Characterization of overmolded thermoplastic composite joints and sizing methods for hybrid structures

Journées des doctorants CETIM

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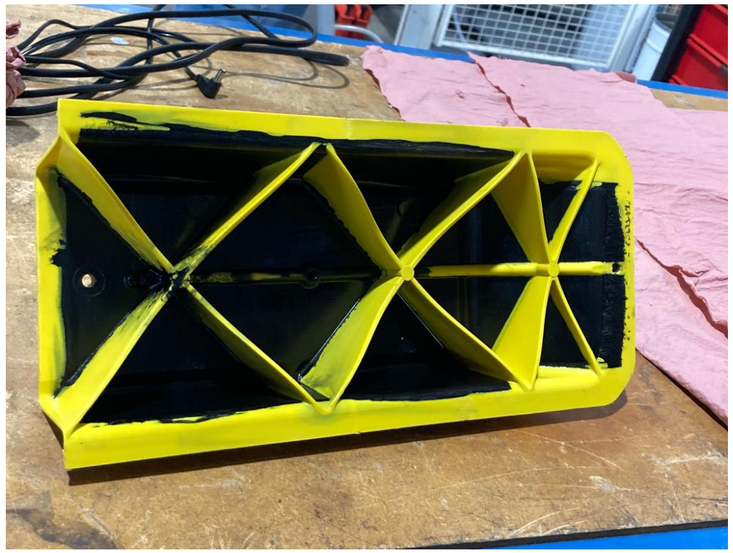
Motivations

- **What is Quilted Stratum Process**
  - Thermoforming of thermoplastic composite parts made up of long fiber patches
  - Overmolded elements in short fibers

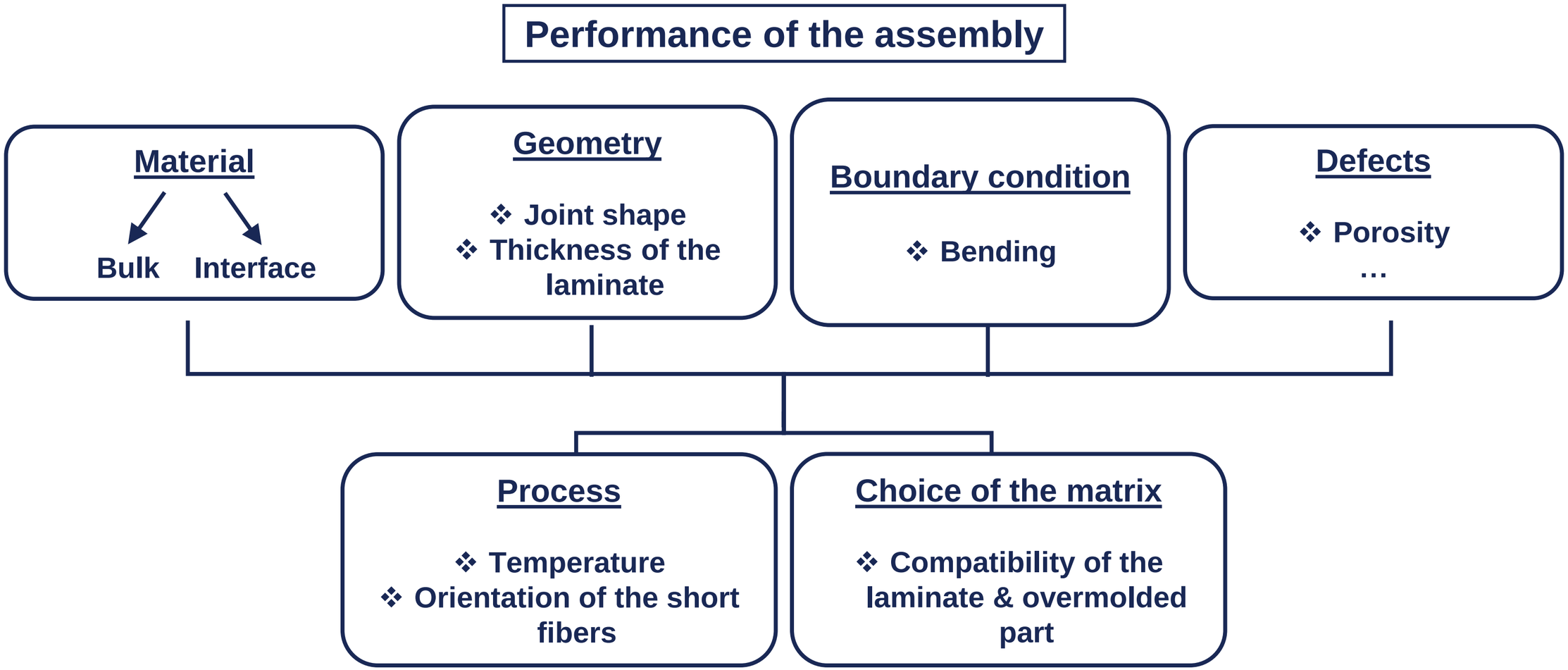
  Long fiber patches can be prepared before ➔ <u>fast process</u>
- **Difficulties with the mechanical behavior of the interface long/short fibers**
  - Sizing (criterion?) + characterization
- **Experimental results from CETIM**
  - Tensile tests on T joint samples



