Structural Health Sensing & Monitoring

Advanced Material department

Raquel Travieso Puente, PhD

raquel.travieso@aimen.es

11th June 2019

- SHM

- Fiber Optic Sensors (FOS) & DC-dielectric sensors towards manufacturing and SHM of composites

- SHM
  - Definition
  - Past Catastrophic Failures
  - SHM Applications
  - SHM Advantages
  - SHM Steps

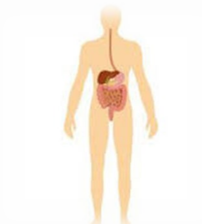
- Fiber Optic Sensors (FOS) & DC-dielectric towards manufacturing and SHM (NERO project)

SHM - Definition

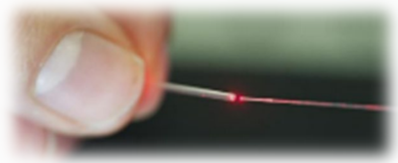
*S*tructural *H*ealth *M*onitoring (*SHM*)

the process of implementing a damage detection that can affect the system's performance and characterization strategy for engineering structures.

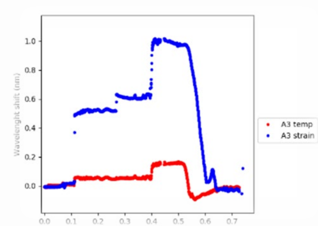
System

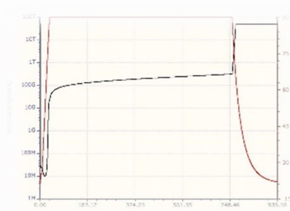



Sensors


Signal



Analysis



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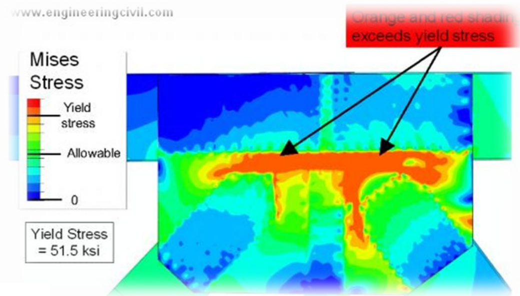
SHM – Past Catastrophic Failures



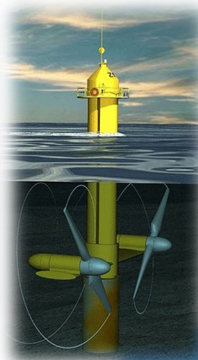
I-35 bridge collapse (Minneapolis, US, 2007)
Need of repair – failure of gusset
13 killed
+145 seriously injured

Sampoong department store collapse due to overload (Seoul, South Korea, 1955)
502 killed people
937 injured

Chevron Oil Explosion (Richmond, California, 2013)
Old pipe - Crude oil leaking
+15000 residents needed medical attention

SHM - Applications

- **Civil engineering**
  - Buildings
  - Bridges
  - Dams
  - Tunnels
  - Mining



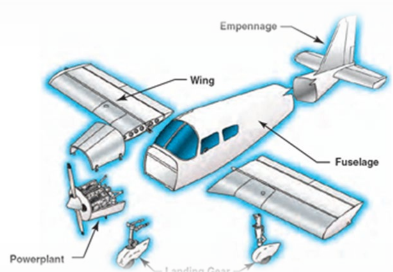
- **Energy**
  - Oil&gas installations and pipelines
  - Wind turbines
  - Nuclear plants
  - Tidal wave generators

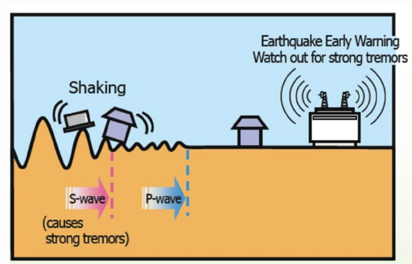
- **Chemical installations**
  - Piping
  - Tanks

- **Transportation**
  - Automotive
  - Trains
  - Ships/boats

- **Geophysics**
  - Soil mechanics
  - Volcanoes
  - Earthquakes

- **Aerospace**
  - Civil and military airplanes
  - Space craft
  - Helicopters

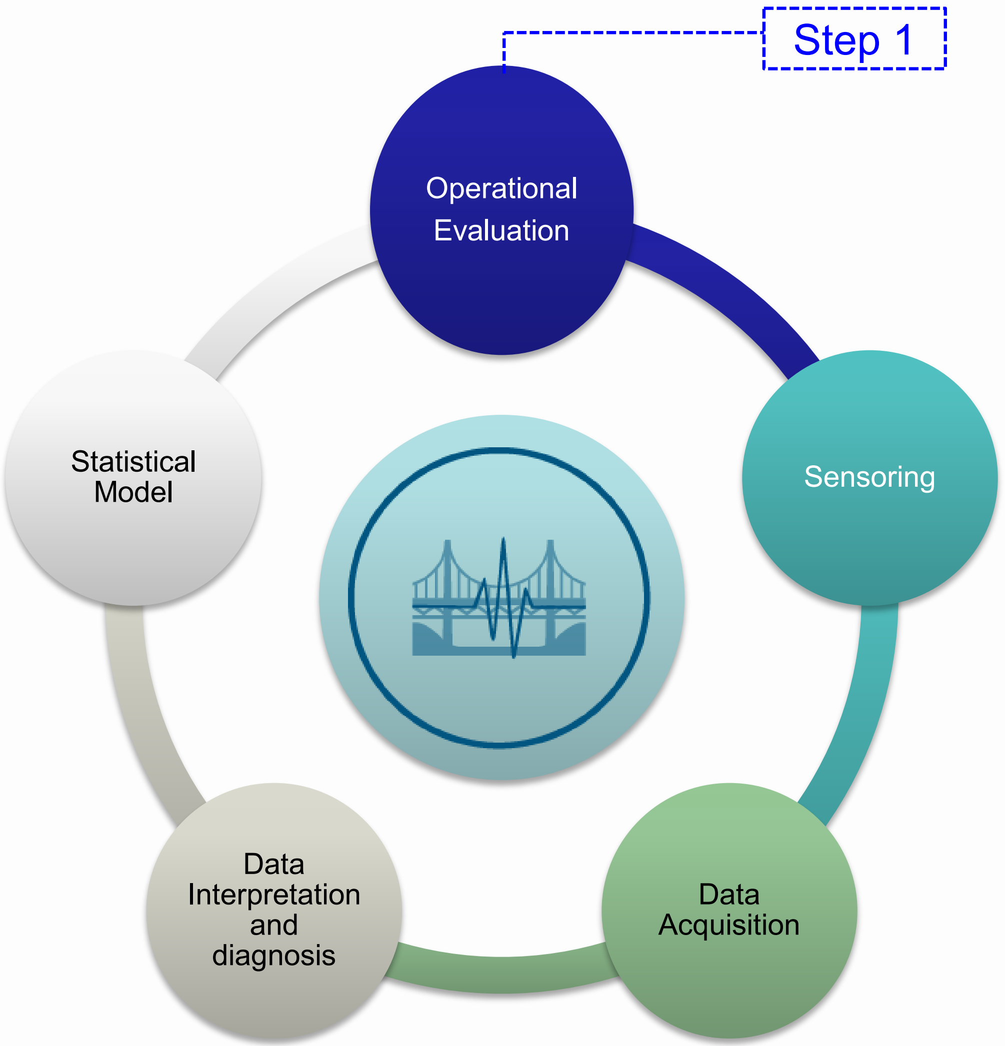


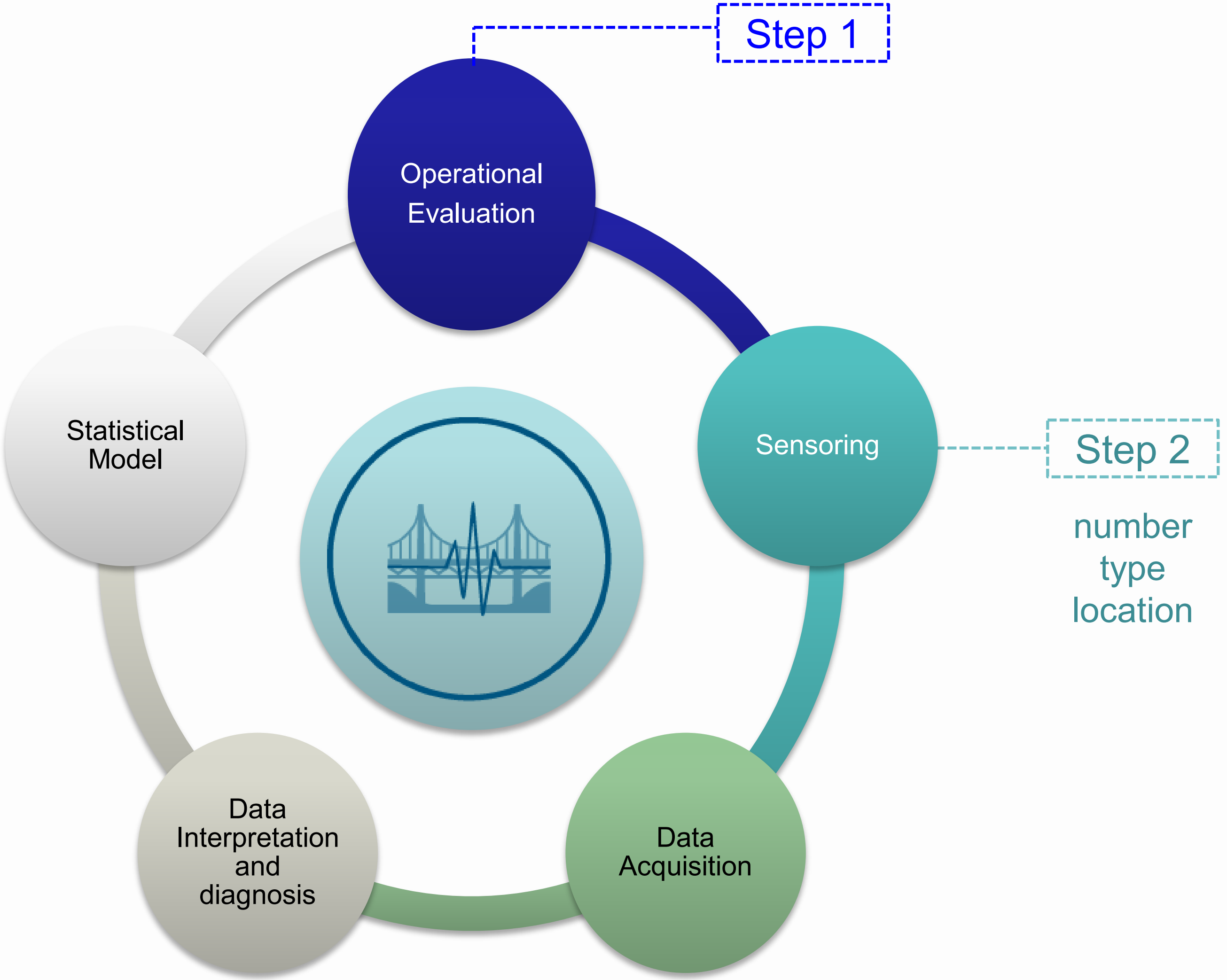


SHM - Advantages

- ✓ **Sensoring damage** due to: strain, rotation, temperature, corrosion, leakage, etc.
- ✓ **Manufacturing control**:
  - curing control
  - defect control
  - reduce rejection

- ✓ **In service control**:
  - detecting damage in early stage to enable proactive responses
  - replacing schedule-driven maintenance with condition-based maintenance
  - timely warning of impending failures
- ✓ Increase structures **lifetime**
- ✓ **Time** and **cost effective**


Step 1
Operational Evaluation
Sensoring
Data Acquisition
Data Interpretation and diagnosis
Statistical Model



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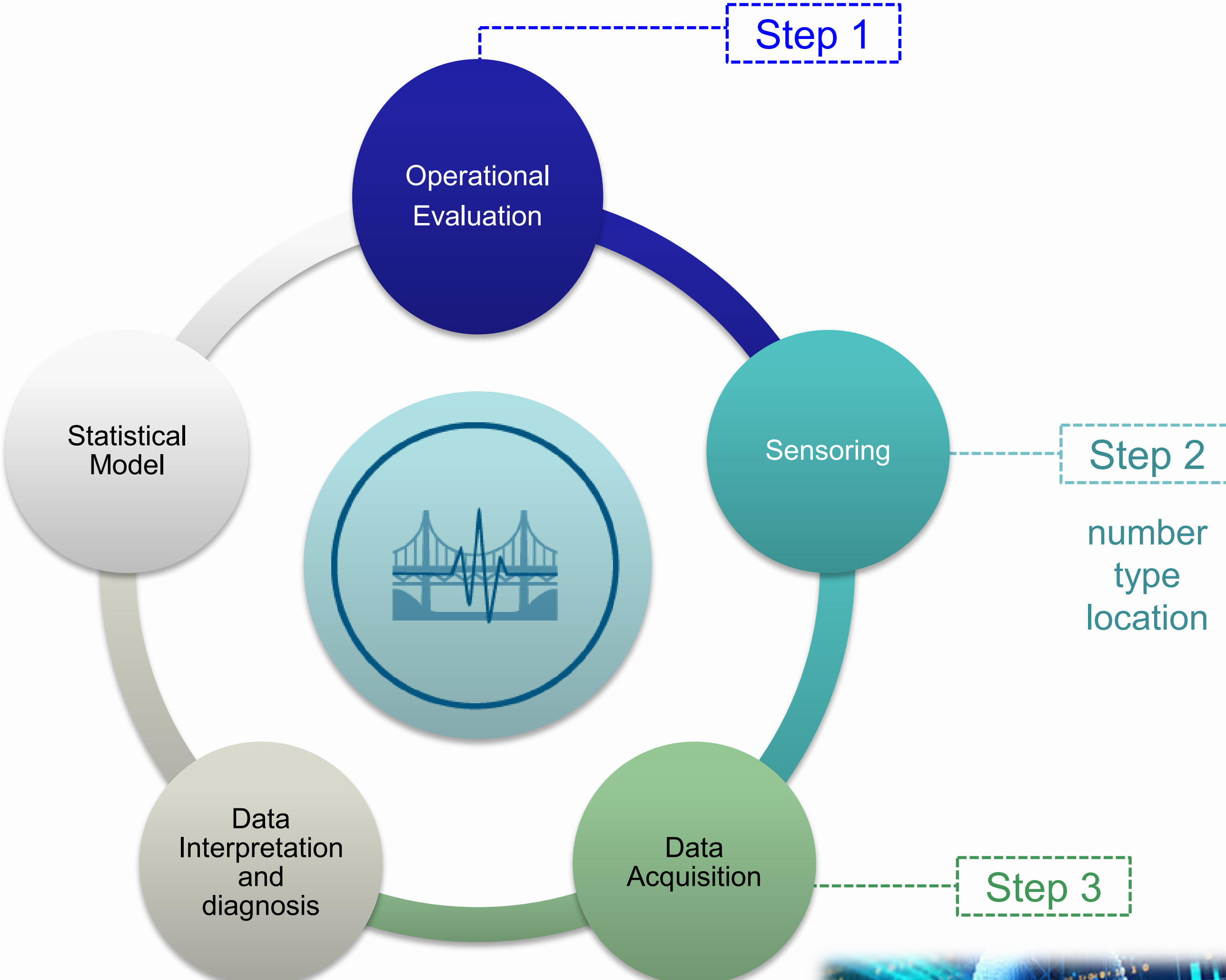
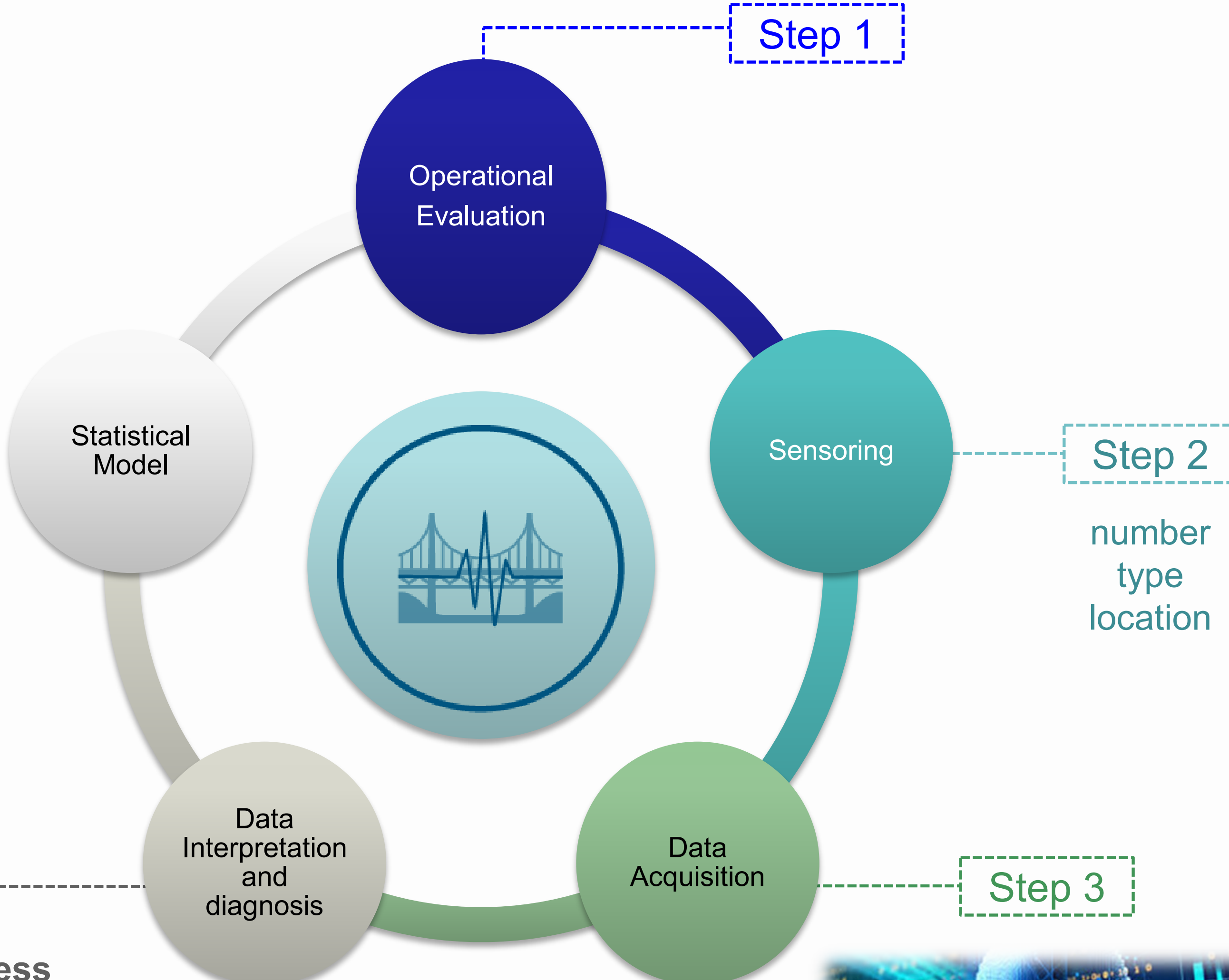
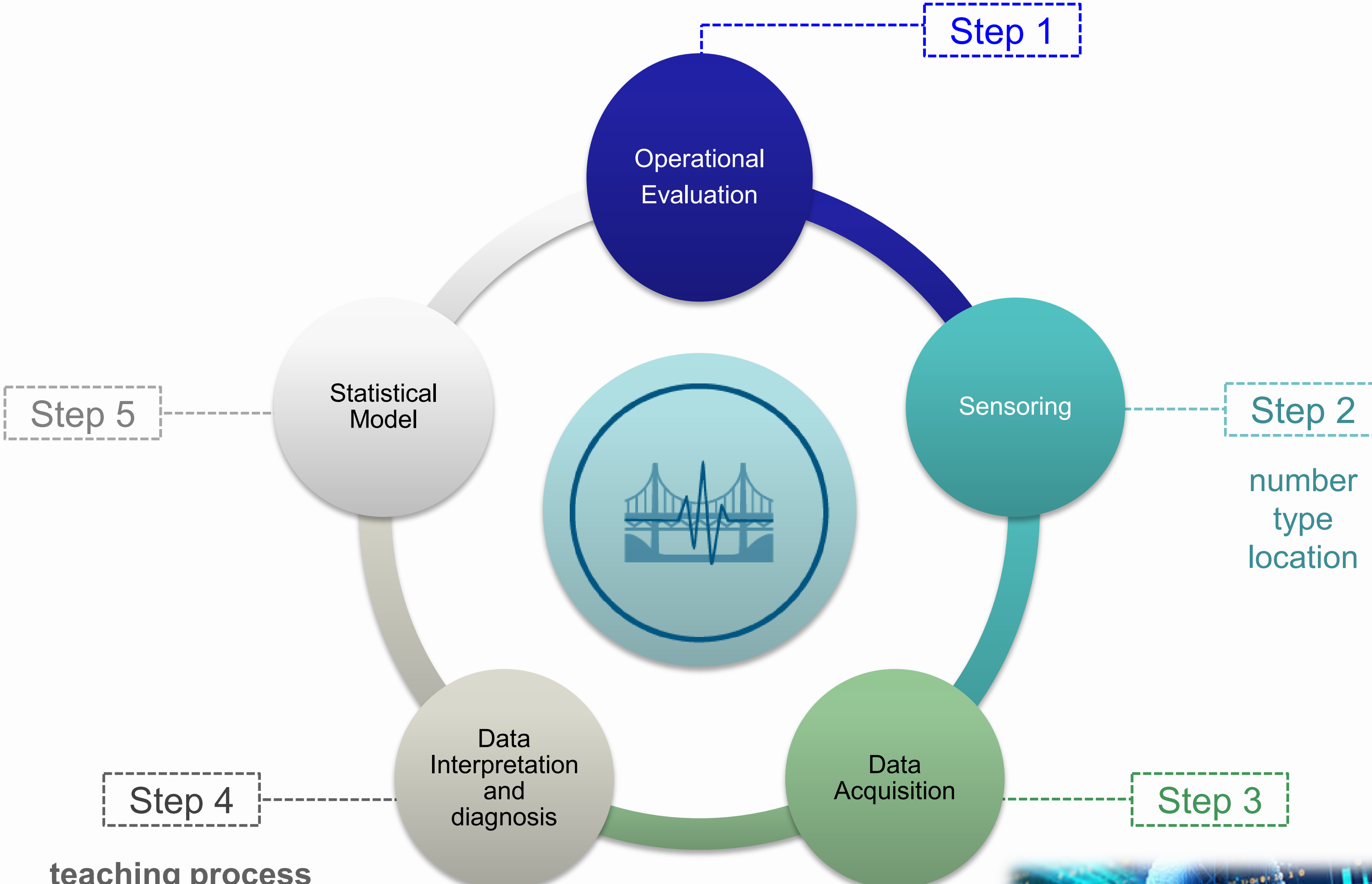
SHM - Steps


