

Investigating the Sensitivity of Fiber Bragg Grating to a Process Induced Gap during Vacuum Bag Consolidation in Thermoplastic Composite Laminates

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ONERA, Département: DMAS – Unité de recherche: EPIC

Session : Axe 2 Couplages thermo-hygromécaniques et écoulements dans les milieux fibreux

Jeudi, 14 Novembre, 2024

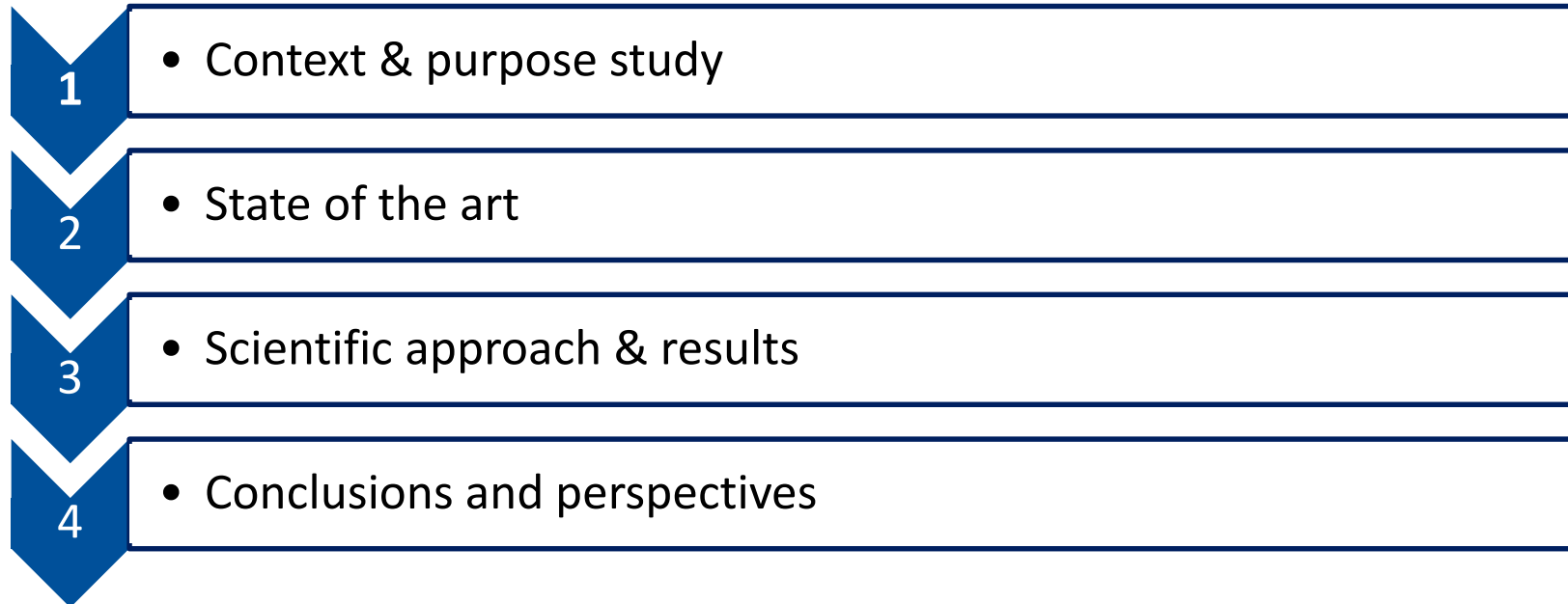
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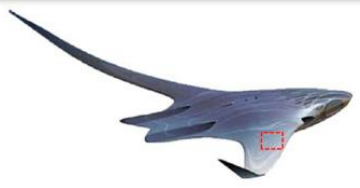


Presentation overview



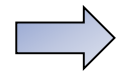
1. Industrial context & purpose of the study

Aeronautical applications

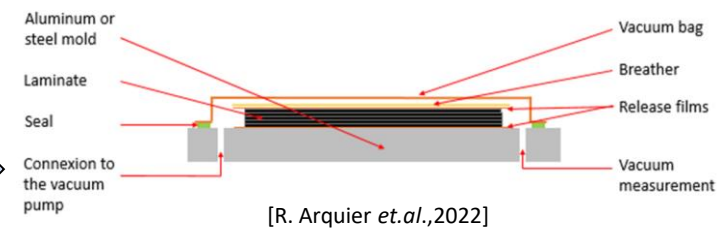


[Z.Zhao et al., 2023]

