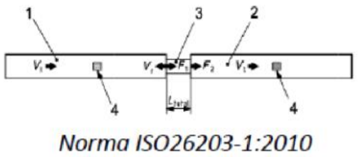
uc3m

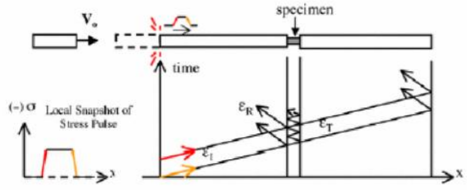
ASOCIACIÓN ESPAÑOLA DE MATERIALES COMPUESTOS

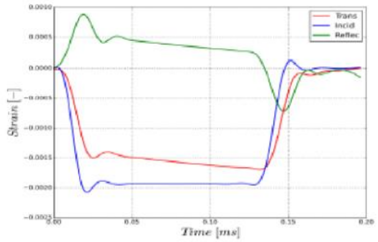
¿Por qué se usan 2 barras en el ensayo de Barra Hopkinson?

5. TRABAJOS FUTUROS









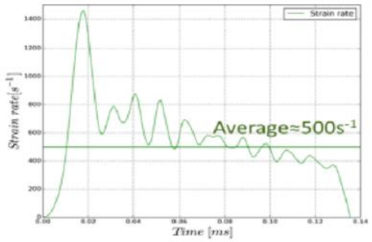


Figura: SHPB compresión

5. TRABAJOS FUTUROS

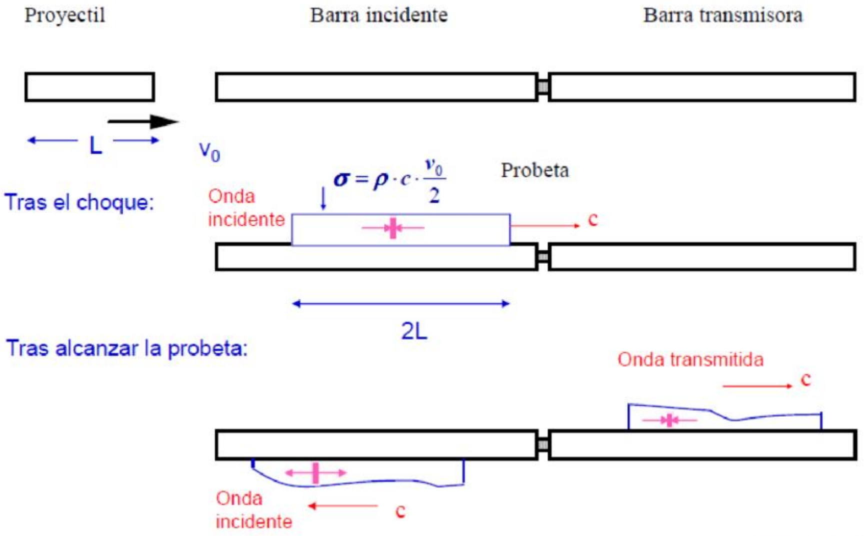


Figura: SHPB compresión

5. TRABAJOS FUTUROS

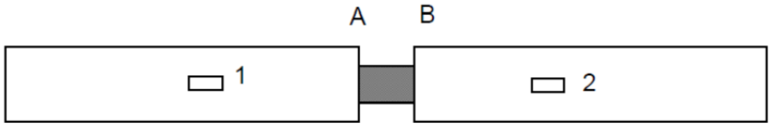


Figura: SHPB compresión

Valor de las deformaciones en las secciones A y B

$$\varepsilon_A(t) = \varepsilon_I(t) + \varepsilon_r(t)$$

$$\varepsilon_B(t) = \varepsilon_T(t)$$

Valor de las tensiones en las secciones A y B

$$\sigma_A(t) = E(\varepsilon_I(t) + \varepsilon_r(t))$$

$$\sigma_B(t) = E(\varepsilon_T(t))$$

Valor de las velocidades en las secciones A y B

$$v_A(t) = -c\varepsilon_I(t) + c\varepsilon_r(t)$$

$$v_B(t) = -c\varepsilon_T(t)$$

Valor de las Fuerzas en las secciones A y B

$$F_A(t) = A_A E(\varepsilon_I(t) + \varepsilon_r(t))$$

$$F_B(t) = A_B E(\varepsilon_T(t))$$

5. TRABAJOS FUTUROS

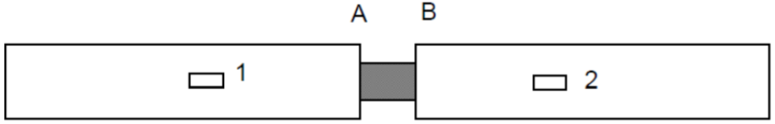


Figura: SHPB compresión

Valor de la velocidad de deformación en la probeta:

$$\dot{\varepsilon}(t) = \frac{v_A - v_B}{L} = -\frac{c}{L}(\varepsilon_I(t) - \varepsilon_r(t) - \varepsilon_T(t)) = \frac{2c}{L}\varepsilon_r(t)$$