Step 1
Operational Evaluation
Sensoring
Step 2
number
type
location
Data Acquisition
Step 3
Data Interpretation and diagnosis
Statistical Model

SHM - Steps



teaching process
convert sensor data
to damage information



teaching process
convert sensor data
to damage information

❖ SHM

❖ Fiber Optic Sensors (FOS) & DC-dielectric sensors towards manufacturing and SHM of composites

- Aim
- Technologies & Materials
- Technology A: DC-Dielectric sensors

- Technology B: Fiber Optic Sensors (FOS)
- Real case at Galventus

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NERO

ADVANCED MONITORING SYSTEMS DEVELOPMENT FOR MANUFACTURING PROCESSING AND SERVICING OF COMPOSITES BASED ON NON-INVASIVE EMBEDDED SENSORS

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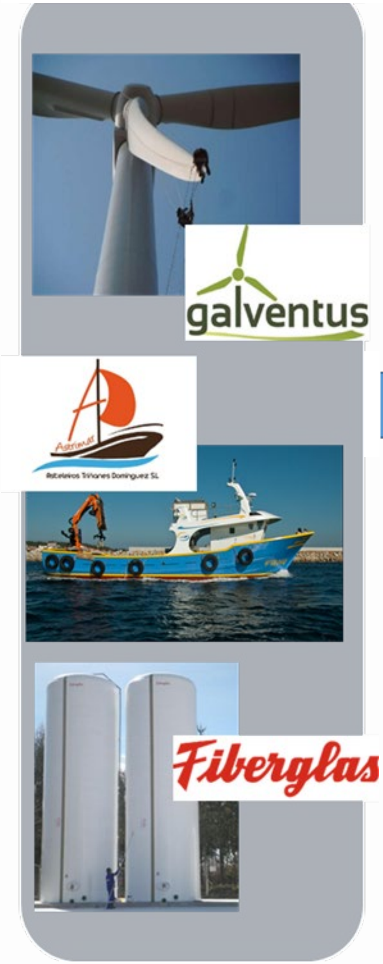
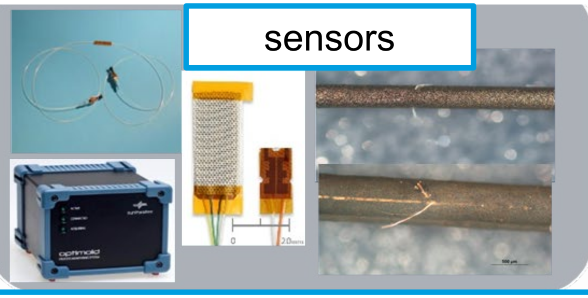
Aim of the project

SECTORS INVOLVED

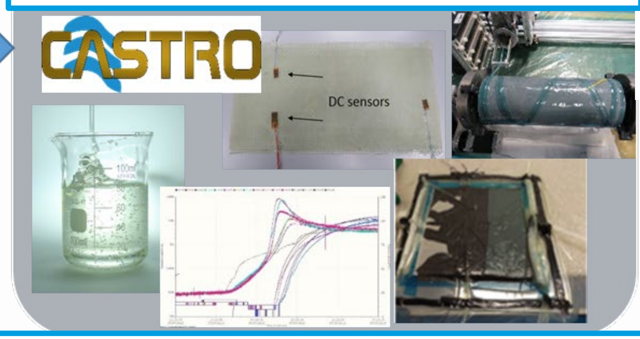


TECHNOLOGICAL DEVELOPMENT

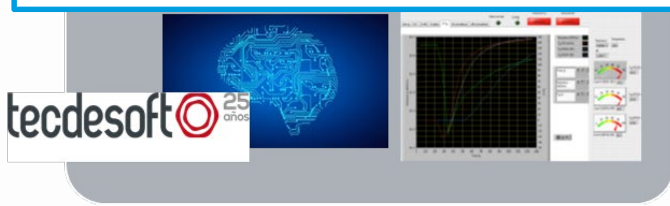
sensors



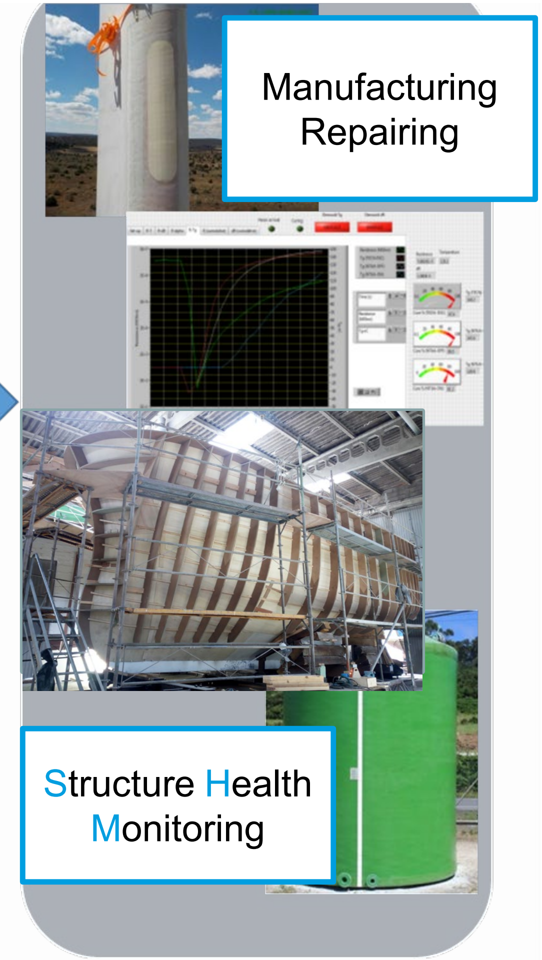
material responses characterization



machine learning & software development



USE-CASES



Manufacturing Repairing

Structure Health Monitoring

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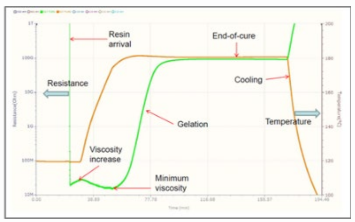
Aim of the project

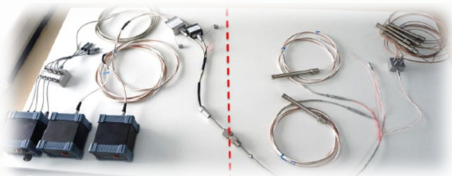
CUTTING-EDGE CONTROL SYSTEMS

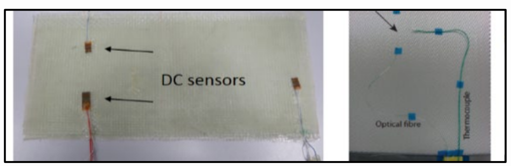
- Greater control in curing process
- New leaking detection

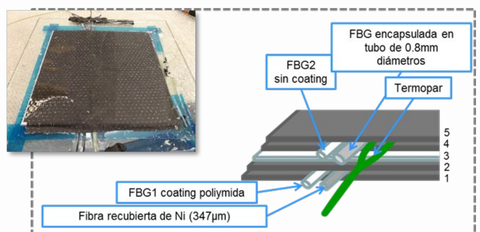
- Ensuring product quality
- Reducing rejection rates in production
- Minimizing manufacturing time

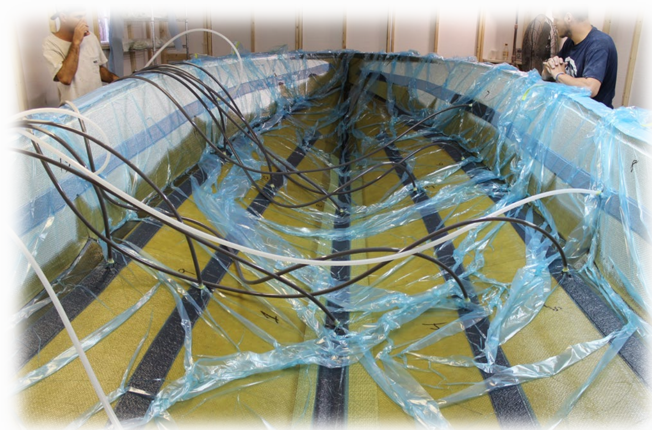
Validation of technology in materials and structures employed by each user











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- Aim
- Technologies & Materials
- Technology A: DC-Dielectric sensors

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Advanced Materials

Thermoset & thermoplastic composites

Process out of autoclave

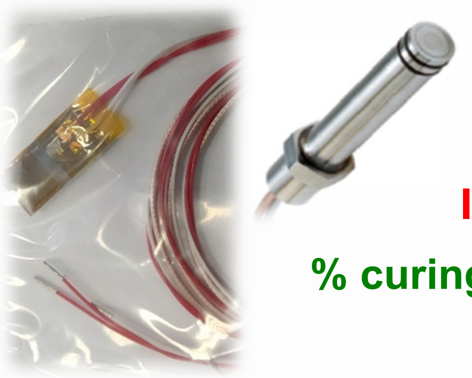
Monitoring manufacturing of composites

Technology A

DC-DIELECTRIC SENSORS

Resin flow and cure evolution

Monitoring based on ion mobility or dielectric measurement



Invasive

% curing degree signal

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Advanced Materials

Thermoset & thermoplastic composites

Process out of autoclave

Monitoring manufacturing of composites

Robotic & Control

Photonic sensors

Smart manufacturing – Machine Learning

Manufacturing process control

Structural Health Monitoring (SHM)

Technology A

DC-DIELECTRIC SENSORS

Resin flow and cure evolution

Monitoring based on ion mobility or dielectric measurement

Technology B

FIBER OPTIC SENSORS (FOS)

Fiber Bragg Grating (FBG) – localized

Distributed - continuous

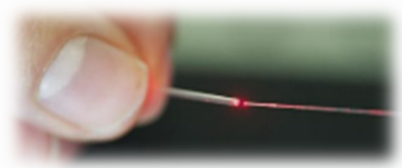
Invasive

% curing degree signal

TEACH

Non-invasive

Unknown signal



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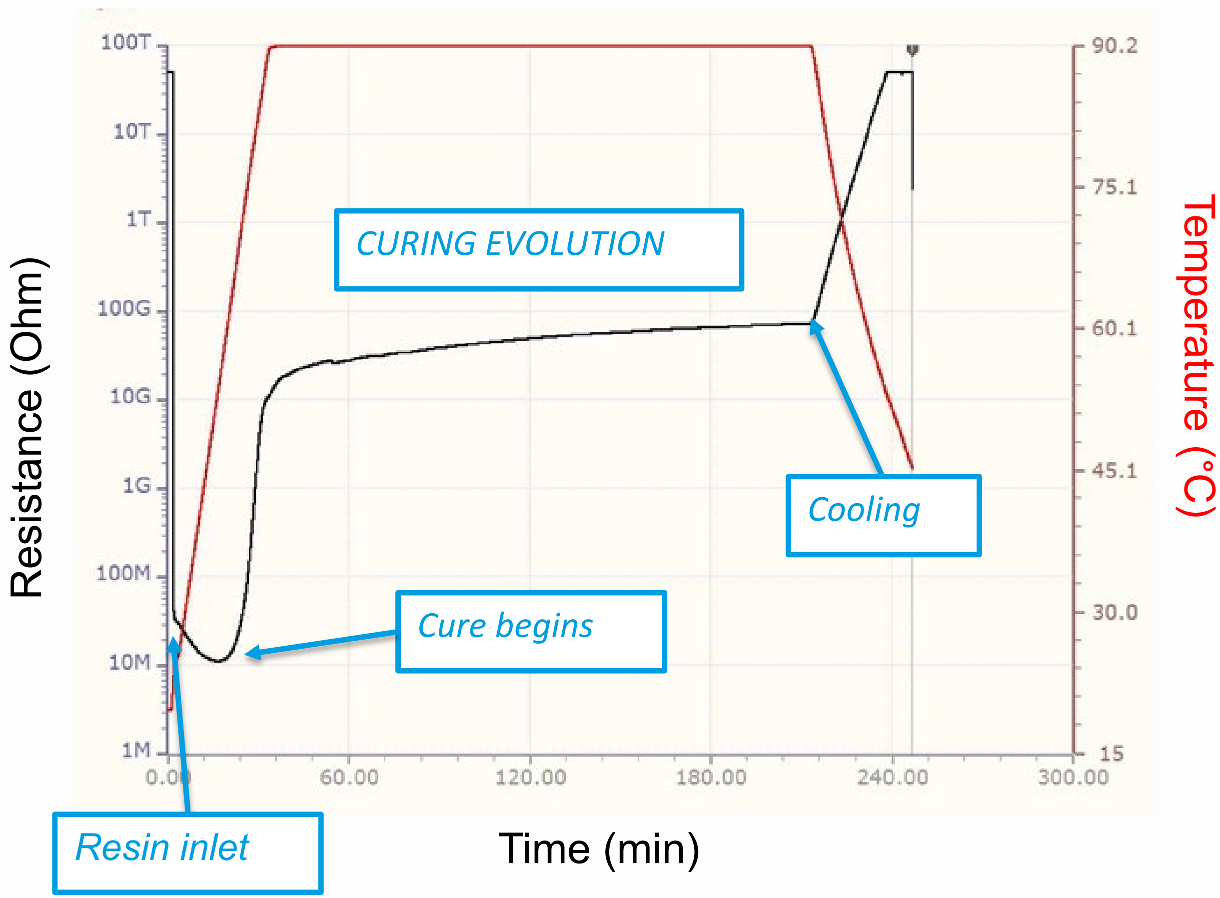
Technology A – DC-Dielectric sensors