Growing use of **high-performance carbon fiber/thermoplastic composites** in structural applications



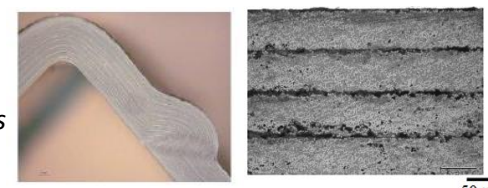
Material used : UD prepreg **CF/LM-PAEK**



[R. Arquier et al., 2022]

High **temperature resistance**

Excellent **mechanical properties** *Out-of-plane waviness*



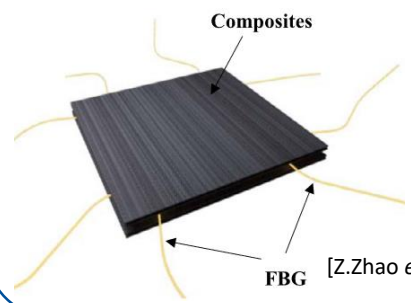
[Mukhopadhyay et al., 2015] [F. Saffar et al., 2019] 50 μm

Manufacturing process :
Poor **consolidation process** →
Process induced defects

Interply porosities

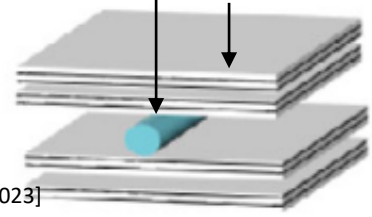
Study purpose: Development of a methodology for an **in-depth understanding of consolidation phenomena & detection of process-induced defects**

Proposed solution : Process monitoring with embedded FBG



[Z.Zhao et al., 2023]

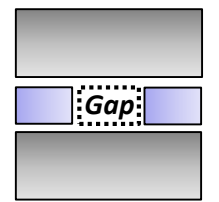
Fibre Bragg Grating (FBG) : Sensor sensitive to temperature & strain
Prepreg stacking



Process monitoring & Smart composites
→ **Real-time monitoring of the health state of the structure**



Evaluating FBG's sensitivity to
 Consolidation process
 Process induced « **gap** »

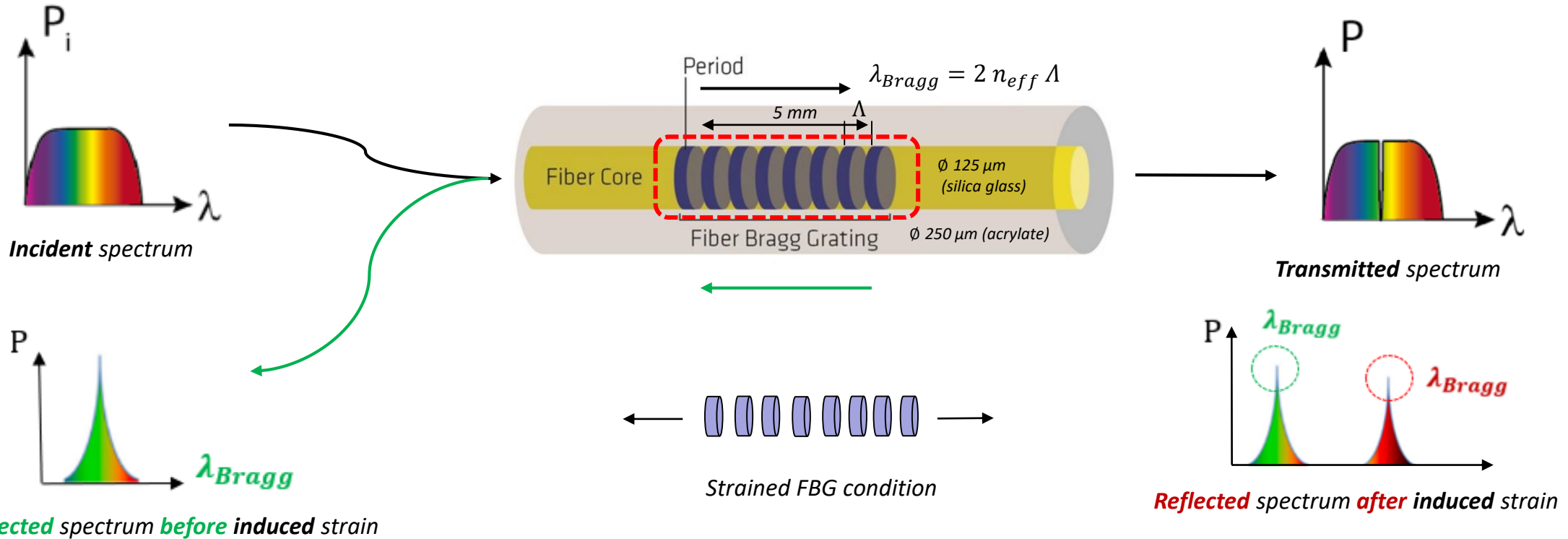


Defect induced during during AFP process (Automated Fibre Placement)

How does an FBG work ?

