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)
Structural Health Monitoring (SHM)

the process of implementing a damage detection that can affect the system’s performance and characterization strategy for engineering structures.
SHM – Past Catastrophic Failures

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

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

Chevron Oil Explosion (Richmond, California, 2013)
Old pipe - Crude oil leaking
+15000 residents needed medical attention
• Civil engineering
  Buildings
  Bridges
  Dams
  Tunnels
  Mining

• Chemical installations
  Piping
  Tanks

• Aerospace
  Civil and military airplanes
  Space craft
  Helicopters

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

• Transportation
  Automotive
  Trains
  Ships/boats

• Geophysics
  Soil mechanics
  Volcanoes
  Earthquakes
✓ **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**
Operational Evaluation

Statistical Model

Data Interpretation and diagnosis

Sensoring

Data Acquisition

Step 1

Step 2

number
type
location
SHM - Steps

Step 1: Operational Evaluation

Step 2: Sensoring
- number
- type
- location

Step 3: Data Acquisition

Statistical Model

Data Interpretation and diagnosis

Data

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SHM - Steps

Step 1: Operational Evaluation

Step 2: Sensoring

Step 3: Data Acquisition

Step 4: Data Interpretation and diagnosis

Teaching process:
Convert sensor data to damage information
SHM - Steps

Step 1: Operational Evaluation

Step 2: Sensoring
  - number type location

Step 3: Data Acquisition

Step 4: Data Interpretation and diagnosis
  - teaching process convert sensor data to damage information

Step 5: Statistical Model

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 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
ADVANCED MONITORING SYSTEMS DEVELOPMENT FOR MANUFACTURING PROCESSING AND SERVICING OF COMPOSITES BASED ON NON-INVASIVE EMBEDDED SENSORS
Aim of the project

TECHNOLOGICAL DEVELOPMENT

- sensors
- material responses characterization
- machine learning & software development

USE-CASES

- Manufacturing
- Repairing

SECTORS INVOLVED

- 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
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
Technology A

DC-DIELECTRIC SENSORS

Resin flow and cure evolution
Monitoring based on ion mobility or dielectric measurement

Thermoset & thermoplastic composites
Process out of autoclave
Monitoring manufacturing of composites

Invasive
% curing degree signal
Technologies & Materials

**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

**Technology B**

FIBER OPTIC SENSORS (FOS)
Fiber Bragg Grating (FBG) – localized
Distributed - continuous

**Robotic & Control**

Photonic sensors
Smart manufacturing – Machine Learning
Manufacturing process control
Structural Health Monitoring (SHM)

Invasive
% curing degree signal

Non-invasive
Unknown signal

TEACH
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
Technology A – DC-Dielectric sensors

Monitoring Manufacturing
Resin flow and cure evolution
based on ion mobility or dielectric measurement

Curing Evolution

Temperature (°C)

Time (min)

Resin inlet

Cure begins

Cooling
Monitoring Manufacturing
Resin flow and cure evolution based on ion mobility or dielectric measurement

\[ \alpha = \frac{H_T - H_R}{H_T} \times 100 \]

- \( \alpha \) (%): curing degree
- \( H_R \): heat reaction
- \( H_T \): heat 100% cure

**Example Calculation:**

\[ \text{curing degree} = \frac{307.3 - 2.4}{307.3} = 99\% \]
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
In SHM, most commonly used Fiber Optic Sensors (FOS) is Fiber Bragg Grating (FBG) sensors, with multiplexing capacity.
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
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 (<1000°C)
✓ 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 fundamentals
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**
17:30-19:00 (12\textsuperscript{th} June)
visit to Galventus - reparation of wind turbine blades

**LEADING EDGE REPARATION by Hand lay-up manual process**

- Study of the damage
- Surface treatment
Monitoring manufacturing process

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
✔ Sensor set-up

FBG sensor
steel protection
temperature
strain

Dielectric sensor
temperature
curing degree

FBG sensor
temperature
strain
Monitoring manufacturing process

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
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FBG sensor
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Dielectric sensor
- Temperature
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FBG sensor
- Temperature
- Strain
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
- Sensor set-up
- Double sided tape to limit the zone to be repaired
Monitoring manufacturing process

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
✓ Sensor set-up
✓ Double sided tape
✓ Resin + catalyst
✓ Reinforcement: glass fiber
Monitoring manufacturing process

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
- Sensor set-up
- Double sided tape
- Resin + catalyst
- Reinforcement: glass fiber
- Second layer of FBG sensors
17:30-19:00 (12\textsuperscript{th} June )
visit to Galventus - reparation of wind turbine blades