Monitoring Manufacturing

Resin flow and cure evolution

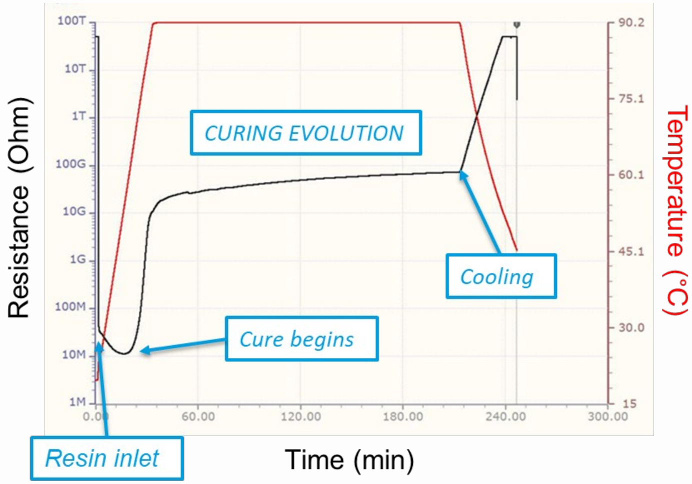
based on ion mobility or dielectric measurement

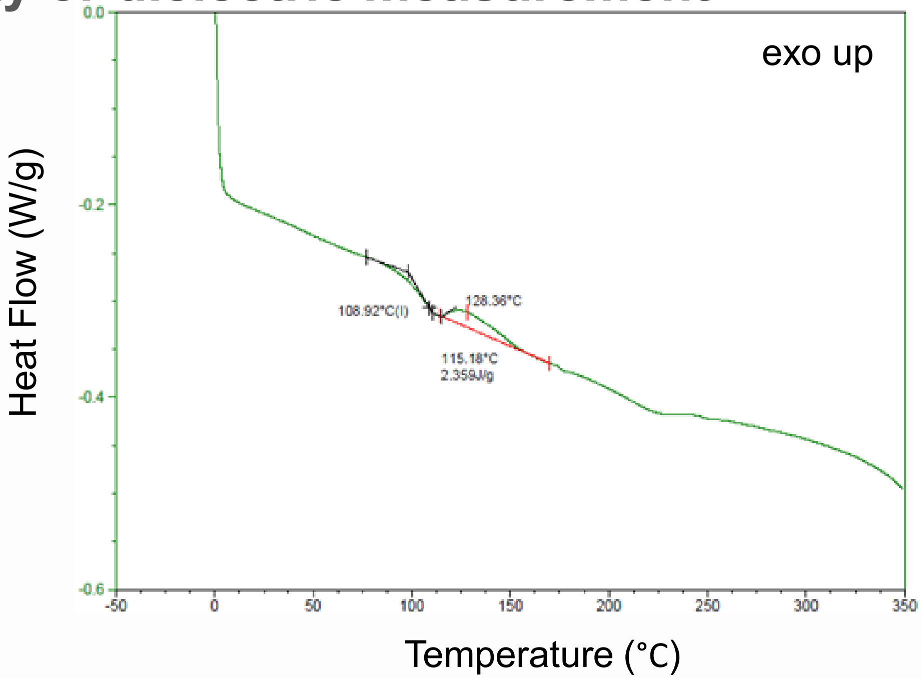


Monitoring Manufacturing

Resin flow and cure evolution

based on ion mobility or dielectric measurement





$$\alpha = \frac{H_T - H_r}{H_T} \times 100$$

α (%): curing degree
H_R: heat reaction
H_T: heat 100% cure

curing degree = (307.3-2.4) / 307.3 = **99 %**

raquel.travieso@aimen.es

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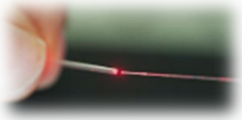
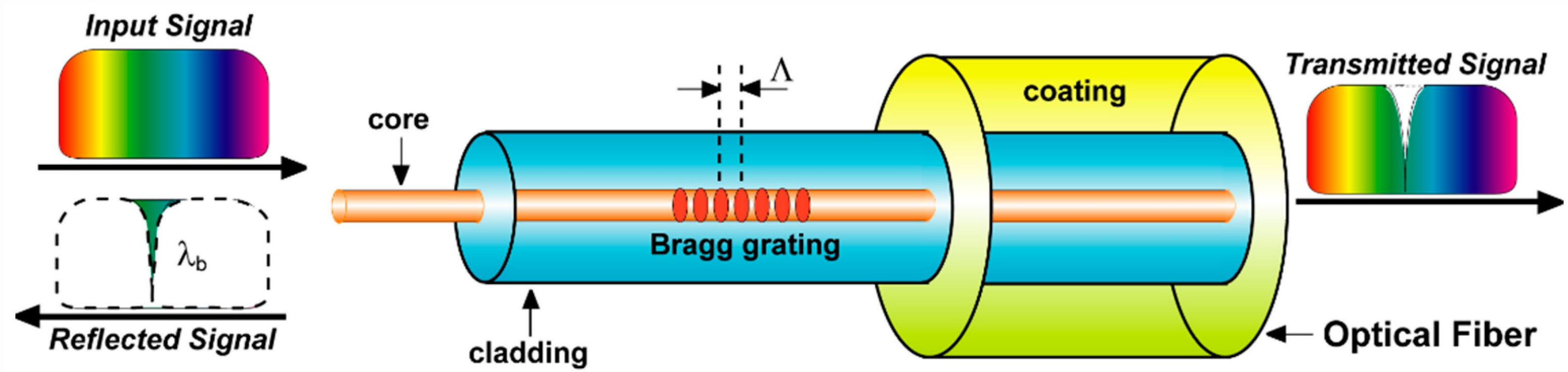
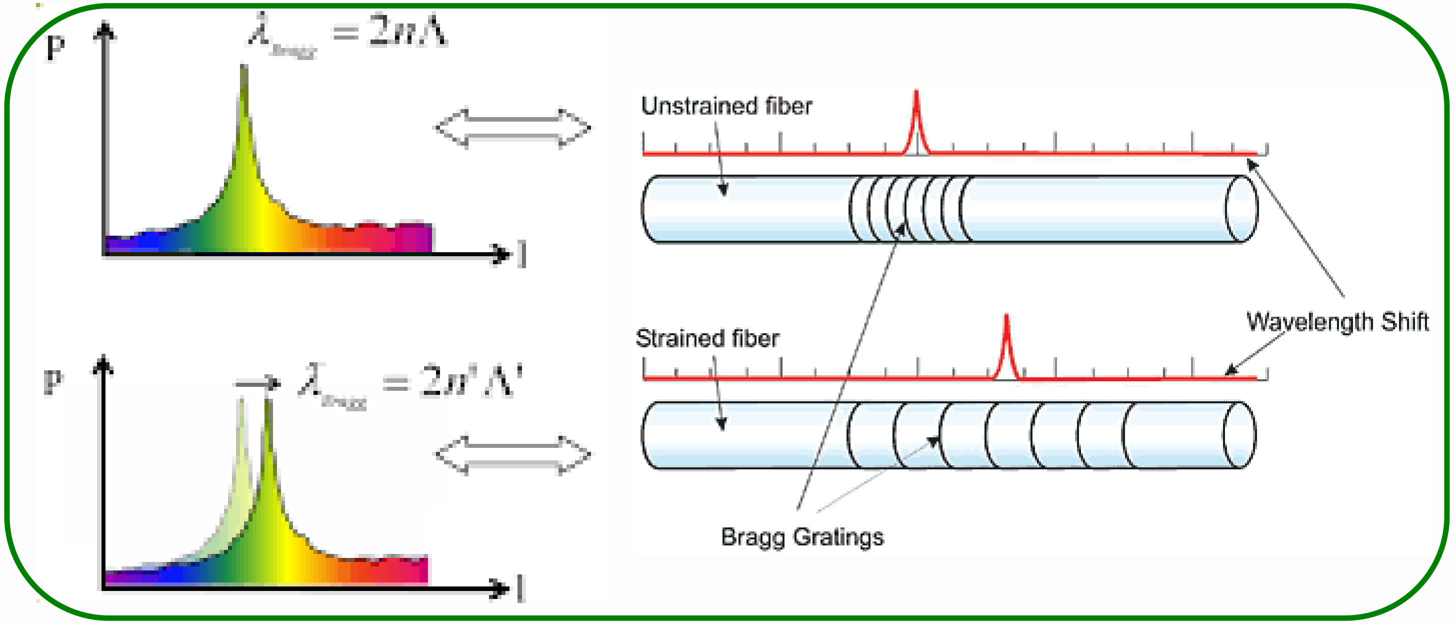
Technology B - FOS - Fiber Bragg Grating (FBG)

In SHM, most commonly used Fiber Optic Sensors (**FOS**) is Fiber Bragg Grating (**FBG**) sensors, with Multiplexing capacity







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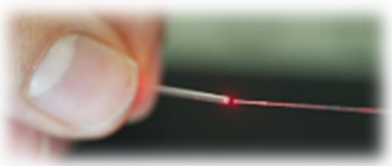
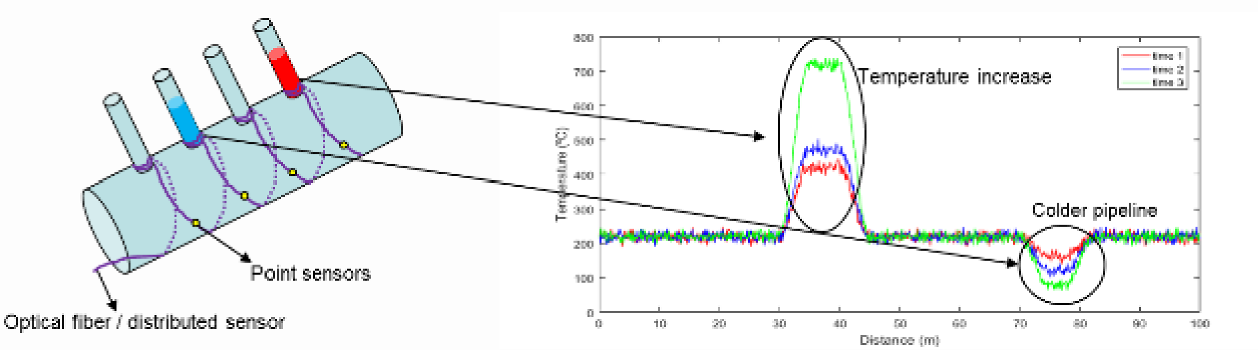
Fiber optic point sensors interrogator development (FBG)

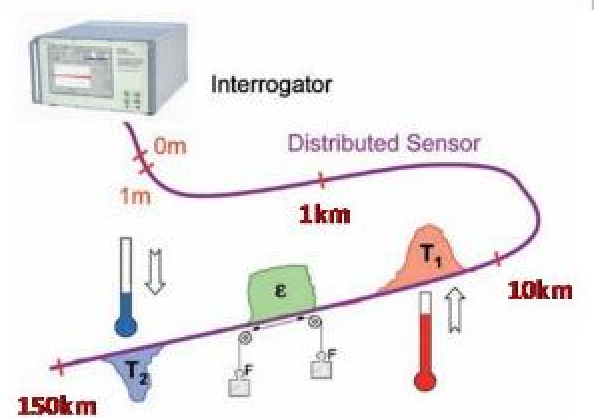
- ✓ High resolution and accurate measurements in localized locations (**critical points**)



Fiber optic distributed sensors interrogator development (Brillouin or Rayleigh)

- ✓ Distributed (continuous) measurements along distance





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Technology B - Fiber Optic Sensors (FOS)

Advantages:

- ✓ Small size 125µm of diameter
- ✓ Light weight
- ✓ Passive: immune to electric and electromagnetic fields
- ✓ Easy integration into a wide variety of structures and materials, including composite materials, with little interference due to their small size and cylindrical geometry
- ✓ Resistant to harsh environments and high temperatures (<1000ºC)
- ✓ High sensitivity and resolution
- ✓ Multiplexing capability to form sensing networks
- ✓ Remote sensing capability
- ✓ Single ended remote operation over several km
- ✓ Can monitor a wide range of physical and chemical parameters: **temperature, strain, humidity, pressure, pH, acoustic emissions, vibrations,** etc.

Disadvantages:

- ✓ NOT mature technology
- ✓ Fragile
- ✓ Necessary to know its fundaments

I+D+i Oportunity

- SHM
- **Fiber Optic Sensors (FOS) & DC-dielectric sensors towards manufacturing and SHM of composites**
  - Aim
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  - Technology A: DC-Dielectric sensors

  - Technology B: Fiber Optic Sensors (FOS)
  - **Real case at Galventus**

17:30-19:00 (12th June)
visit to Galventus - reparation of wind turbine blades

LEADING EDGE REPARATION by Hand lay-up manual process

- ✓ Study of the damage
- ✓ Surface treatment

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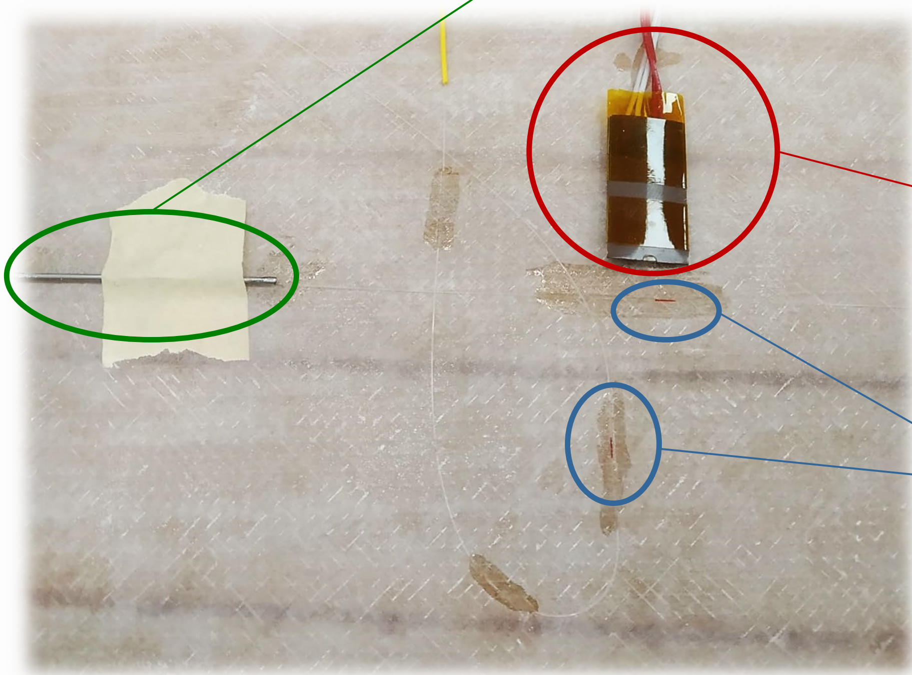

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LEADING EDGE REPARATION by HAND LAY-UP manual process

- ✓ Study of the damage
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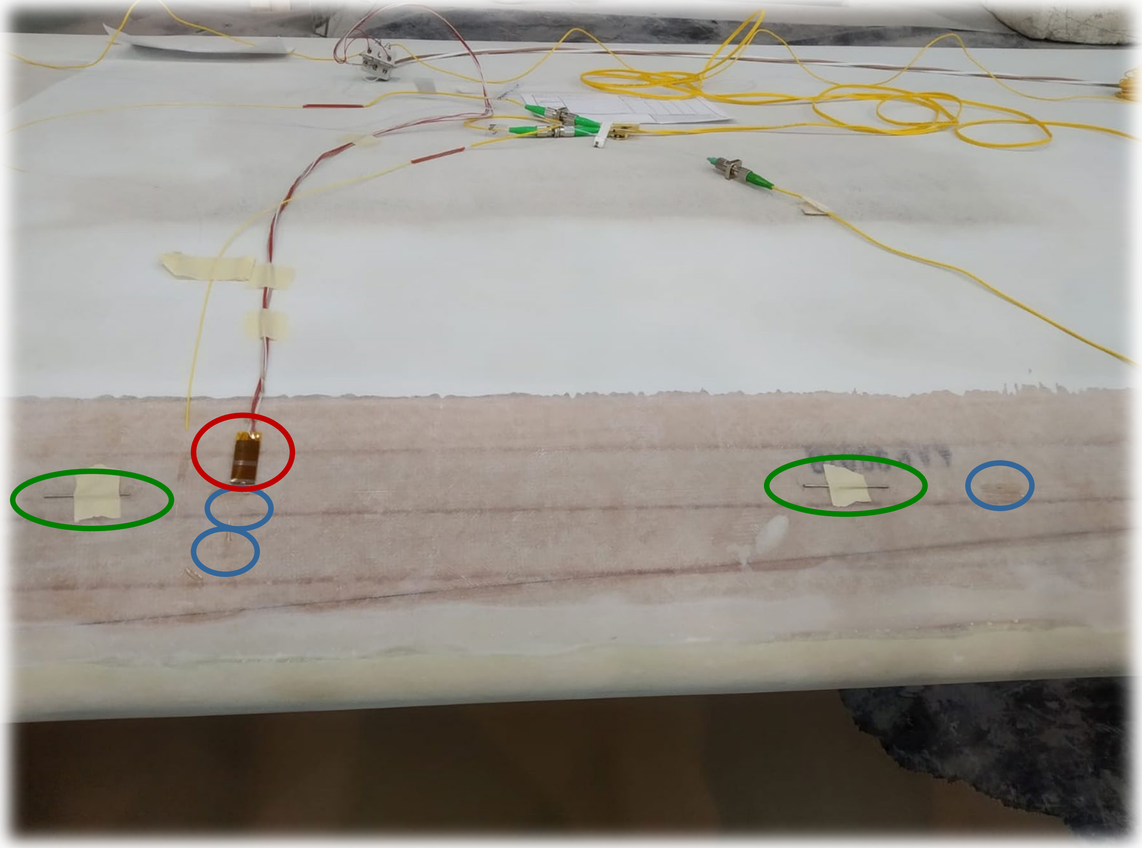
FBG sensor
steel protection
temperature
~~strain~~