2. State of the art : FBG principle

FBG principle



$$\frac{\Delta \lambda_B}{\lambda_B} = K_T \cdot \Delta T + K_\varepsilon \cdot \varepsilon + K_p \cdot \Delta P$$

With :

$$K_T = 0.009^\circ C^{-3} \Delta T^2 + 0.09^\circ C^{-2} \Delta T + 1565^\circ C^{-1}$$

$$K_\varepsilon = 0.0012 \mu def^{-1}$$

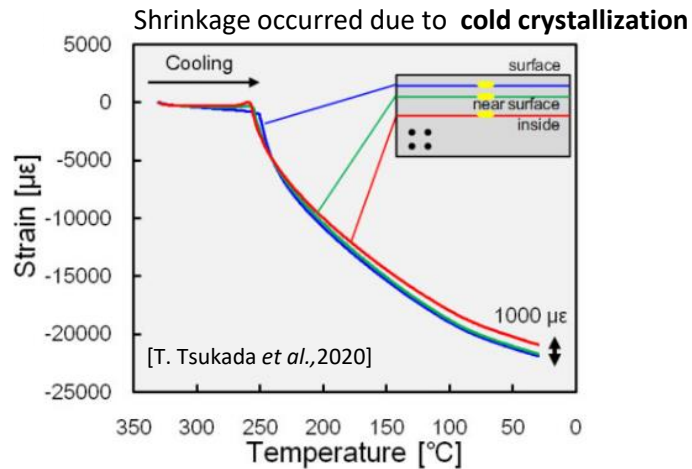
[Teraxion, I.Garcia et al., 2015]

[R.J. Black et. al., 2008]

Literature review :
Process monitoring & detection of process-induced defects by embedded FBG

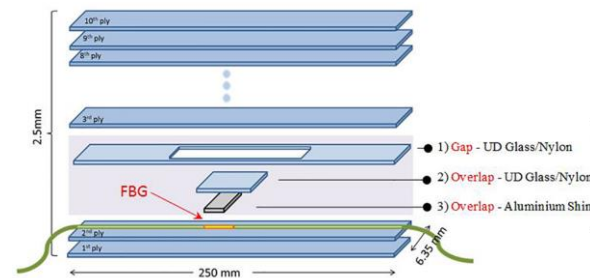
2. State of the art : Process monitoring & defect detection by embedded FBG

Process monitoring by embedded FBG

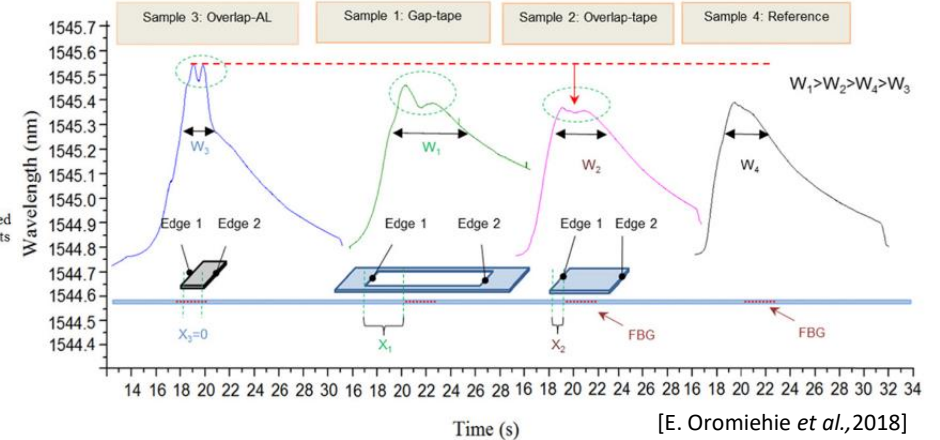


In-plane transverse strain histories of CF/PPS measured during cooling process during molding

Identification of process-induced defects during composite manufacturing n AFP with embedded FBG