**LEADING EDGE REPARATION by HAND LAY-UP manual process**

- Study of the damage
- Surface treatment
- Sensor set-up
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- Resin + catalyst
- Reinforcement: glass fiber
- Second layer of FBG sensors
- Resin + catalyst
- Reinforcement: glass fiber
- ......
Monitoring manufacturing process

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- Reinforcement: glass fiber
- ........
- Bleeding blanket
- Peel ply
17:30-19:00 (12th June)
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- 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

**LEADING EDGE REPARATION by HAND LAY-UP manual process**

![Graph showing temperature, resistance, and time](image)

- **Resin inlet**
- Temperature (°C)
- Resistance (Ohm)
- Time (min)
Monitoring manufacturing process

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

LEADING EDGE REPARATION by HAND LAY-UP manual process

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Resistance (Ohm)</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room $T^g$</td>
<td>Cure begins</td>
<td>Heat up</td>
</tr>
<tr>
<td>Resin inlet</td>
<td>Curing @</td>
<td>Post-curing</td>
</tr>
</tbody>
</table>

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Monitoring manufacturing process

Manufacturing control by monitoring the full process

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

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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

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

Available Resin Arrival and Temperature Sensors

- In-mould Durable
  - High Temp RTM

- 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/THERMOPHORES 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).
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
Embedded RFID (Radio Frequency Identification) systems

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

STRUCTURAL HEALTH MONITORING: Fiber optic sensors (FOS)
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_
- 45 min _90°C_

Cure begins
Cure ends??
Cooling

Resin inlet

%Cure (1) = (307.3 - 2.4) / 307.3 = 99 %

%Cure (2) = (307.3 - 5.2) / 307.3 = 98 %

Not homogeneous curing?

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

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- Embeddement of sensor into the laminate.
- Advantages: Not invasive – not affect 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
CONTENT

1. SHM Introduction
   1.1. Past Catastrophic Structural (w/o SHM) Failures
   1.2. SHM Process
   1.3. SHM Applications
   1.4. Wireless SHM Architecture and Applications

2. SHM Development and Technologies

3. Old SHM Technology
   3.1. MEMS
   3.2. Piezoelectric Sensors
   3.3. Ultrasonic Sensors

4. New SHM Technology
   4.2. Fiber Optic Sensors (FOS)
   4.6. Wireless Sensors Network
   4.7. Embedded RFID Systems

5. Emerging and Future SHM Technology
   5.1. Self Healing SHM
   5.2. Carbon Nanotube (CNT) Sensors
   5.3. Energy Harvesting

6. SHM Feasibility
   6.1. How Far Can It Goes

7. Conclusion
<table>
<thead>
<tr>
<th>Traditional (Legacy) DAQ System</th>
<th>High-Definition Fiber Optic Sensing (HD-FOS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Sensors</strong></td>
<td><strong>Distributed ‘Continuous’ Measurements</strong></td>
</tr>
<tr>
<td>Multiple Wires Per Sensor</td>
<td></td>
</tr>
<tr>
<td>DAQ System</td>
<td>HD-FOS Interrogator</td>
</tr>
<tr>
<td>Foil strain gages, thermocouples, RTDs, etc.</td>
<td>Utilizes the naturally occurring Rayleigh backscatter in fiber core</td>
</tr>
</tbody>
</table>

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

- 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

- Single-point sensor

- Multiplexed (quasi-distributed) sensor

- Distributed sensor

Sensing element

Multiple sensing points

Continuous sensing element
Fiber Optic Sensor Types

- Point Sensor: Fabry-Pérot
- Quasi distributed (multiplexed): FBG
- Long base: SOFO
- Distributed: Brillouin and Raman
MULTIMATERIAL - PROJECTS

Shipbuilding sector:

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

- Back side steel monitoring
- Composite laminate monitoring
- Adhesive layer monitoring

Damaged steel repaired with composite over-laminated
AM - Composites vs. other materials

Low density, high resistance & stiffness
Long fiber: Unidirectional, 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

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✓ **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
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 lay up and Filament winding techniques.
- Allow the control of manufacturing process: Vacuum level, Ingress of resin, Wetting of the layers and Curing of the resin.
- 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, Ingress of resin, Wetting of the layers and Curing of the resin.
- 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
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 650°C.