Dielectric sensor
temperature
curing degree

FBG sensor
temperature
strain



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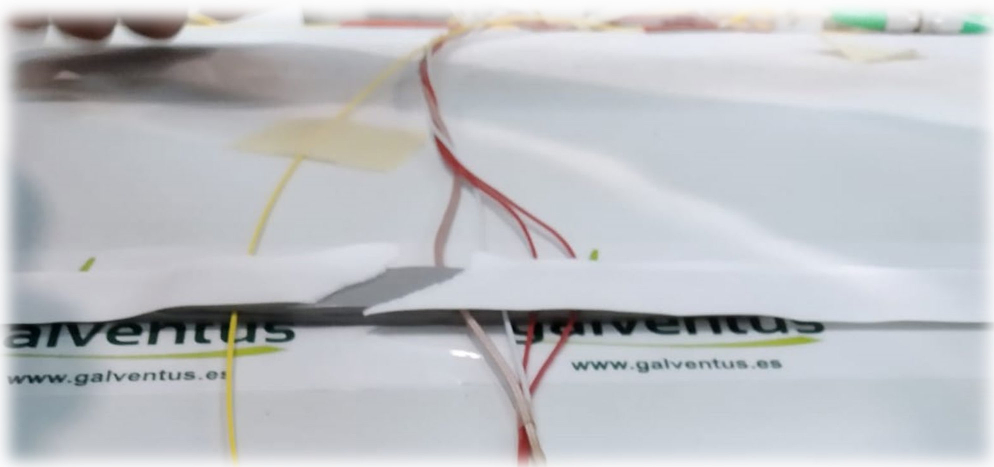
LEADING EDGE REPARATION by HAND LAY-UP manual process

- ✓ Study of the damage
- ✓ Surface treatment
- ✓ Sensor set-up
- ✓ Double sided tape to limit the zone to be repaired



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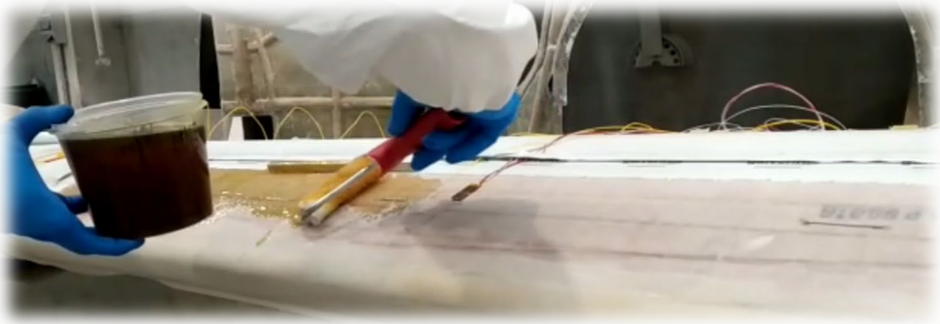
LEADING EDGE REPARATION by HAND LAY-UP manual process

- ✓ Study of the damage
- ✓ Surface treatment
- ✓ Sensor set-up
- ✓ Double sided tape
- ✓ Resin + catalyst
- ✓ Reinforcement: glass fiber



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LEADING EDGE REPARATION by HAND LAY-UP manual process

- ✓ Study of the damage
- ✓ Surface treatment
- ✓ Sensor set-up
- ✓ Double sided tape
- ✓ Resin + catalyst
- ✓ Reinforcement: glass fiber
- ✓ Second layer of FBG sensors

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- ✓ Resin + catalyst
- ✓ Reinforcement: glass fiber
- ✓ Second layer of FBG sensors
- ✓ Resin + catalyst
- ✓ Reinforcement: glass fiber
- ✓ ……

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<u>LEADING EDGE REPARATION by HAND LAY-UP manual process</u>

- ✓ Study of the damage
- ✓ Surface treatment
- ✓ Sensor set-up
- ✓ Double sided tape
- ✓ Resin + catalyst
- ✓ Reinforcement: glass fiber
- ✓ Second layer of FBG sensors
- ✓ Resin + catalyst
- ✓ Reinforcement: glass fiber
- ✓ ……..
- ✓ Bleeding blanket
- ✓ Peel ply

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- ✓ Resin + catalyst
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- ✓ Second layer of FBG sensors
- ✓ Resin + catalyst
- ✓ Reinforcement: glass fiber
- ✓ …..
- ✓ Bleeding blanket
- ✓ Peel ply
- ✓ Absorption blanket

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Monitoring manufacturing process

17:30-19:00 (12th June)
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galventus

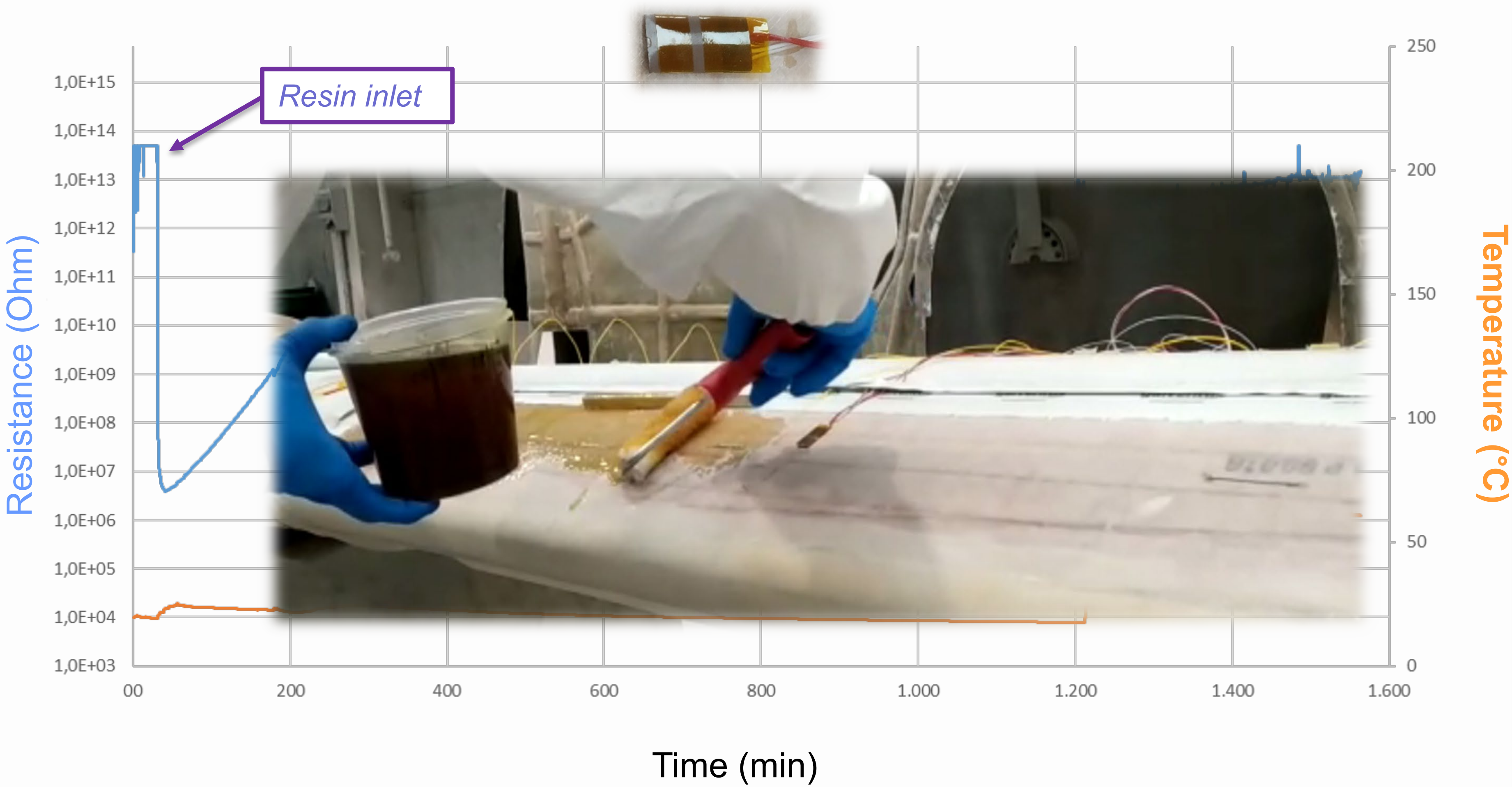
LEADING EDGE REPARATION by HAND LAY-UP manual process

- ✓ Study of the damage
- ✓ Surface treatment
- ✓ Sensor set-up
- ✓ Double sided tape
- ✓ Resin + catalyst
- ✓ Reinforcement: glass fiber
- ✓ Second layer of FBG sensors
- ✓ Resin + catalyst
- ✓ Reinforcement: glass fiber
- ✓ …..
- ✓ Bleeding blanket
- ✓ Peel ply
- ✓ Absorption blanket
- ✓ Plastic bag > vacuum

17:30-19:00 (12th June)
visit to Galventus - reparation of wind turbine blades

galventus

LEADING EDGE REPARATION by HAND LAY-UP manual process



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17:30-19:00 (12th June)
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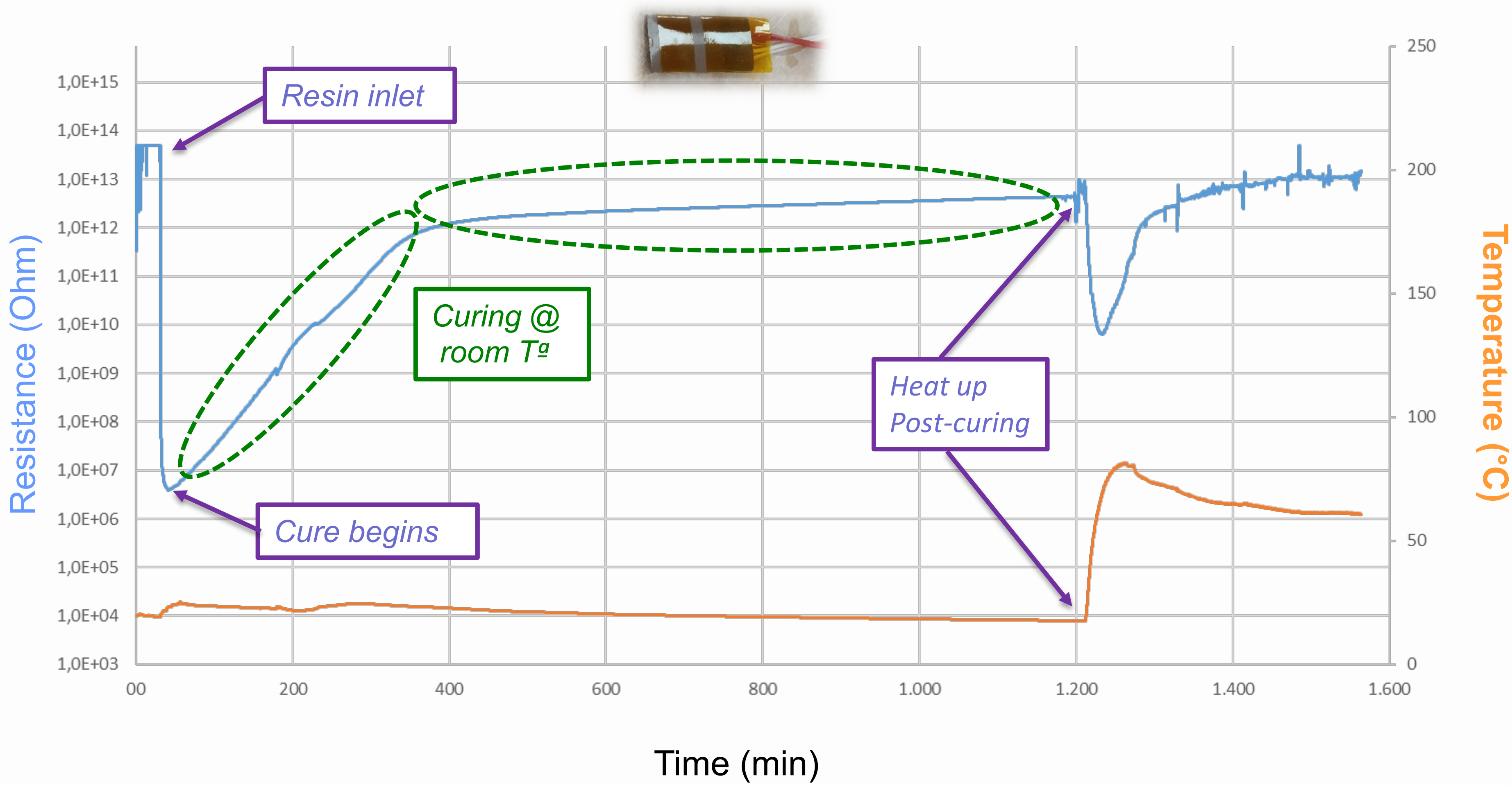
LEADING EDGE REPARATION by HAND LAY-UP manual process



Monitoring manufacturing process


Tracking the flow of resin infusion is easy, just look for the dark areas to see the progress.

Manufacturing control by monitoring the full process

Fiber Optic Sensors (FOS) + DC-Dielectric sensors =

- ✓ Teaching process from DC to FOS
- ✓ Control of manufacturing process:
  - Vacuum level
  - Resin inlet
  - Wetting of the layers
  - Resine curing degree
  - Defect control
  - Reduce rejection

- ✓ Embedded sensors for in service monitoring (SHM):
  - Detecting damage in early stage (corrosion, strain, leakage, etc.)
  - Replace Schedule-driven maintenance with condition-based maintenance
  - Timely warning of impending failures

- ✓ Lifetime control
- ✓ Improves safety
- ✓ Time and cost effective

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CENTRO TECNOLÓGICO

aimen@aimen.es
www.aimen.es

Sede Central
Centro de Aplicaciones Láser
Polígono Industrial de Cataboi
SUR-PI-2 (Sector 2) Parcela 3
ES 36418 O PORRIÑO - Pontevedra
Telf. +34 986 344 000

Sede Torneiros
Edificio Armando Priegue
Relva 27 A – Torneiros
ES 36410 O PORRIÑO - Pontevedra
Telf. +34 986 344 000

Delegación A Coruña
Polígono Industrial de Pocomaco
Parcela D-22 Oficina 20
ES 15190 A CORUÑA
Telf. +34 637 127 253

Delegación Madrid
C/ Rodríguez San Pedro 2
Planta 6, Oficina 609 Edificio Inter
ES 28015 MADRID
Telf. +34 687 448 915

Delegación Andalucía
C/ Leonardo da Vinci 18
ES 41092 SEVILLA
Telf. +34 670 412 243

Delegación Zona Norte
Parque Tecnológico de Zamudio
Edificio 103, Planta 2
ES 48170 ZAMUIDO - Vizcaya
Telf. +34 662 489 181

Thanks for your attention

Raquel Travieso Puente | *Senior R&D&I Advanced Materials*
Tlf. +34 986 344 000 (ext. 3211) | mvl: +34 670 95 24 15
e-mail: raquel.travieso@aimen.es

Technology A – DC-Dielectric sensors

Corroborar que los durables son esos dos los que tenemos

Available Cure/ Viscosity Sensors

Durable sensor

High Temp RTM
- Resin arrival
- Viscosity rise
- Gelation
- End-of-cure

Flexible sensor

VI and RT cure
- Resin arrival
- Viscosity rise
- Gelation
- End-of-cure

Inline sensor

- Avoid pipe cleaning
- Adjust cycle
- Mixing ratio check

Pot sensor

- Mixing ratio
- Resin Quality
- Resin aging
- Adjust cycle

Available Resin Arrival and Temperature Sensors

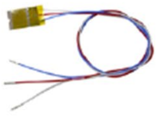
In-mould Durable

- High Temp RTM

Gate Durable

- ideal for vacuum infusion in oven/ autoclave (gates, pipelines, pots etc.)