Configuration of defect induced laminates glass fiber/nylon manufactured using AFP



Size effect of embedded defects on the reflected wavelength (in the fourth lay-up)

Existing challenges & proposed solutions of our study

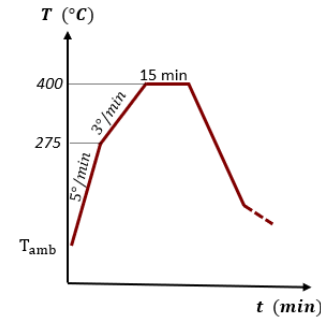
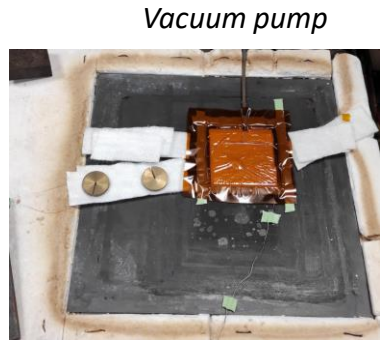
- ❑ Manufacturing methods such as AFP, hot-press, autoclave (specialized knowledge and skills, high manufacturing cost) → **VBO (Only Vacuum Bag) processing**
- ❑ Deeper comprehension of **consolidation phenomena** → **In-situ monitoring of consolidation process with embedded sensor in VBO**
- ❑ Use of embedded **FBG sensors** → **Calibration** prior to their embedment in the laminate



*Scientific approach :
Manufacturing process & introduction of the defect*

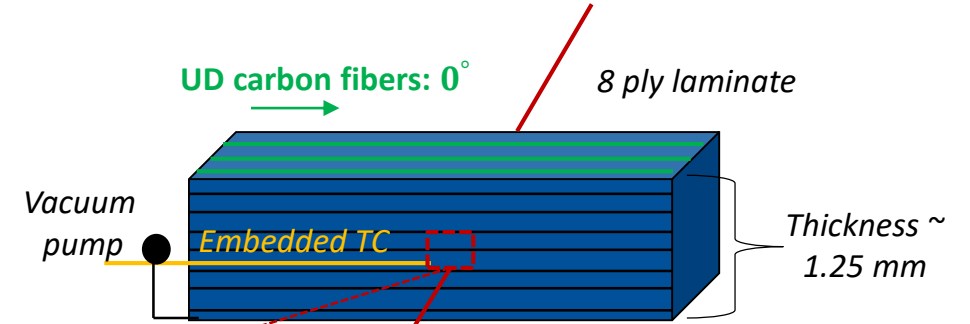
3. Manufacturing process & study cases

Manufacturing method, FBG embedment & introduction of the defect



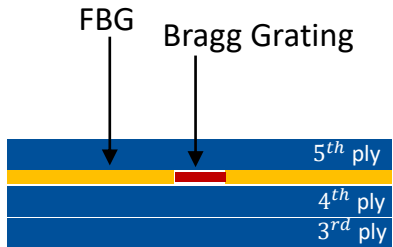
Manufacturing process -> **VBO**
(Only Vacuum Bag Processing)
($P_{max} = 1 \text{ bar}$)

TP Consolidation

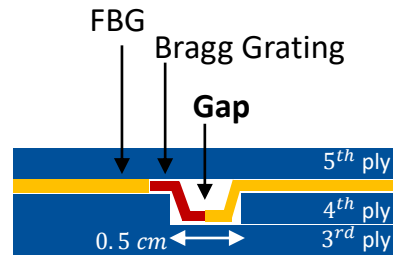


Study cases :

Without gap



With gap



Cross section view

Introduction of an **artificially**
induced gap on the 4th ply :
FBG overlaps the gap

FBG
FBG perpendicular to carbon fibers →
Sensitivity to matrix physicochemical phenomena

Methodology :