Demonstrator of the process

Long/short fibers interface failure

Motivations



Motivations

Performance of the assembly

Material

Bulk Interface

Geometry

- Joint shape
- Thickness of the laminate

Boundary condition

- Bending

Defects

- Porosity

…

Process

- Temperature
- Orientation of the short fibers

Choice of the matrix

- Compatibility of the laminate & overmolded part

Objectives:

1. Understand the influence of the geometry & material on the behavior of the structure
2. Propose ways/ideas for modeling + sizing method for this kind of joint

Approach

Numerical aspect

- **Hypotheses**
  - Simulation of the failure ➔ **cohesive zone model (CZM)** { Maximum stress; Critial energy release rate; Stiffness }
  - Snap-back problem ➔ **dissipation-driven method** [Gutiérrez, 2003]
- **Variables**
  - **Geometry:** joint shape, laminate thickness, boundary condition
  - **Material:** parameters of the cohesive law

① ❖ Clarify the role of each parameter in the global behavior

② ❖ Identify the parameters for the cohesive law ❖ Validate the modeling & simulation approach

Experimental aspect

- **Microscopy & CT scan observation of different samples**
- **Characterization:** climbing drum peel (CDP), end notched flexure (ENF)
  - Manufacturing difficulties of plane samples

  ➔ search for the parameters of the cohesive law
- **Validation:** tensile tests on T joints

Approach

First year

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Experimental aspect (in progress)

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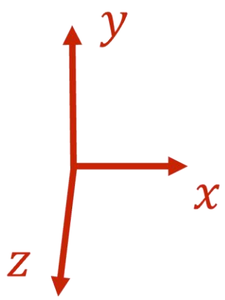
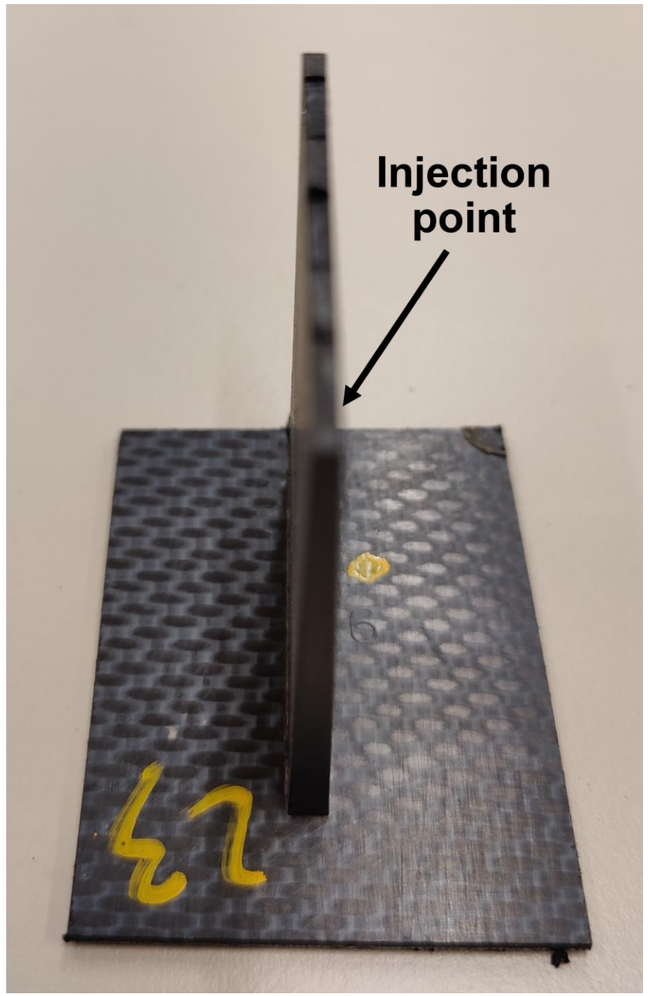
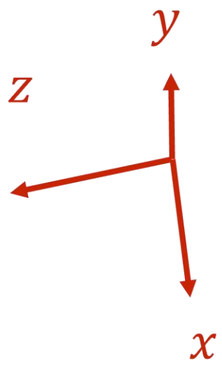
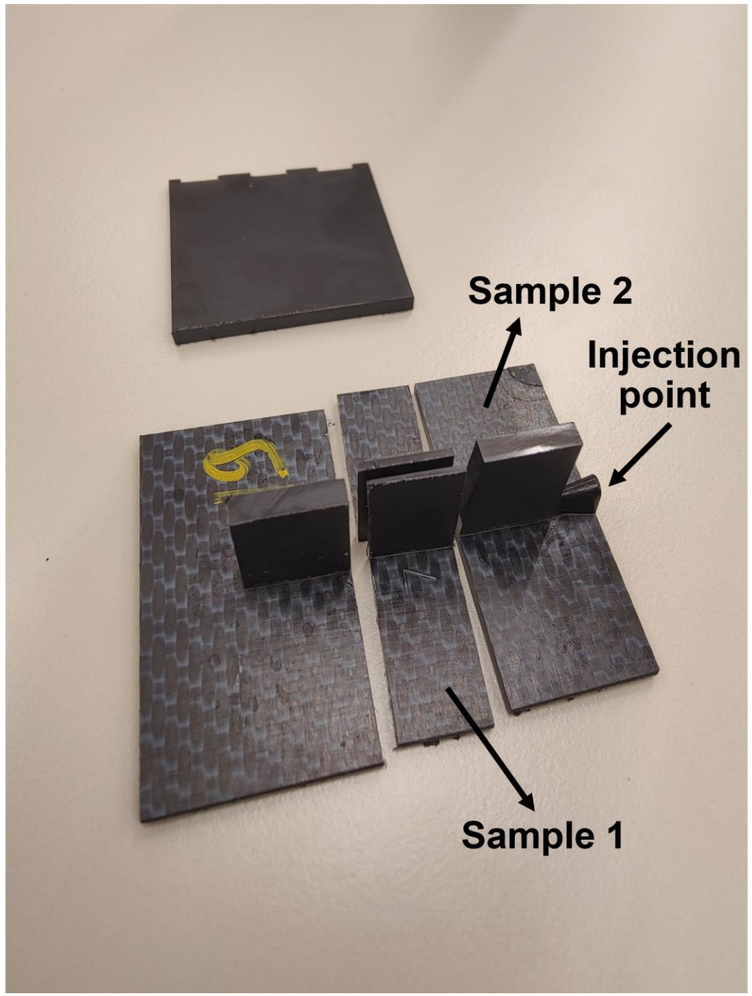
Microscopy & CT scan: T joint samples