Flexible Disposable

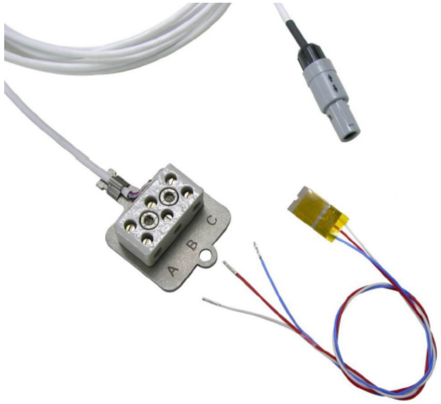


FloWire Disposable

Infusion and RTM
- Curved surfaces
- In the laminate for development
- Over the peel-ply
- Suitable for very long parts
- no extra protection for Carbon Fibre Preforms

FLEXIBLE RESIN ARRIVAL/TEMPERATURE SENSORS

The dimensions of the standard resin arrival sensor are 22x12x1.2 mm approx., however in most areas the sensor thickness is ~0,6mm. Each sensor has two wires for sensing of resin arrival, and two or three wires if additional temperature sensor has been integrated. The diameter of each wire is ~1,0mm.



Each adaptor has:

1) **A plastic plug end:** suitable for the OPTIFLOW unit connection as shown in the picture above. This plug is push-pull quick connect as shown in page 8 of this manual.
2) **A white ceramic screw terminal end:** suitable for the connection of the RAT (resin arrival and temperature) sensor's wires. Each RAT sensor comes with 3 wires (white, red and blue as shown in the photo below).

raquel.travieso@aimen.es

Sensors for SHM - Types

Buscar defin basica de cada tipo de sensor:
Piezoelectricos, ultrasonic, MEMS, wireless and embedded
Mirar en que consisten los wireless y RFID

Old SHM Technology

MEMS (microelectromechanical systems)

Piezoelectric

Ultrasonic

New SHM Technology

FOS (Fiber Optic Sensors)

Wireless sensors network

Embbedded RFID (Radio Frequency Identification) systems

PROCESS MONITORING - resin flow and cure evolution: DC-Dielectric sensors and FOS

STRUCTURAL HEALTH MONITORING: Fiber optic sensors (FOS)

raquel.travieso@aimen.es

Available Cure/ Viscosity Sensors

Durable sensor

High Temp RTM
- Resin arrival
- Viscosity rise
- Gelation
- End-of-cure

Flexible sensor

VI and RT cure
- Resin arrival
- Viscosity rise
- Gelation
- End-of-cure

Inline sensor

- Avoid pipe cleaning
- Adjust cycle
- Mixing ratio check

Pot sensor

- Mixing ratio
- Resin Quality
- Resin aging
- Adjust cycle

Available Resin Arrival and Temperature Sensors

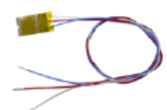
In-mould Durable

- High Temp RTM

Gate Durable

- ideal for vacuum infusion in oven/ autoclave (gates, pipelines, pots etc.)

Flexible Disposable



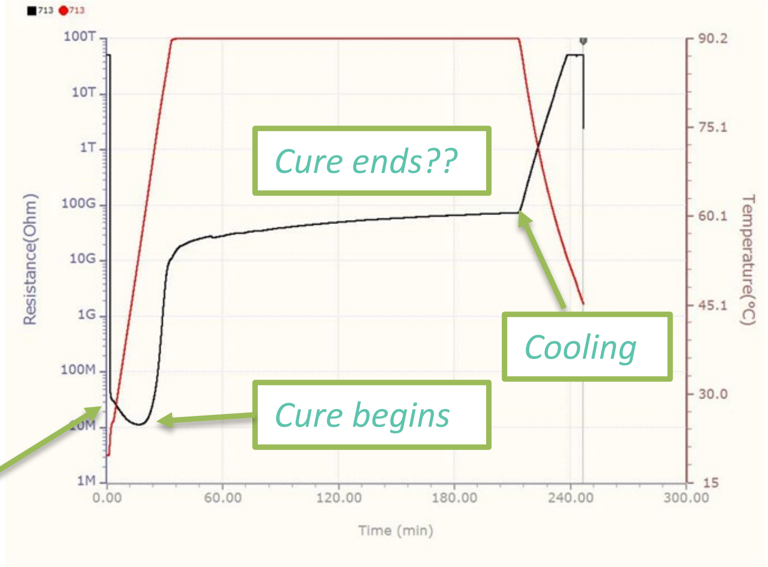
FloWire Disposable

Infusion and RTM
- Curved surfaces
- In the laminate for development
- Over the peel-ply
- Suitable for very long parts
- no extra protection for Carbon Fibre Preforms

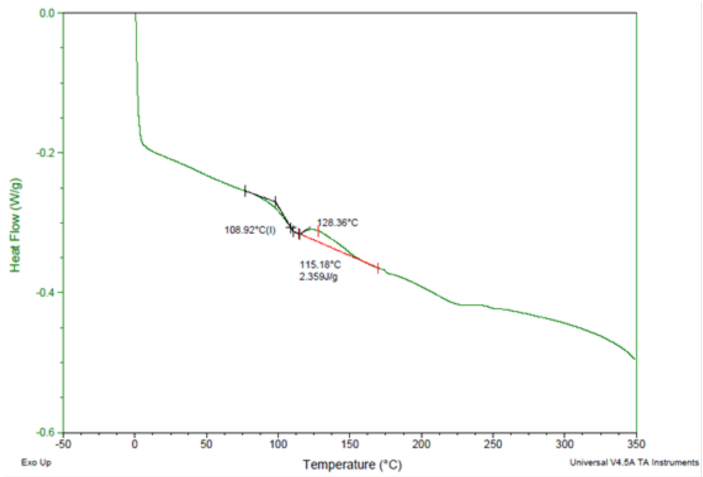
Ensayos realizados

VE Epovia

180 min _90°C

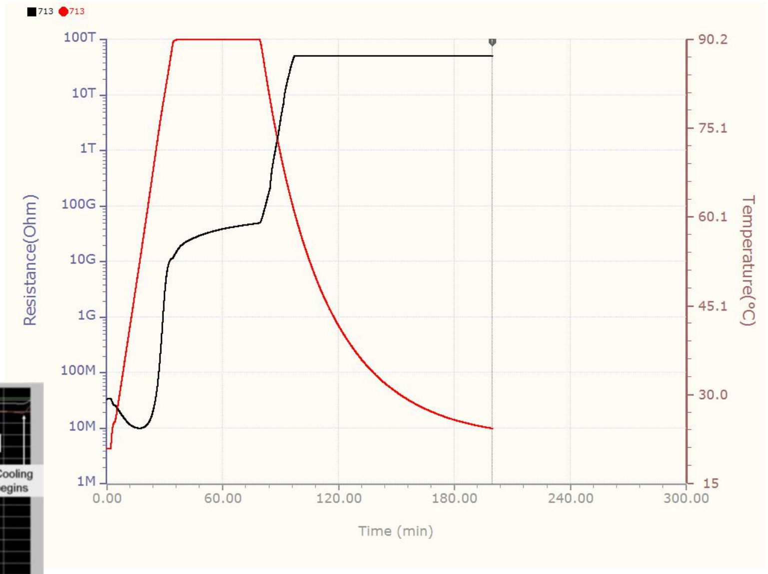


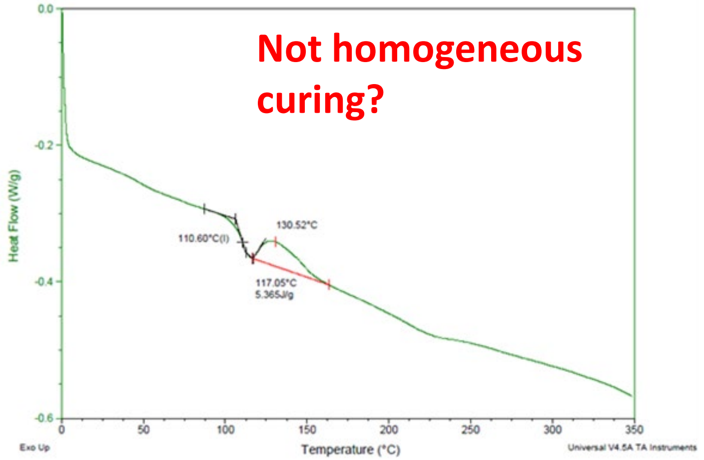
Resin inlet



%Cure = (307.3-5.4) / 307.3 = **98 %**

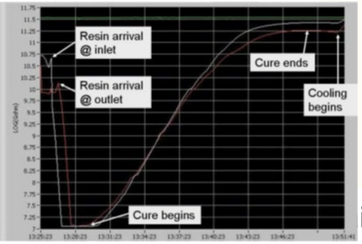
45 min _90°C





Not homogeneous curing?

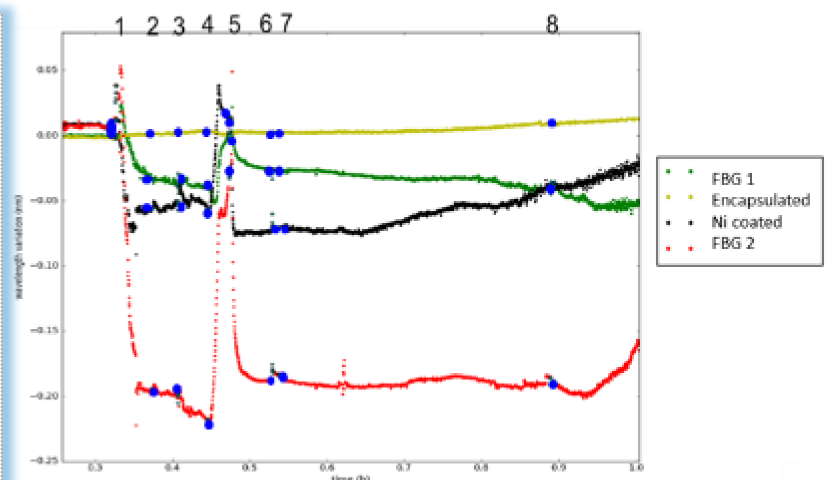
%Cure (1) = (307.3-2.4) / 307.3 = **99 %**
%Cure (2) = (307.3-5.2) / 307.3 = **98 %**



Data acquisition

Embedding FBG sensor into composite material to monitoring the manufacturing process and its live work.

- ✓ Possible monitoring the composite manufacturing process for:
  - Infusion method
  - RTM (Resin Transfer Moulding) method
  - Hand lay up technique
  - Filament winding
- ✓ Allow the control of manufacturing process:
  - Vacuum level
  - Ingess of resine
  - Wetting of the layers
  - Curing of the resine
- ✓ Possible use the embedded sensors for monitoring the composite life.



1-5 Vacuum pump on and off
6-7 Resine ingress to the composite
8. Resine reach the sensors

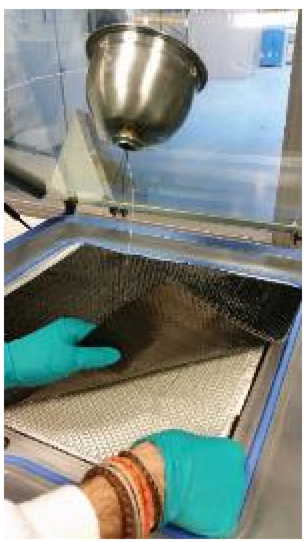
raquel.travieso@aimen.es

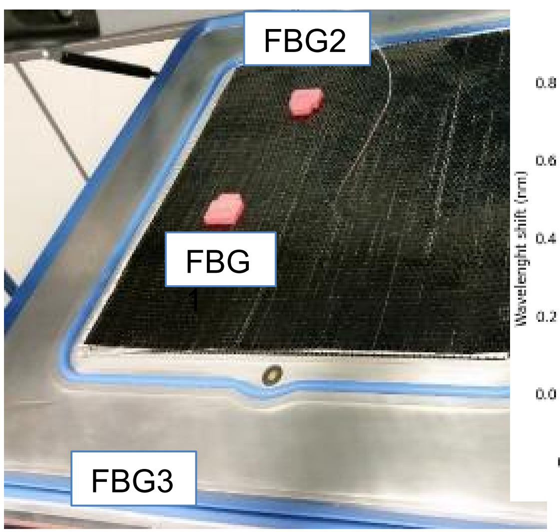
Set up

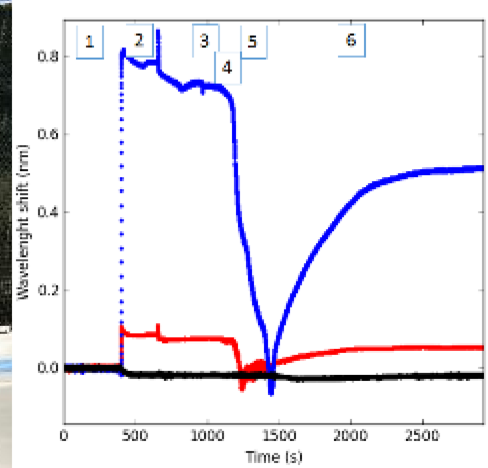
Poner todo el set up de diferentes capas y sensores

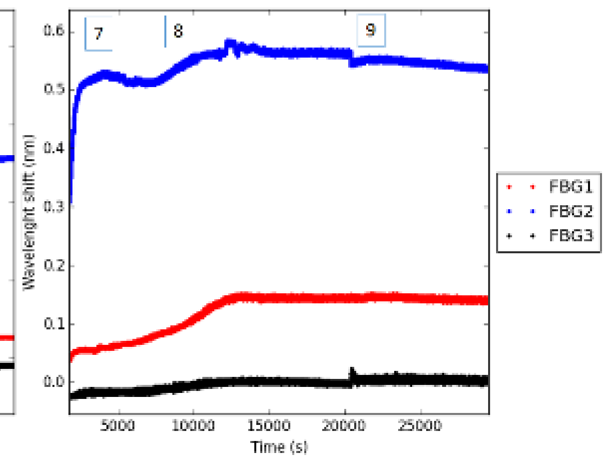
Monitoring of composites manufacturing based on optic sensors

- Embeddement of sensor into the laminate.
- Advantages: Not invasive – not afect the material properties, multiplexing capability, on-line measurements.
- Monitoring of flow arrival and curing process.
- Once the sensor is embedded in the component, it can act as strain sensor in service









raquel.travieso@aimen.es

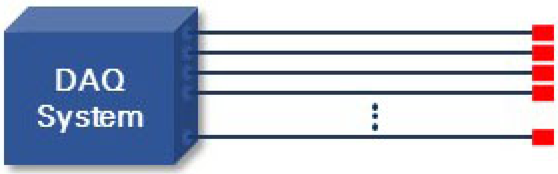
CONTENT

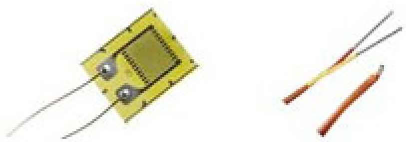
Recortar diapositiva

raquel.travieso@aimen.es

Traditional (Legacy) DAQ System Electrical Sensors

Multiple Wires Per Sensor





Foil strain gages, thermocouples, RTDs, etc.

- Standard method for basic measurements
- Electrical – sensitive to EMI, etc.
- Bulky, metallic wiring

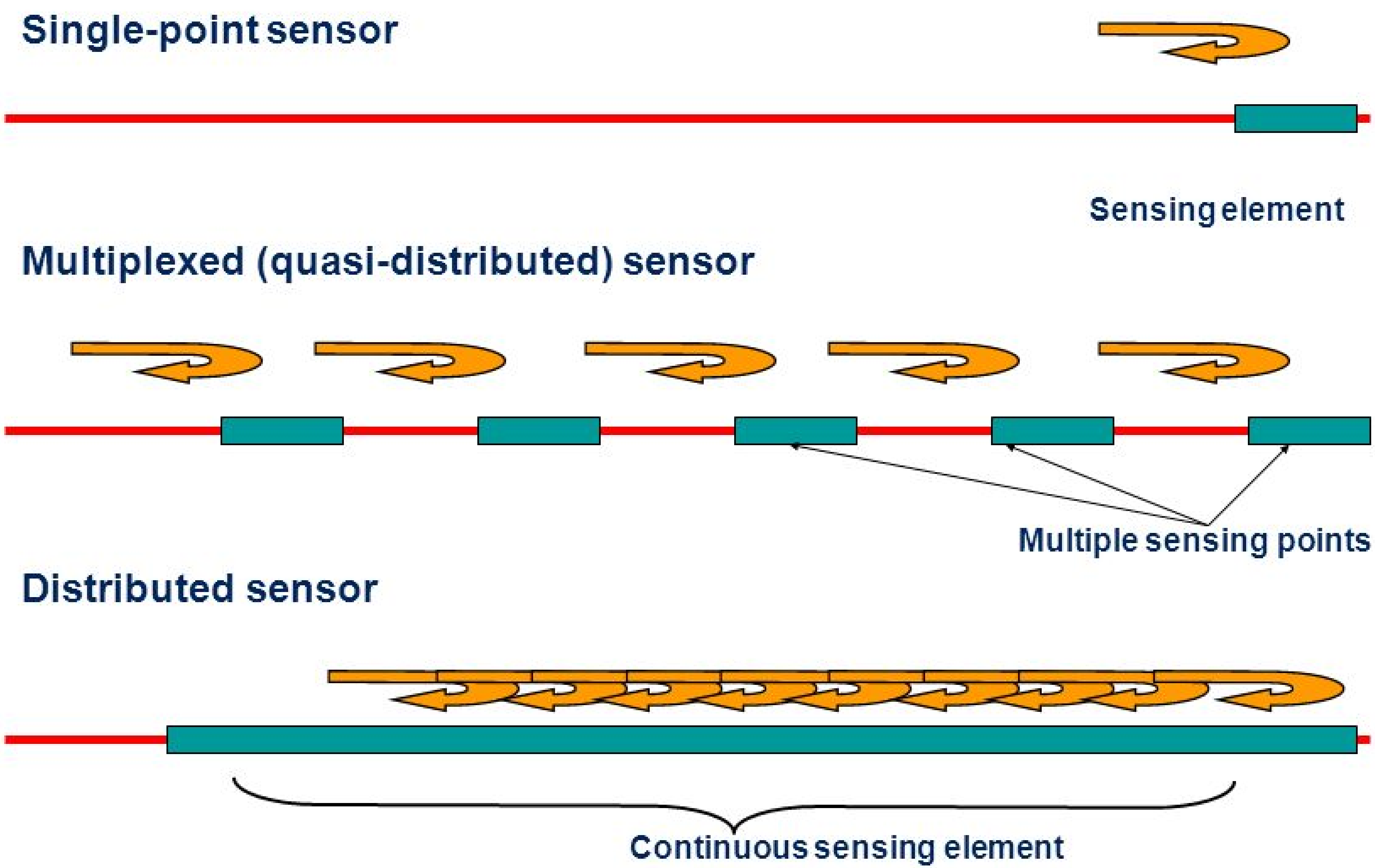
High-Definition Fiber Optic Sensing (HD-FOS)