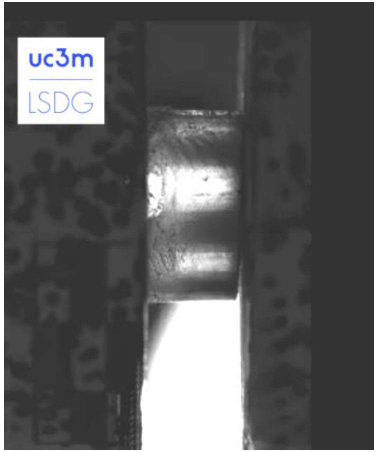
Valor de deformación en la probeta:

$$\varepsilon(t) = \int \dot{\varepsilon}(t)dt = \frac{2c}{L}\int \varepsilon_r(t)dt$$

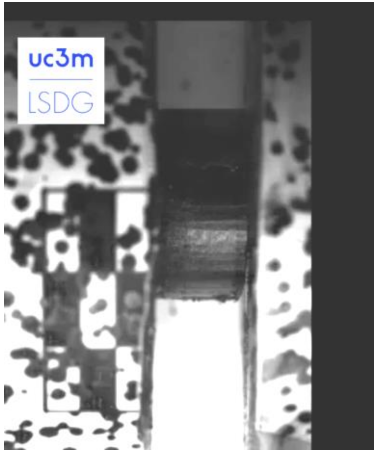
Valor de tensión en la probeta:

$$\sigma(t) = \frac{F_A + F_B}{2A_s} = \frac{A_B E}{2A_s}(\varepsilon_I(t) + \varepsilon_r(t) + \varepsilon_T(t)) = \frac{A_B E}{A_s}\varepsilon_T(t)$$

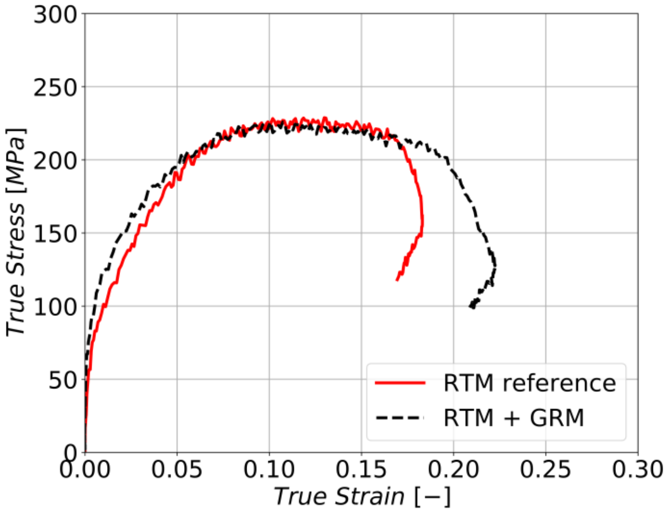
5. TRABAJOS FUTUROS



GRM 0%



GRM 0.4%



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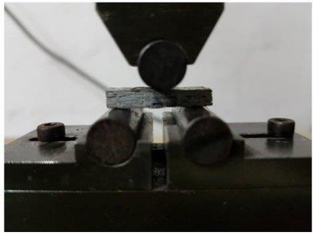
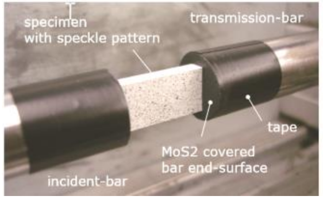
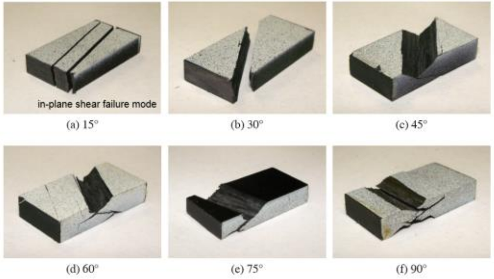
- **Caracterización estática**