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
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

Heat storage tank
Cold salt
Hot salt
Cold steam/water
Hot steam

550°C
300°C

Solar field
Receiver

Electric energy generation through the day

Energy generation
0h 12h 24h Day time
By direct sunlight
By thermal storage

New heat storage system concept

Novel Hybrid Energy Storage System for New Plants
Novel Thermal Energy Storage System for Existing Plants

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

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)

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

- Laser Cladding
- Automatic and Manual TIG welding
- Casting

Embedded Materials:

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

**Strain characterization**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Recharge line on one side of the Ni coated FBG sensor. The sensor is partially embedded in the tin alloy.</td>
</tr>
<tr>
<td>2</td>
<td>Recharge line on the other side of the Ni coated FBG sensor. The sensor is almost embedded in the tin alloy.</td>
</tr>
<tr>
<td>3</td>
<td>Recharge line on the Ni coated FBG sensor. The sensor is totally embedded in the tin alloy.</td>
</tr>
</tbody>
</table>

**Thermal characterization**

- The minimum coating thickness of a embedded fiber was: 240µm.
- The losses are around 2 dB.
Embedding of FBG sensors into metallic structures by:

- **Laser Cladding**
- **Automatic and Manual TIG welding**
- **Casting**

**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.

---

### Strain characterization

**Cu coated FBG embedded**

- Blue: Up & Down 1
- Red: Up & Down 2
- Yellow: Up & Down 3

---

### Thermal characterization

- **Cu coated FBG sensor**
  - Red: before been embedded
  - Black: after been embedded

---

<table>
<thead>
<tr>
<th>Coating</th>
<th>Thickness (µm)</th>
<th>Loss (dB)</th>
<th>Embedded length (cm)</th>
<th>Coating fiber</th>
<th>Cross-section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>518</td>
<td>3.44</td>
<td>4.2</td>
<td>Coating fiber</td>
<td>Cross-section</td>
</tr>
<tr>
<td>Cu</td>
<td>586</td>
<td>3.5</td>
<td>3.5</td>
<td>Coating fiber</td>
<td>Cross-section</td>
</tr>
<tr>
<td>Cu</td>
<td>624</td>
<td>3.7</td>
<td>3.7</td>
<td>Coating fiber</td>
<td>Cross-section</td>
</tr>
<tr>
<td>Cu</td>
<td>685</td>
<td>4</td>
<td>4</td>
<td>Coating fiber</td>
<td>Cross-section</td>
</tr>
<tr>
<td>Ni</td>
<td>525</td>
<td>2.62</td>
<td>3.6</td>
<td>Coating fiber</td>
<td>Cross-section</td>
</tr>
<tr>
<td>Ni</td>
<td>590</td>
<td>3.5</td>
<td>3.5</td>
<td>Coating fiber</td>
<td>Cross-section</td>
</tr>
<tr>
<td>Ni</td>
<td>761</td>
<td>3.2</td>
<td>3</td>
<td>Coating fiber</td>
<td>Cross-section</td>
</tr>
<tr>
<td>Ni</td>
<td>778</td>
<td>4.6</td>
<td>4.6</td>
<td>Coating fiber</td>
<td>Cross-section</td>
</tr>
</tbody>
</table>

- The minimum coating thickness of a embedded fiber was: 240µm.
- The losses are around 2 dB.
Embedding of FBG sensors into metallic structures by:

- **Laser Cladding**
- **Automatic and Manual TIG welding**
- **Casting**

To monitoring, strain, load, temperature, abrasion

The minimum coating thickness of an embedded fiber was: 240µm.

The losses are around 2 dB.
Temperature monitoring in the superheated of a combined cycle power plant. MEMPHIS Project.
- Thermal cycles with a frequency of twice a month.
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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 (5x3m and 550°C)
- Concrete embedded temperature and strain sensors
- Detection of molten salt penetration in concrete wall.

FOS Projects & Applications:
Concrete module
Thermocline tank
✓ Developing of multimaterial structures for offshore applications with high request to fatigue and durability in marine environment. – MIAMI Project.
  o Possible monitoring the composite manufacturing process by Infusion and filament winding techniques.
  o The embedded FOS sensors allow the control of manufacturing process.
  o Possible use the embedded sensors for monitoring the composite life: temperatura, strain, load, corrosión.

Fe coating FBG sensor for marine corrosion
Before corrosion  After corrosion

✓ Geothermal Emission Gas Control – GECO project.
  To lower emissions from geothermal power generation by capturing them for either reuse or storage.
  o AIMEN will design and development of an architecture of distributed fiber optic sensors for in-situ temperature (350°C) and corrosion monitoring in a constructed “closed loop” well testing unit.
Developing of multimaterial structures for offshore applications with high request to fatigue and durability in marine environment.

Monitoring Corrosion in Composite Material

Fe coating FBG sensor for marine corrosion
Before corrosion  After corrosion

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

Graph showing wavelength shift over time for different materials and conditions.
AM - Thermoplastic composites

Compression moulding

Vacuum Infusion of TPC

TPC Pultrusion

Thermoplastic Pultrusion Process Using Commingled Glass/Polypropylene Twintex® Roving

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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
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