Distributed 'Continuous' Measurements

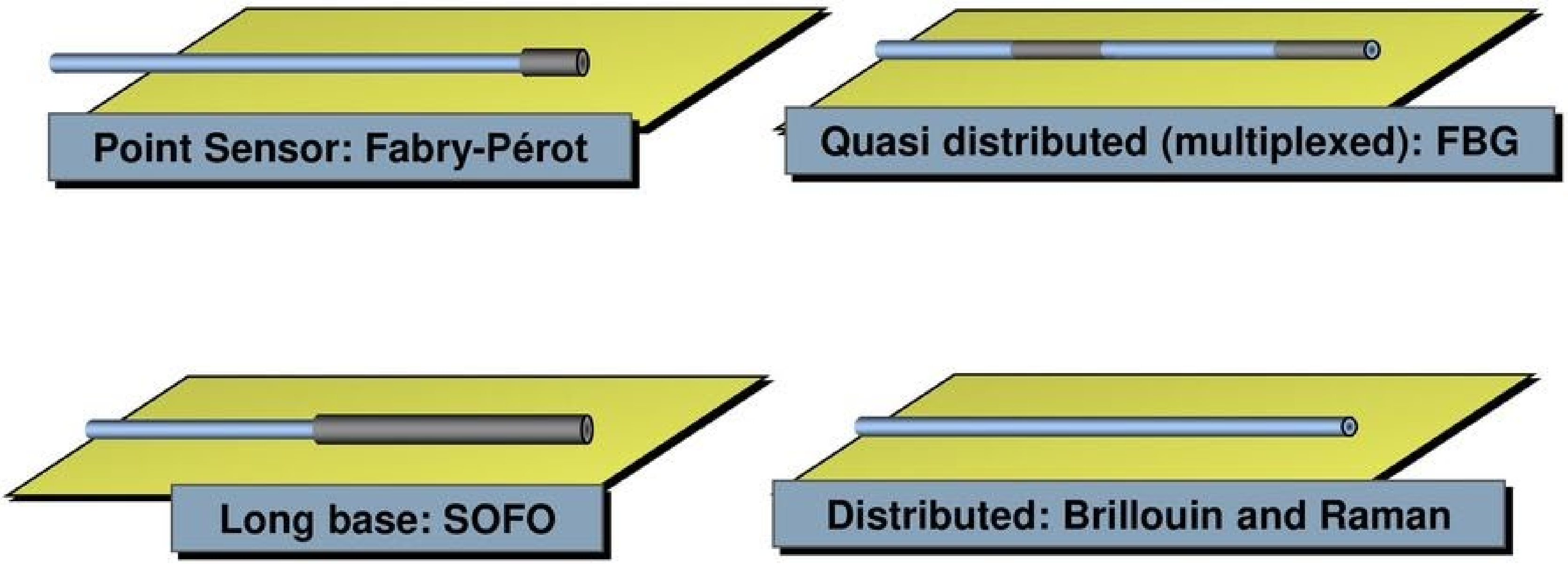
Utilizes the naturally occurring Rayleigh backscatter in fiber core

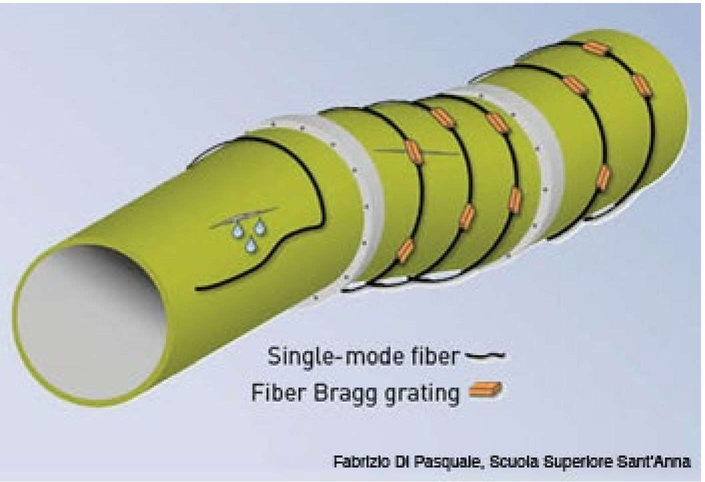
- Optical sensing
- Passive and chemically inert
- Lightweight, embeddable
- High resolution, < 1 mm
- Thousands of gages per meter
- Fast and easy to install

Types of Fiber Optic Sensors



Fiber Optic Sensor Types




Single-mode fiber
Fiber Bragg grating
Fabrizio Di Pasquale, Scuola Superiore Sant'Anna

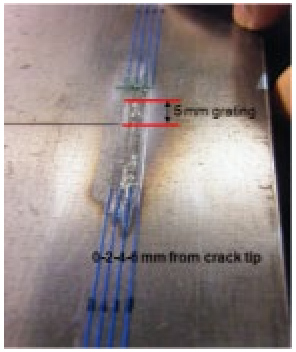
MULTIMATERIAL - PROJECTS

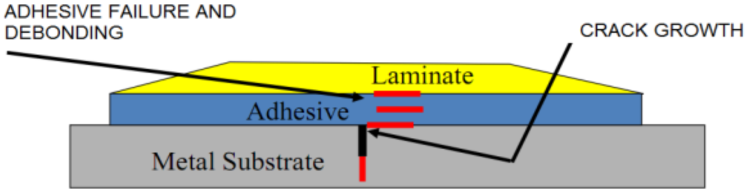
Shipbuilding sector:

Structural health monitoring based on fiber optic sensors (FBGs):

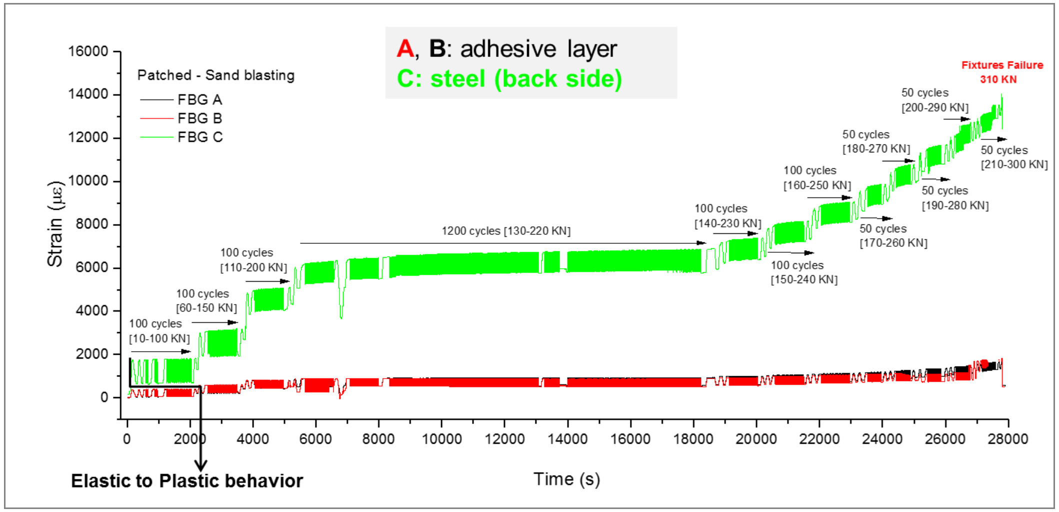
Damaged steel repaired with composite over-laminated

Back side steel monitoring



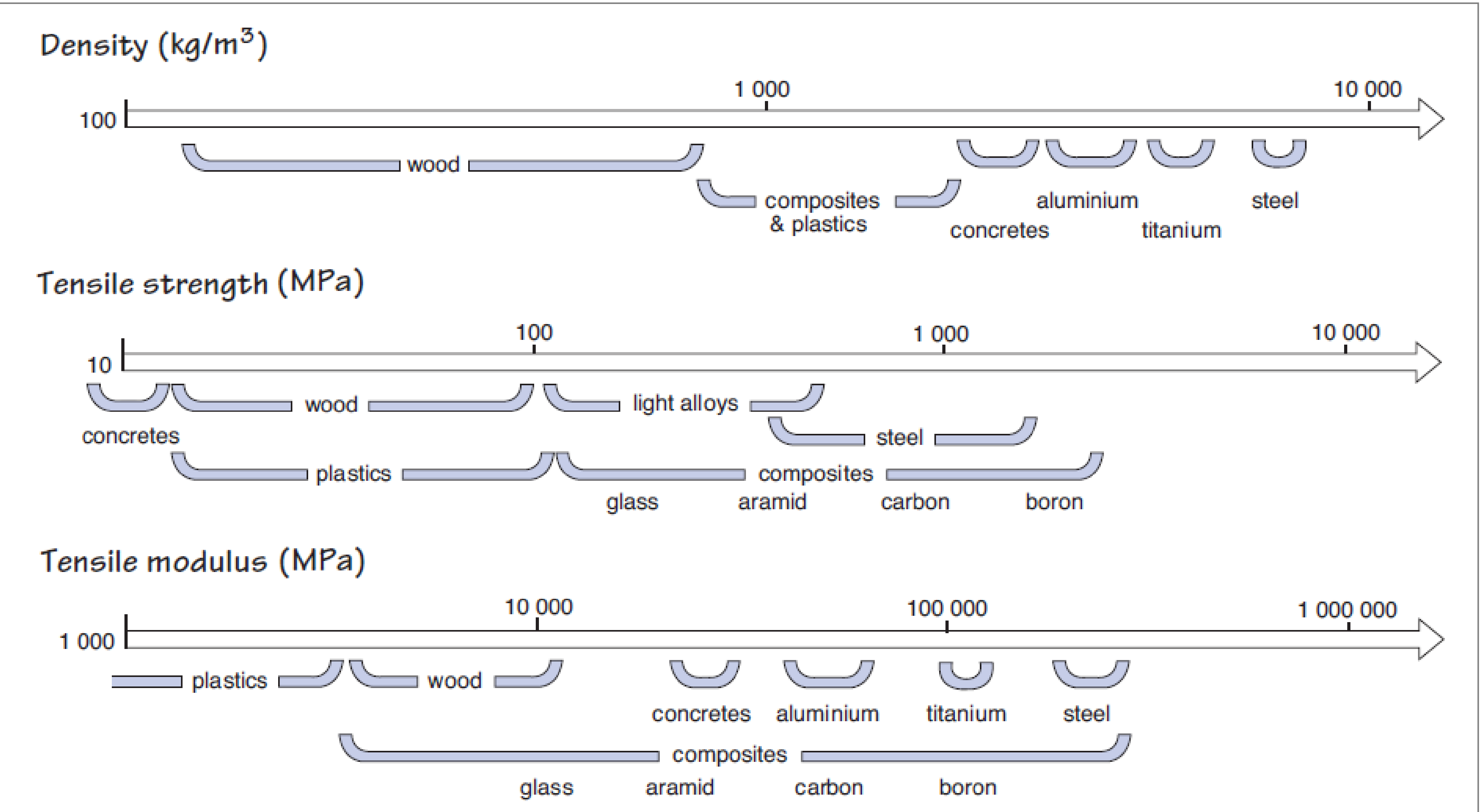


Composite laminate monitoring



Adhesive layer monitoring

AM - Composites vs. other materials



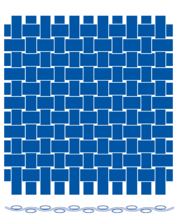
Low density, high resistance & stiffness

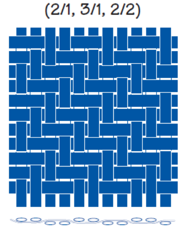
AM - R&D areas

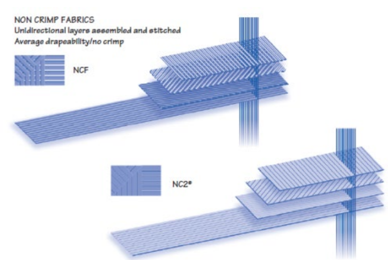
Composite Processing

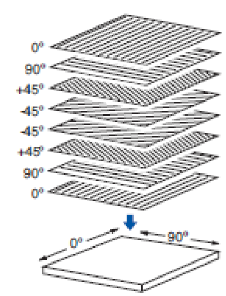
- *Thermoset*
  - Short Fiber
  - Long Fiber
- *Thermoplastic*
  - Short Fiber
  - Long Fiber

Long fiber: Unidirectionnel, fabrics or multi-axial (bear the load)



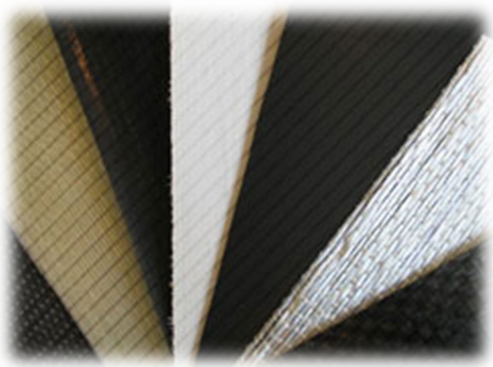


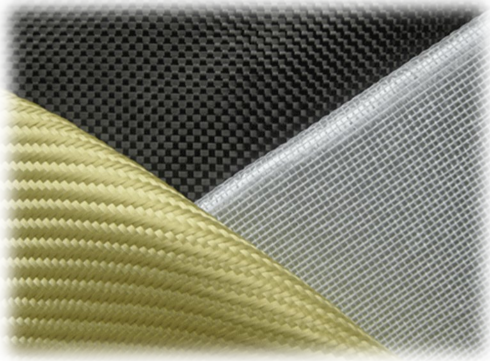




AM - Materials

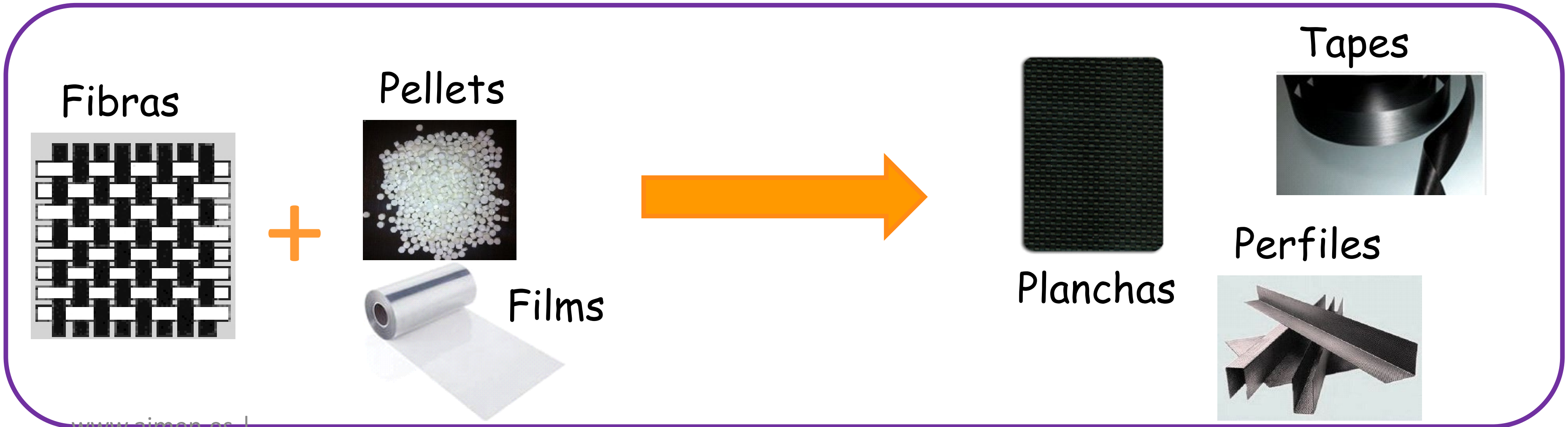
- ✓ Polymer and composites
  - **- Thermosetting** (polyester, vinyl ester, epoxies, phenolic, prepregs)
  - **- Thermoplastic** (polyolefin, PA, PET, ABS, PMMA, etc…)
- ✓ **Biopolymers** thermosetting and thermoplastics
- ✓ **Textiles**: glass fiber, carbon fiber, aramid, natural fibers
- ✓ Development of new polymer by modification with particles and fibers (TP & TS)
- ✓ Elastomeric and TPEs
- ✓ Sandwich structures
- ✓ PUR foams





AM - Thermoplastic composites

- ✓ **Matrices poliméricas**: poliolefinas (HDPE), polieter-eter-quetona (PEEK), poliamidas (PA), polietilenimida (PEI), polietilentereftalato (PET), poli(p-fenilen sulfuro) (PPS)
- ✓ **Fibras**: Vidrio, carbono
- ✓ **Ejemplos comerciales**: TWINTEX, FORTRON, VECTRA, CELSTRAN, TEPEX, CETEX, FULCRUM…




1.4. Wireless SHM Architecture and Applications
Recortar diapositiva
Surface Coverage
Access Control
Turnstile Boom Gate
Central Control via MineBoss
Comms Rack
Proximity Alert System
Antenna Coupler
Amplifiers
Industrial Controller
RF/ Microwave Link
CCTV & Access Control Station
Proximity Alert System
Text, Voice & Data Capabilities
Personnel Tracking
Telemetry & Diagnostics
Electronic Tag Board
Call Station
Wireless Tag Reader
Power Station
Antenna Coupler
BeltBoss
Gas Monitoring
Fire Suppression
Fan Control
Pump Control
Ventilation System
MT5009
8

FOS Projects & Applications:

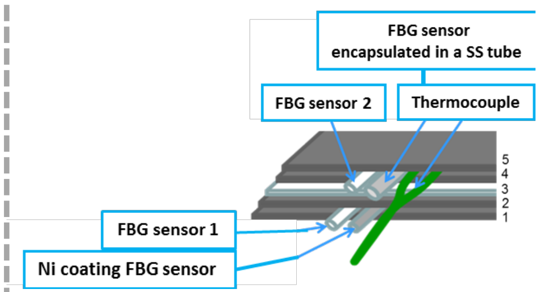
✓ Embedding FBG sensor into composite material to monitoring the manufacturing process and its live work.