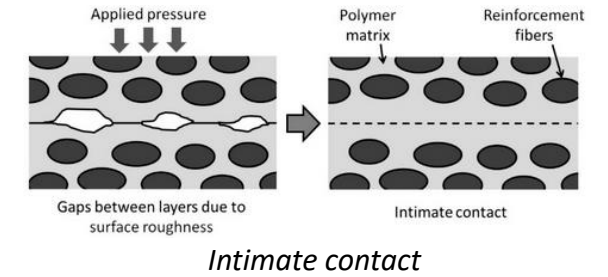
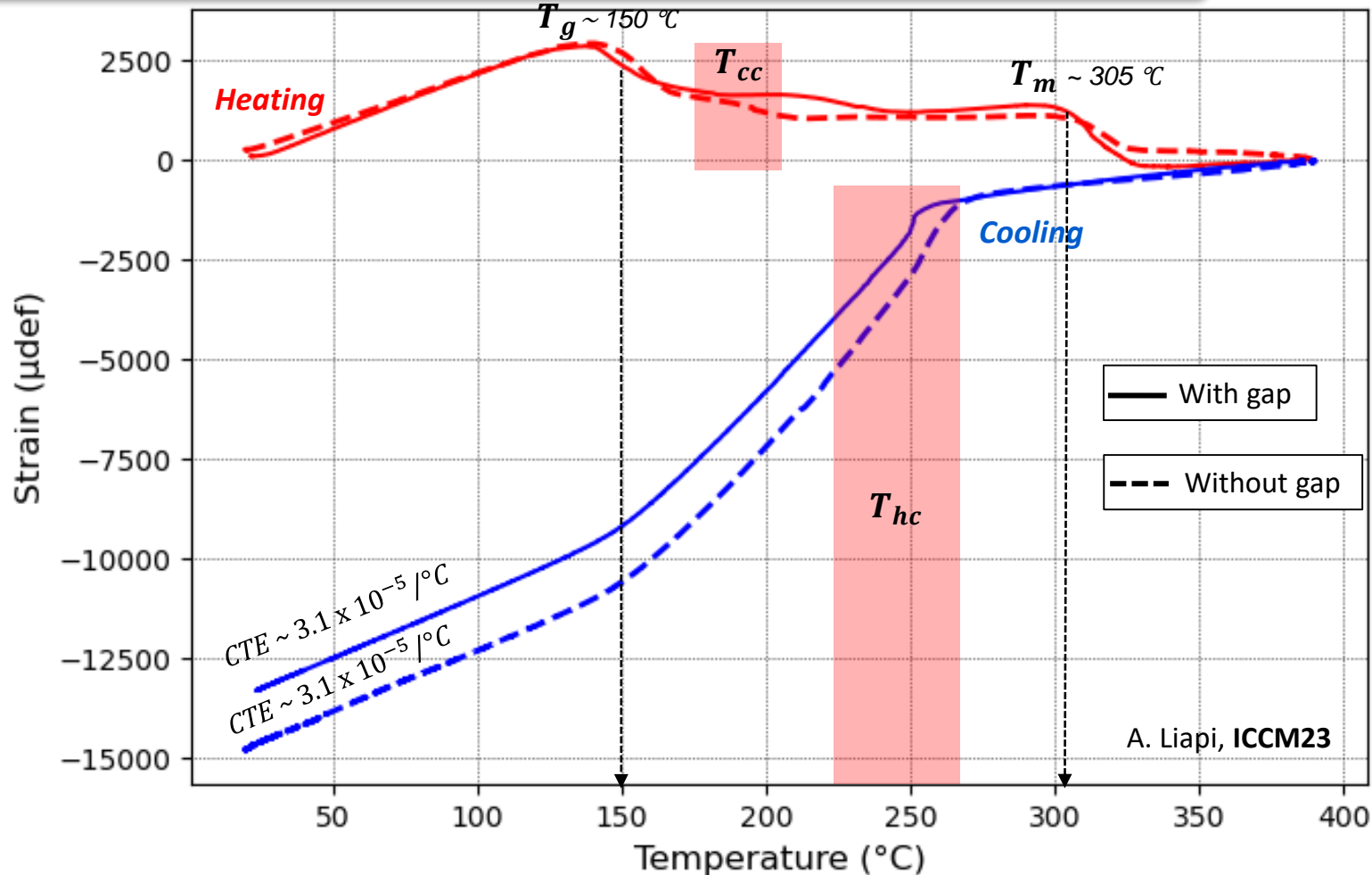
During consolidation process :

- Strain monitoring
- FBG Spectrum intensity monitoring

Principal results :
FBG monitoring of transverse strain during consolidation

3. Process monitoring with/without induced gap

Transverse strain monitoring during consolidation cycle with/without induced gap



[Y. D. Boon et al., 2021]