- **Caracterización a alta velocidad de deformación**



H. Koerber et al. (2010)



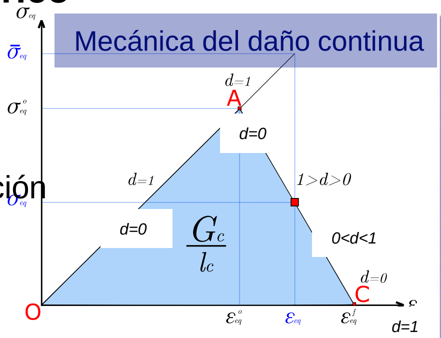
5. TRABAJOS FUTUROS

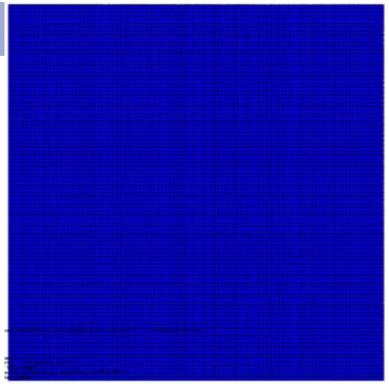
AEMAC ASOCIACIÓN ESPAÑOLA DE MATERIALES COMPUESTOS

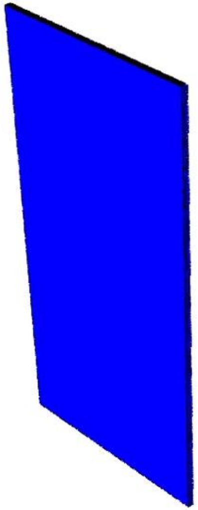
Puesta a punto de modelo numérico

Input

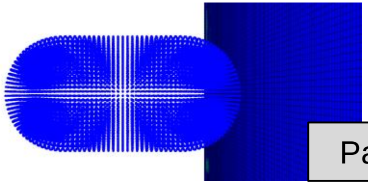
Caracterización laminados E_1, E_2, G_{12}, nu_{12}, X_t, Y_t ,X_c, Y_c ,S_{12}, G_{IC} y G_{IIC}
Caracterización alta velocidad deformación laminado (Influencia de $\dot{\varepsilon}$)







SIMULIA Abaqus



Partículas SPH

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Conclusiones

6. CONCLUSIONES

- Se ha fabricado un borde de ataque Airbus A350XWB con resina reforzado con grafeno.
- Los impactos realizados en el borde de ataque no muestran diferencias aparentes con el caso de referencia.
- Los ensayos CAI han permitido seleccionar la configuración Gatam 1.2% 2*TM que muestra casi un 10% de mejora media.
- Es necesario una adecuada caracterización de la resina y del laminado para entender correctamente las mejoras proporcionadas por el grafeno.

6. CONCLUSIONES

GRAPHENE FLAGSHIP

CORE 3 (2020-2023)

Cinta Unidireccional	Resin Infusion
Muy común en la industria aeronáutica Las propiedades de la resina sonmás influyentes	Aún menores costes RTM porque solo es necesario 1 molde

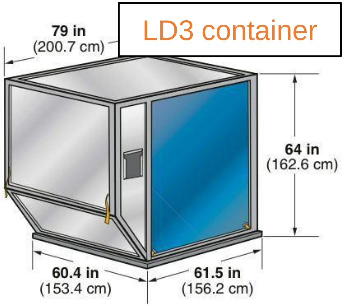
6. CONCLUSIONES

HORIZON 2020

GRAPHENE FLAGSHIP

CORE 3 (2020-2023)

uc3m AIRBUS EVONIK GRUPO ANTOLIN AERnnova



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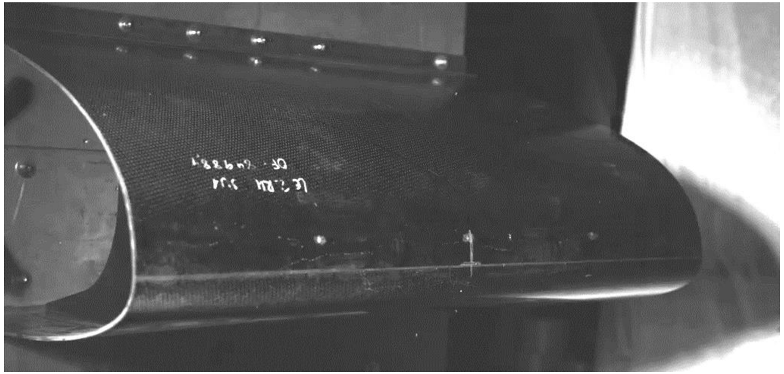
BONUS TRACK ¿Qué hará un un impacto de substituto de 30 kJ en un borde de ataque?

BONUS TRACK



MUCHAS GRACIAS