- Possible monitoring the composite manufacturing process for: Infusion, RTM, Hand kay up and Filament winding techniques.
- Allow the control of manufacturing process: Vacuum level, Ingess of resine, Wetting of the layers and Curing of the resine
- Possible use the embedded sensors for monitoring the composite life.

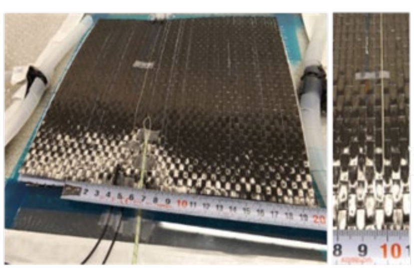
✓ Developing of multimaterial structures for offshore applications with high request to fatigue and durability in marine environment – MIAMI Project.

- Fatigue Monitoring .
- Allow the control of manufacturing process: Vacuum level, Ingess of resine, Wetting of the layers and Curing of the resine
- Possible use the embedded sensors for monitoring the composite life.

Infusion technique



Integration of the FBG sensors between the layers of the composite

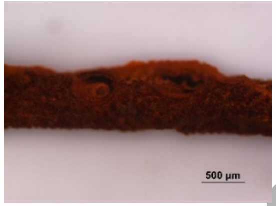


FBG sensors embedded by filament winding
Multimaterial tube of 8m of length

Fe coating FBG sensor for marine corrosion

Before corrosion

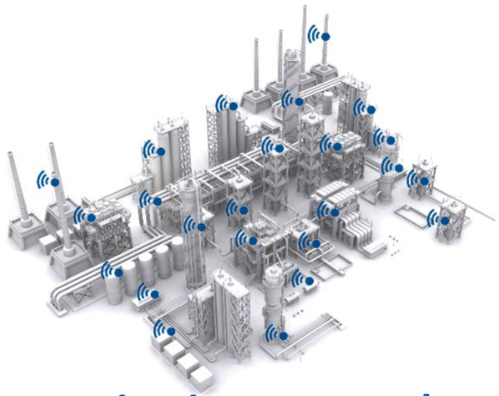
After corrosion

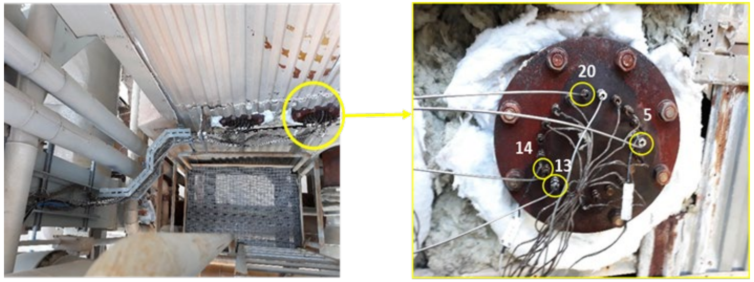


FOS Projects & Applications:

✓ Temperature monitoring in the superheated of a combined cycle power plant. COLIFO Project.

- Thermal cycles with a frequency of twice a month.
- Maximum temperatures around 650oC.





Ingress of FBG sensors through a flange

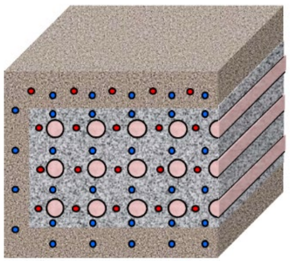
FBG sensors installation in some tubes of the superheated.

✓ Monitoring system development for heat storage systems.

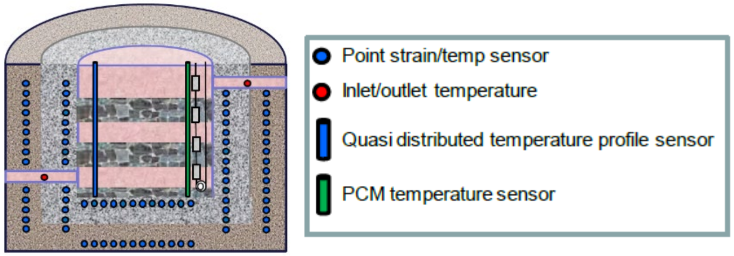
NewSOL project - NMBP-17-2016 - NEW StOrage Latent and sensible concept for highly efficient CSP plants

- Molten salt temperature profile in tank depth (packaged FBG arrays and distributed sensors)
- Concrete embedded temperature/strain sensors (FBG and distributed)
- Molten salt penetration in concrete wall

Concrete module



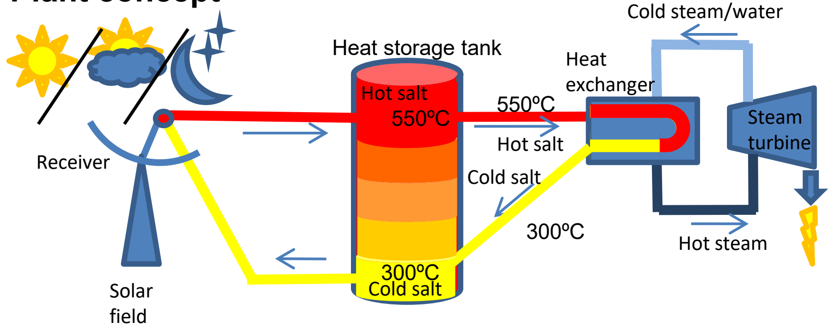
Thermocline tank



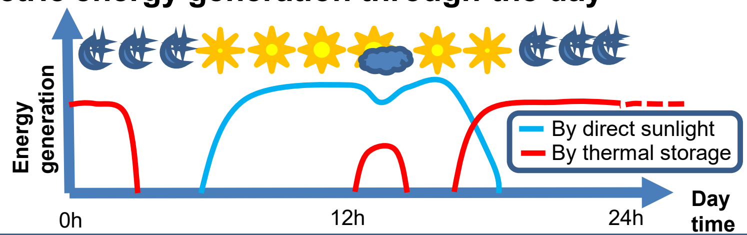
NewSOL - NEW StOrage Latent and sensible concept for highly efficient CSP plants

NewSOL project - NMBP-17-2016 - NEW StOrage Latent and sensible concept for highly efficient CSP plants

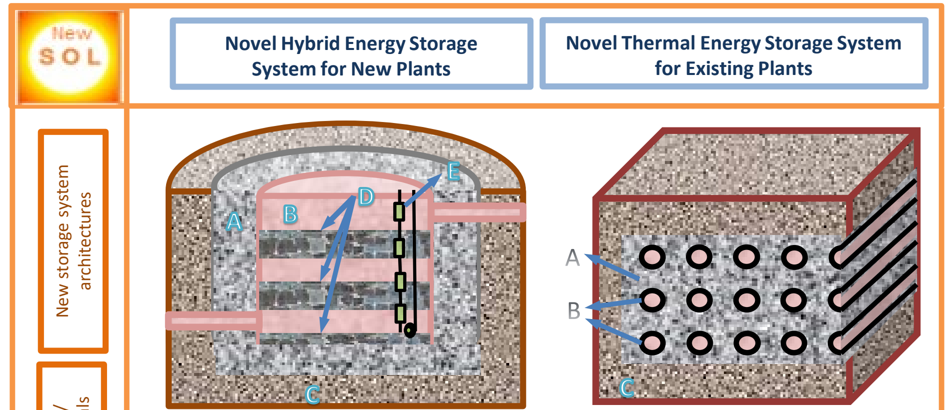
Plant concept



Electric energy generation through the day



New heat storage system concept



A) Ultra High thermal performance concrete
B) Advanced Ca-ternary molten salts (incorporating also nanoparticles)
C) Insulating foam concrete with aerogels
D) Low cost thermocline filler rock material
E) Encapsulated PCM´s

A) High thermal performance concrete
B) Advanced Ca-ternary molten salts
C) Insulating lightweight aggregates concrete

Monitoring system development for heat storage systems

- Molten salt temperature profile in tank depth (packaged FBG arrays and distributed sensors)
- Concrete embedded temperature/strain sensors (FBG and distributed)
- Molten salt penetration in concrete wall (corrosion sensor)

www.aimen.es | ander.zornoza@aimen.es

A. Zornoza, T. Grandal, and S. fraga, "Solar molten salt temperature monitoring with fiber optic sensors," in Advanced Photonics 2016 (IPR, NOMA, Sensors, Networks, SPPCom, SOF), OSA Technical Digest (online) (Optical Society of America, 2016), paper SeM4D.5.

FOS Projects & Applications:

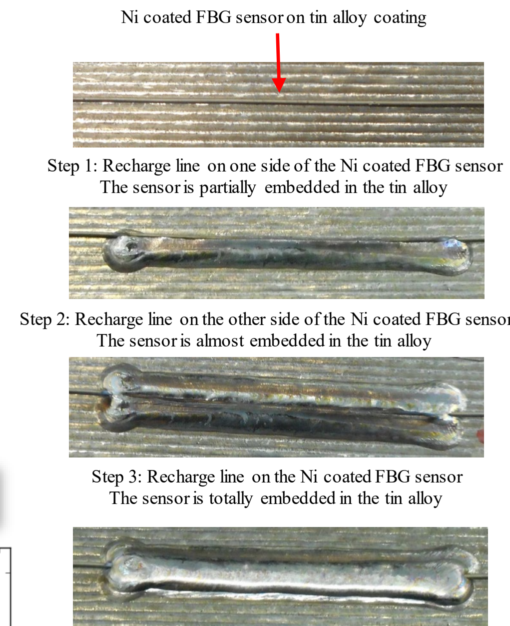
✓ Embedding of FBG sensors into metallic structures by several techniques – NEXT-BEARINGs and FLEXIRAPIDMAN projects.

- Laser Cladding
- Automatic and Manual TIG weldding
- Casting

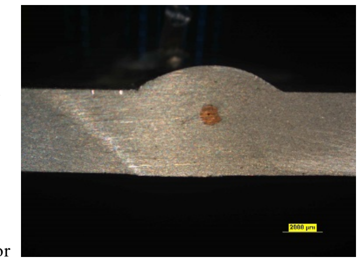
NEXT-BEARINGS
Desarrollo de una nueva generación de componentes navales para la línea de ejes de buques

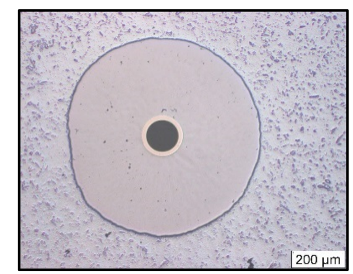
Embedded Materials:

- Antifriction (tin alloy) material for monitoring its erosion and detect cracks.
- Aluminium.



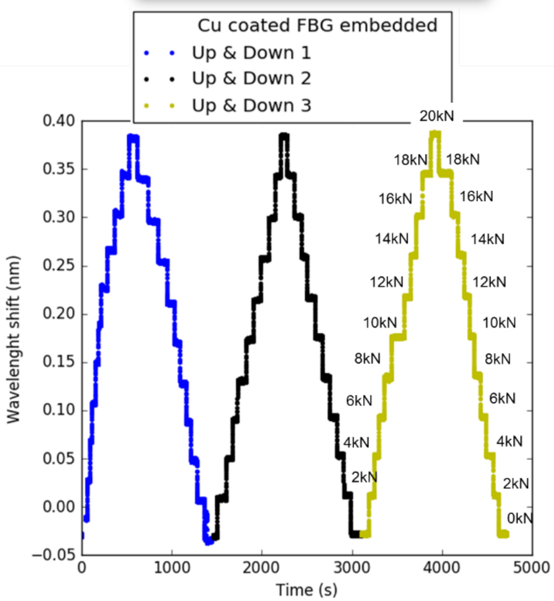
Cu coated FBG sensor embedded into aluminium



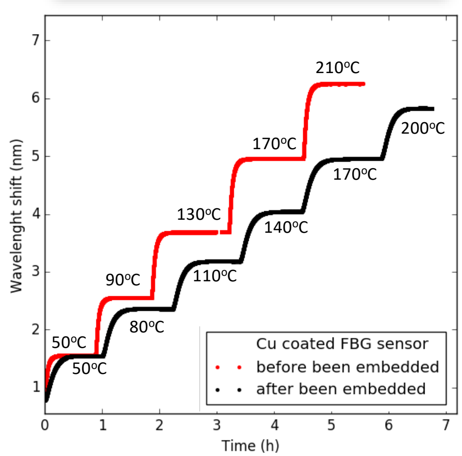


Ni coated FBG sensor embedded into tin alloy

Strain characterization



Thermal characterization

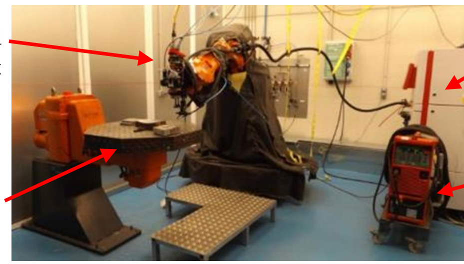


- ✓ The minimum coating thickness of a embedded fiber was: 240µm.
- ✓ The losses are around 2 dB.

Metallic Structures Monitoring

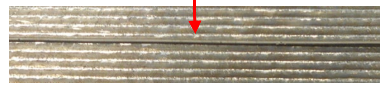
Embedding of FBG sensors into metallic structures by:

- ✓ *Laser Cladding*
- ✓ *Automatic and Manual TIG weldding*
- ✓ *Casting*



Laser cell

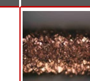
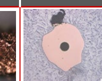
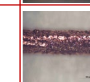
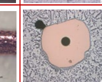
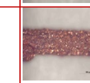
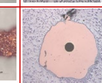
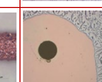
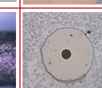
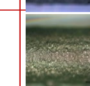
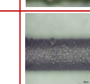
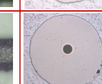
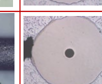
Ni coated FBG sensor on tin alloy coating



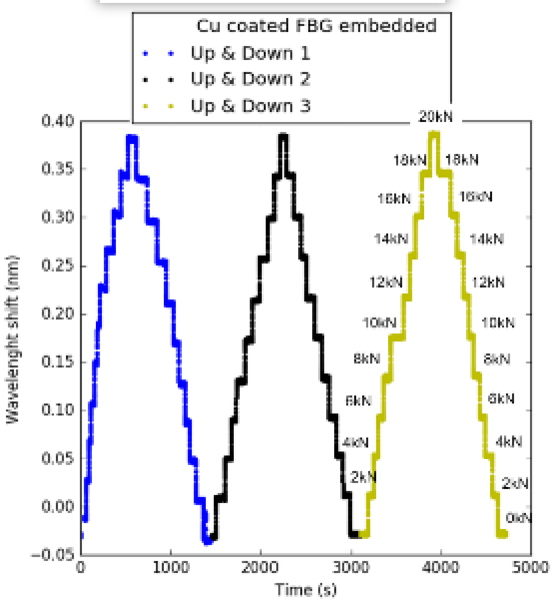
Step 1: Recharge line on one side of the Ni coated FBG sensor
The sensor is partially embedded in the tin alloy

Step 2: Recharge line on the other side of the Ni coated FBG sensor
The sensor is almost embedded in the tin alloy

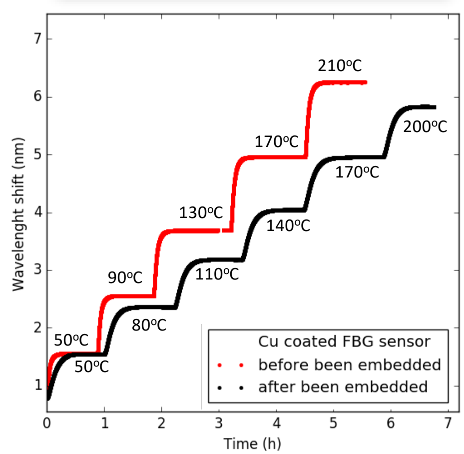
Step 3: Recharge line on the Ni coated FBG sensor
The sensor is totally embedded in the tin alloy

Coating	Thickness (µm)	Loss (dB)	Embedded lenght (cm)	Coating fiber	Cross-section
Cu	518	3.44	4.2		
Cu	586	20.2	3.5		
Cu	624	2.24	3.7		
Cu	685	14.6	4		
Ni	525	2.62	3.6		
Ni	590	2.44	3.5		
Ni	761	1.38	3.2		
Ni	778	4.58	4.6		

Strain characterization



Thermal characterization



- ✓ The mínimum coating thickness of a embedded fiber was: 240µm.
- ✓ The losses are around 2 dB.