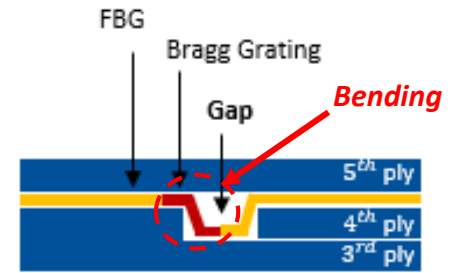
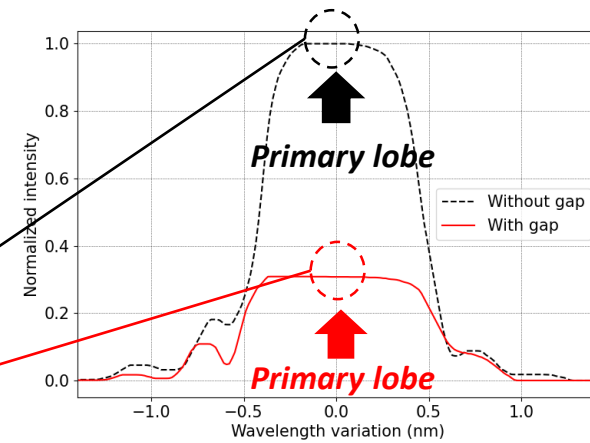
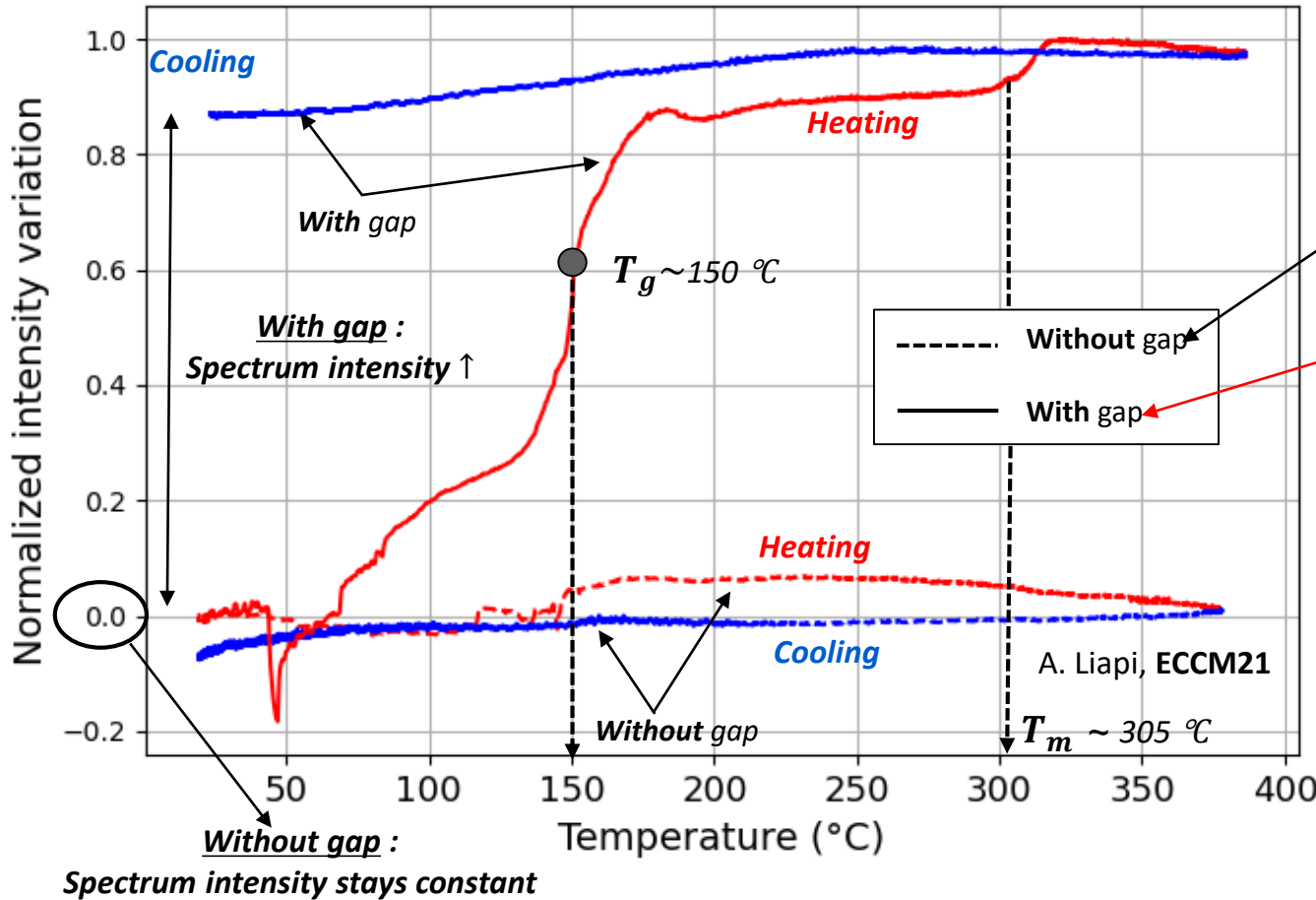
Process monitoring with **gap** →
FBG sensitive to consolidation phenomena, change of state of TP matrix & CTE
 → **Detection of the defect not guaranteed by this representation**

Methodology :
 During consolidation process :
 ✓ Strain monitoring
 ☐ Spectrum intensity monitoring

Principal results :
Monitoring of FBG spectrum intensity during consolidation

3. Intensity spectrum of FBG with/without defect

In-situ monitoring of the FBG's intensity spectrum for laminate samples with/without gap



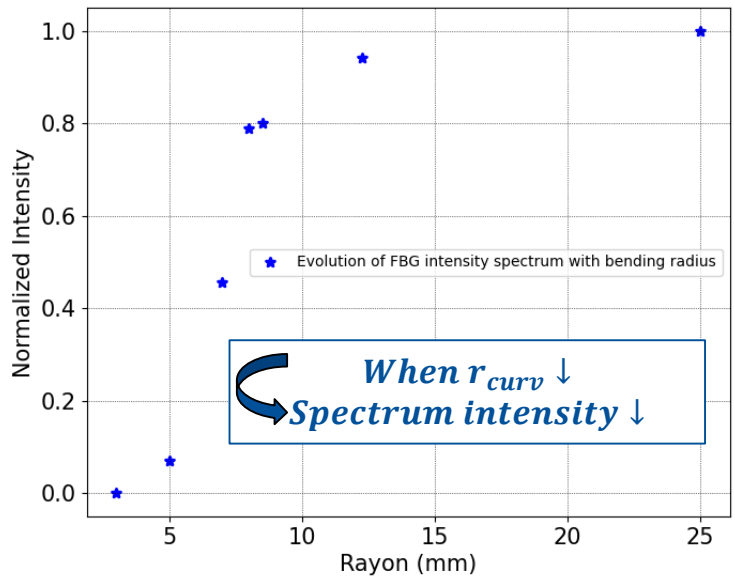
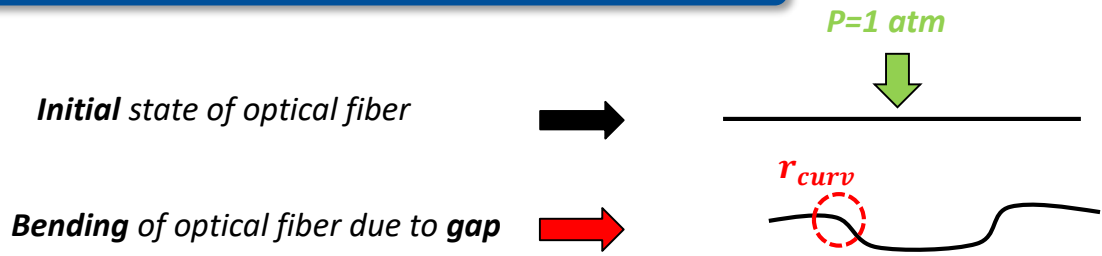
Before consolidation:
Reflected spectrum under vacuum pressure for laminates **without/with gap**

➤ Significant change in spectrum intensity during heating → Influence of the bending radius of the FBG induced by the gap → FBG sensitive to process induced gap

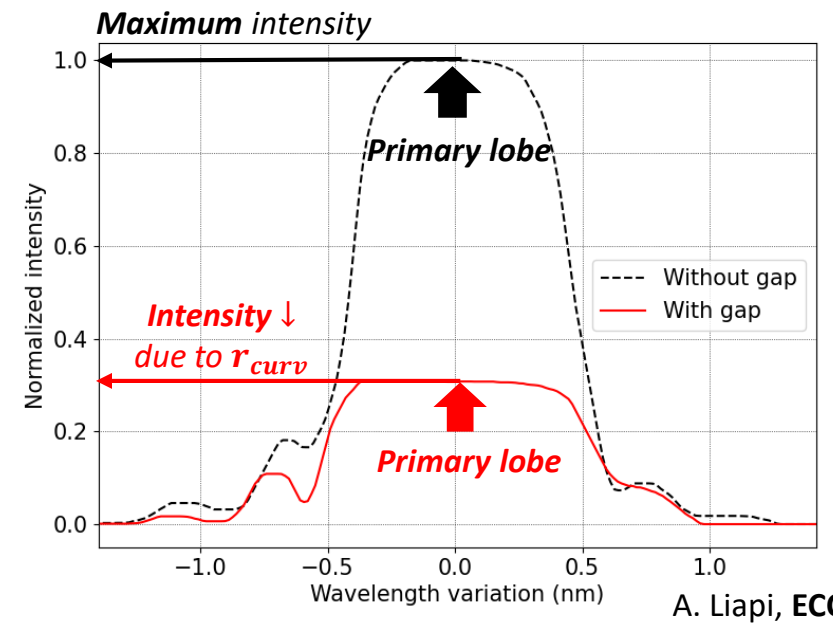
Principal results :
Influence of curvature radius on FBG spectrum