FOS Projects & Applications:

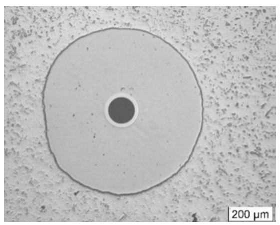
Embedding of FBG sensors into metallic structures by:

Desarrollo de una nueva generación de componentes navales para la línea de ejes de buques

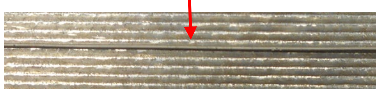
NEXT-BEARINGS

- ✓ *Laser Cladding*
- ✓ *Automatic and Manual TIG weldding*
- ✓ *Casting*

To monitoring, strain, load, temperature, abrasion

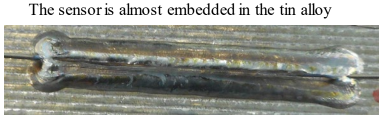


Ni coated FBG sensor on tin alloy coating

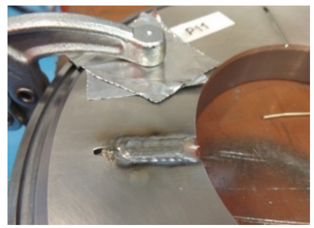


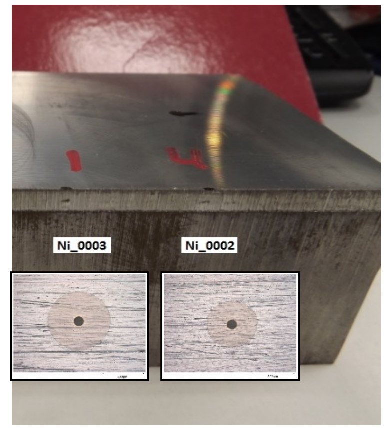
Step 1: Recharge line on one side of the Ni coated FBG sensor
The sensor is partially embedded in the tin alloy

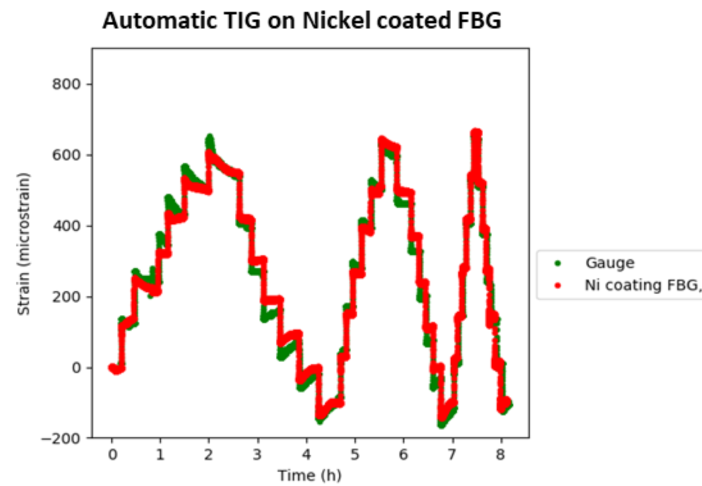
Step 2: Recharge line on the other side of the Ni coated FBG sensor
The sensor is almost embedded in the tin alloy



Step 3: Recharge line on the Ni coated FBG sensor
The sensor is totally embedded in the tin alloy







- ✓ The minimum coating thickness of a embedded fiber was: 240µm.
- ✓ The losses are around 2 dB.

FOS Projects & Applications:

✓ Temperature monitoring in the superheated of a combined cycle power plant. MEMPHIS Project.

- Thermal cycles with a frequency of twice a month.
- Maximum temperatures around 650ºC.

FBG sensors installation in some tubes of the superheated.

MEmpHIS

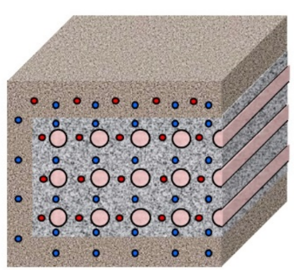
✓ Monitoring system development for heat storage systems.

NewSOL project - NMBP-17-2016 - NEW StOrage Latent and sensible concept for highly efficient CSP plants

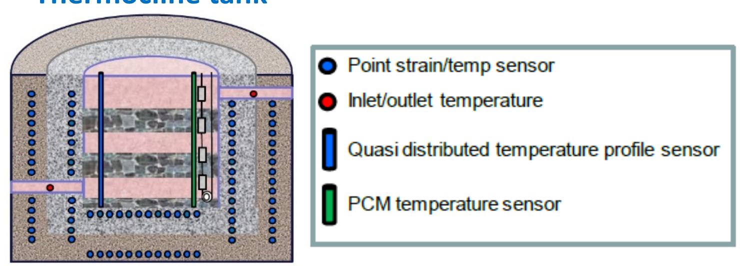
NEWSOL

- Molten salt temperature profile in tank depth (5x3m and 550ºC)
- Concrete embedded temperature and strain sensors
- Detection of molten salt penetration in concrete wall.

Concrete module



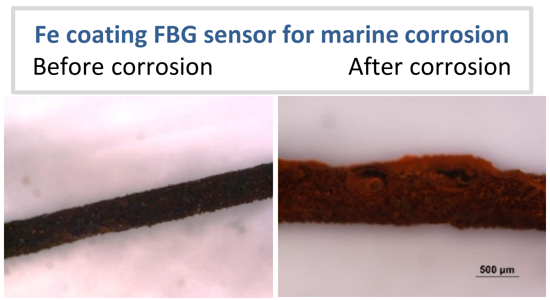
Thermocline tank



FOS Projects & Applications:

✓ Developing of multimaterial structures for offshore applications with high request to fatigue and durability in marine environment. – MIAMI Project.

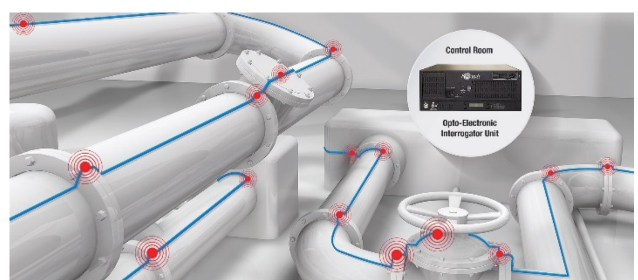
- Possible monitoring the composite manufacturing process by Infusion and filament winding techniques.
- The embedded FOS sensors allow the control of manufacturing process.
- Possible use the embedded sensors for monitoring the composite life: temperatura, strain, load, corrosión.



✓ Geothermal Emission Gas Control – GECO project.

To lower emissions from geothermal power generation by capturing them for either reuse or storage.

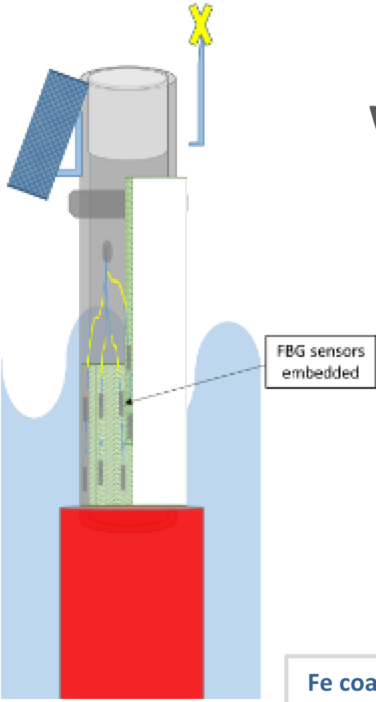
- AIMEN will design and development of an architecture of distributed fiber optic sensors for in-situ temperature (350ºC) and corrosion monitoring in a constructed “closed loop” well testing unit.



Source:fi-ops

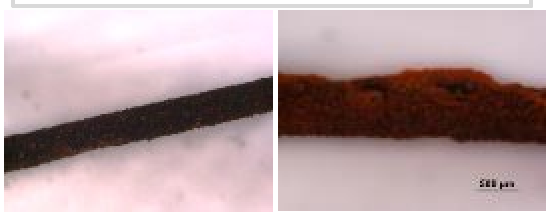
Monitoring Corrosion in Composite Material

Developing of multimaterial structures for offshore applications with high request to fatigue and durability in marine environment.

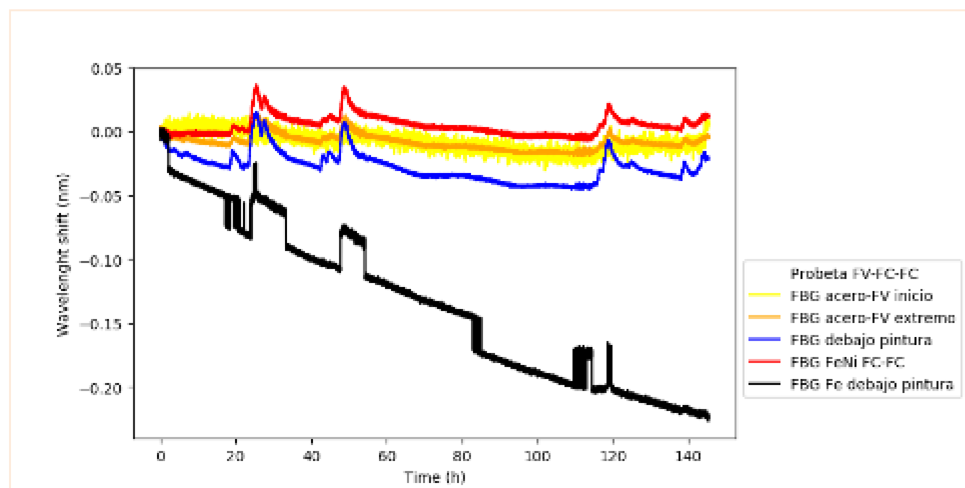


Fe coating FBG sensor for marine corrosion

Before corrosion After corrosion

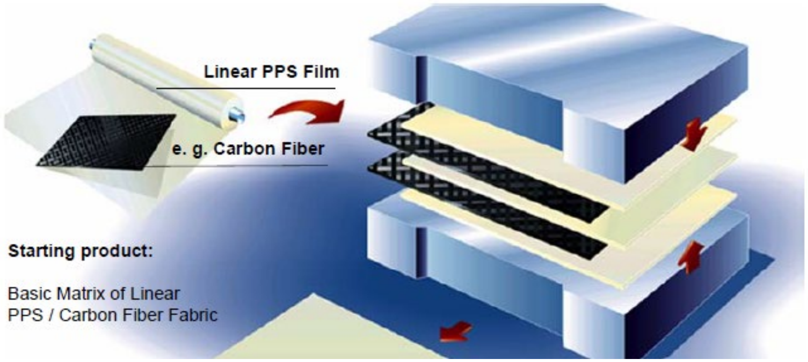


Fe FBG sensors embedded
Between carbon layers and steel-carbon layer.

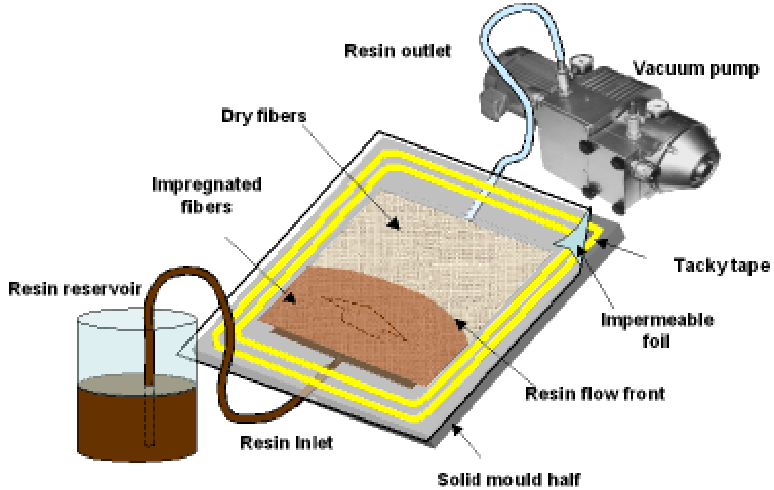


AM - Thermoplastic composites

Compression moulding



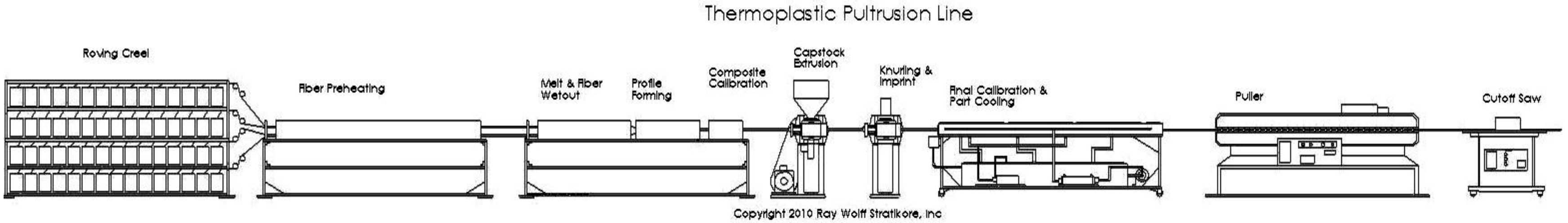
Vacuum Infusion of TPC



Reactive processing of thermoplastic composites (Anionic Polyamide-6)

TPC Pultrussion

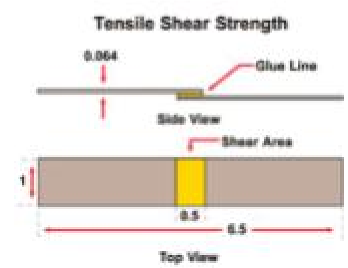
Thermoplastic Pultrusion Process Using Commingled Glass/Polypropylene Twintex® Roving

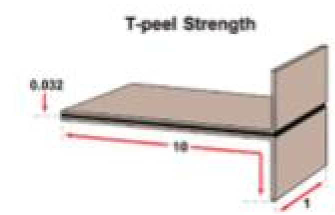


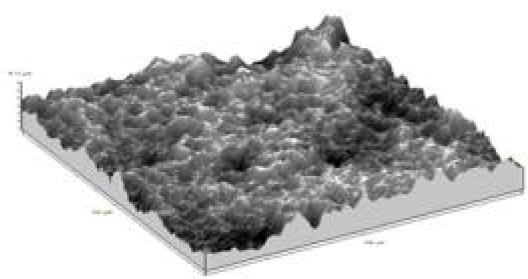
R&D. Advanced Materials

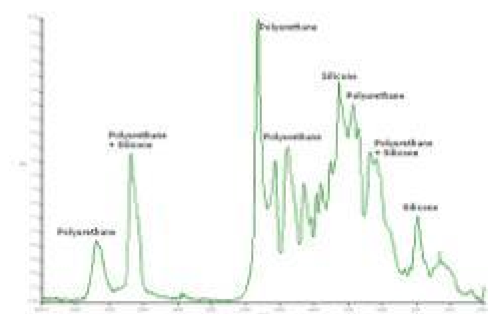
Characterization

- ✓ FTIR, fluorescence RX, SEM, optical microscopy
- ✓ Mechanical characterization: tensile, compression, bending, resiliency, peel, impact, hardness, fatigue.
- ✓ %fiber-matrix
- ✓ Water and solvents absorption
- ✓ Durability, salt chamber, climate chamber
- ✓ Migration (total)
- ✓ Thermal characterization: DSC, TGA, DMA, Vicat







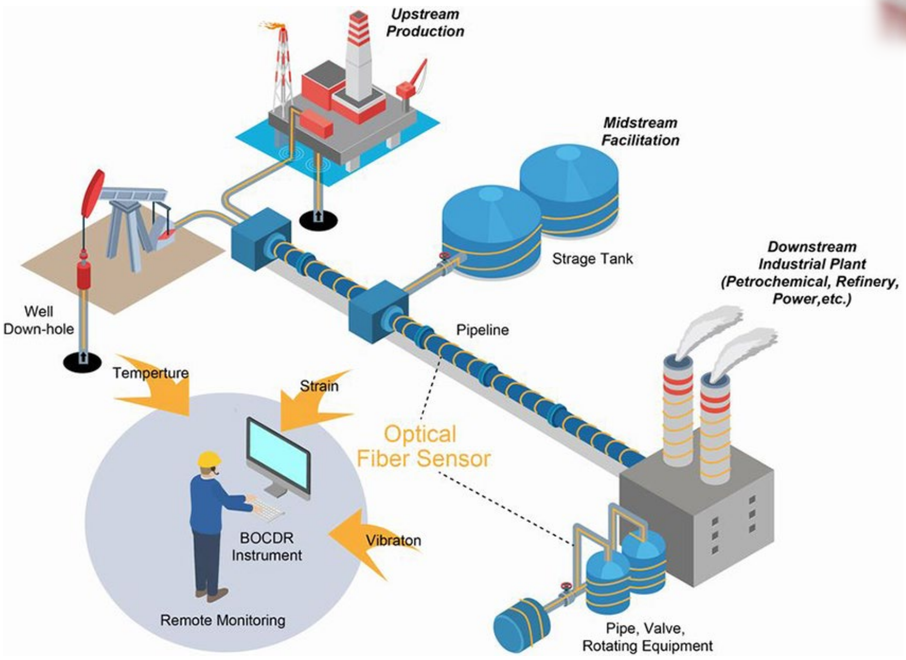


Technology B - Fiber Optic Sensors (FOS)

Possibilities for Structural Health Monitoring (SHM) with FOS:

Gluing or embedding the FOS in **multiple materials** (concrete, composite, metals, polymers, composites, metals, etc.) for monitoring:

- strain
- temperature
- load
- corrosion
- abrasion
- vibration



raquel.travieso@aimen.es

Source:yokogawa