3. Scientific approach : Influence of curvature on spectrum intensity

Influence of FBG curvature on spectrum intensity



Evolution of FBG intensity spectrum with **curvature radius**



Before consolidation:
 Reflected spectrum under **vacuum pressure** for laminates **without/with gap**

Stratifié avec gap :

- Vacuum pressure applied $\rightarrow r_{\text{curv}} \downarrow \rightarrow$ Spectrum intensity \downarrow
- During consolidation \rightarrow Spectrum intensity \uparrow

4. Conclusions & perspectives

Conclusions

Development of an **experimental set-up** for the **in-situ monitoring** of **consolidation** process using embedded FBG:

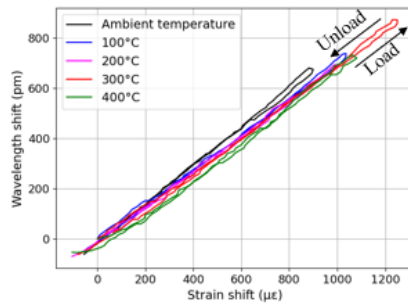
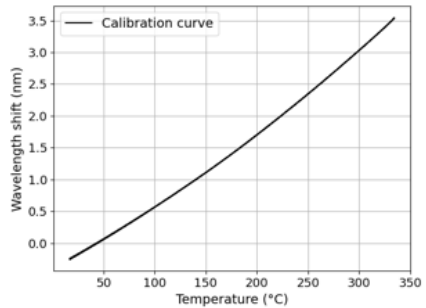
- ✓ Validation of FBG's sensitivity to **consolidation process, change of state of matrix & thermal expansion**
- ✓ Promising first results on the **sensitivity** of FBG to a defect type "gap":
 - Strain** monitoring → FBG sensitive to **change of state** of TP matrix
 - Monitoring of **spectrum intensity** → FBG **bending** due to gap crucial for the **detection/evolution** of the **defect**

Works in progress

❖ **Experimental : Temperature & strain calibration of the optical sensor**



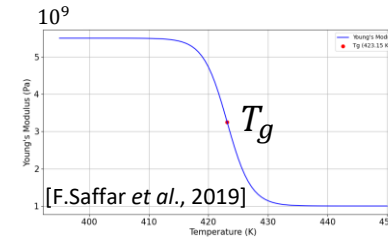
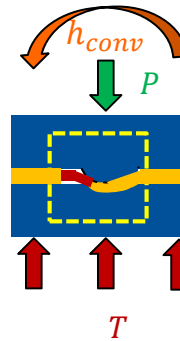
Experimental bench at ONERA



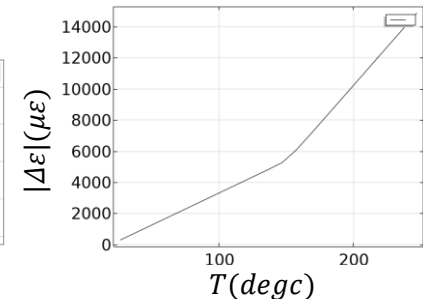
$$\frac{\Delta\lambda_B}{\lambda_B} = K_T \cdot \Delta T + K_\varepsilon \cdot \varepsilon + K_P \cdot \Delta P$$

❖ **Thermomechanical model :**

Influence of gap on process-induced strain field due to the presence of the gap



Jump in Young's Modulus at T_g



Process induced strain without gap

Future work

- Study critical **distance** between the FBG and the defect → FBG's sustained **sensitivity** to the presence of the gap
- Study FBG's sensitivity to different **types & sizes** of defect

Thank you for your attention!