- **Observation of T joint samples: definition of the coordiante system**



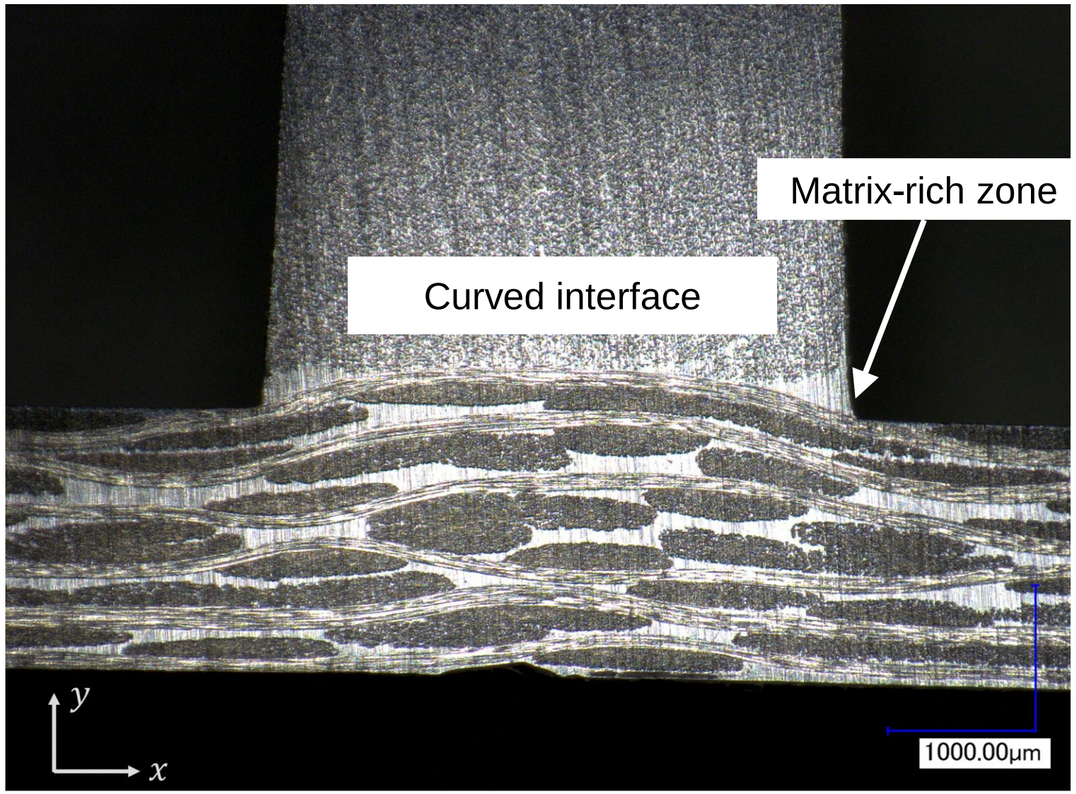


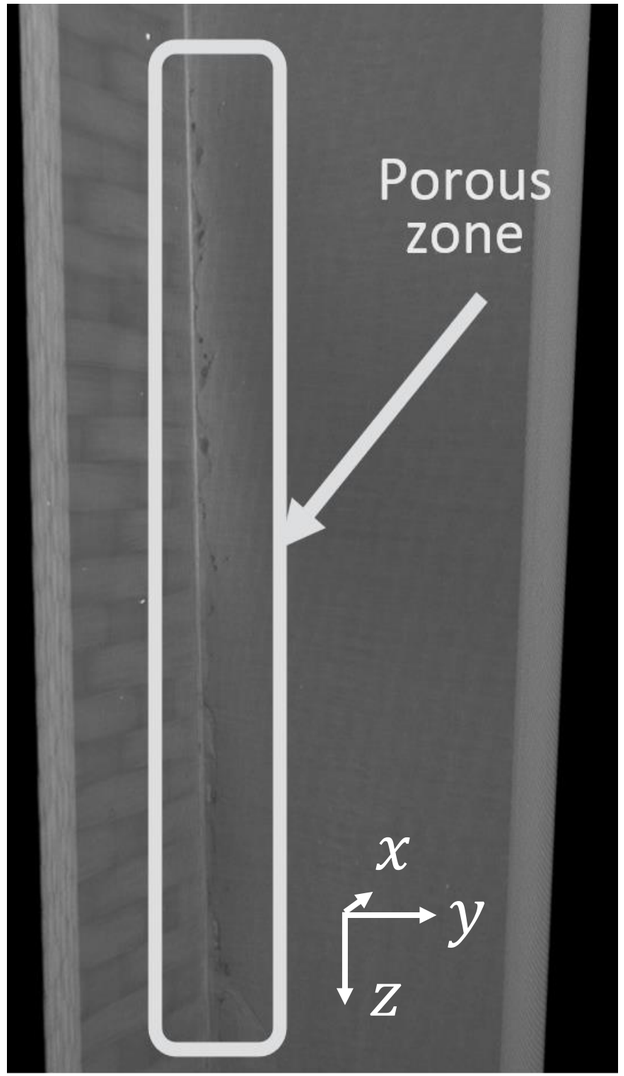




Microscopy & CT scan: T joint samples

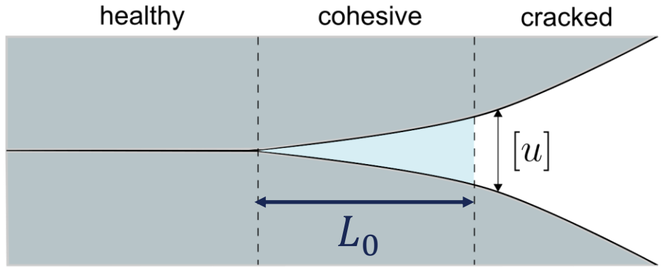
- **Different types of defects observed**
- ➔ **To be taken into account in future simulations**
- ➔ **Could be potentially improved in the process**

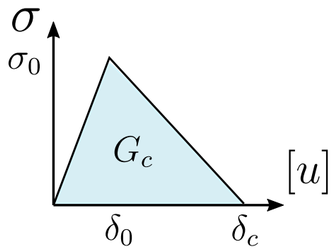




Cohesive zone model

- **Concept**
  - Relates the interface forces σ to the displacement jump $[\![u]\!]$ by a constitutive law





[Bao and Suo, 1992]

- **Characteristic length of the process zone**

$$L_0 \propto \frac{\delta_c E}{\sigma_0} = \frac{G_c E}{\sigma_0^2}$$

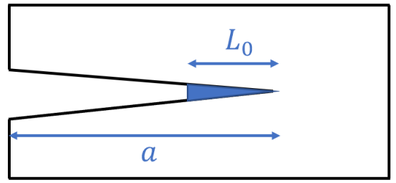
where

δ_c: separation limit

E: Young modulus

G_c: critical energy release rate

- Crack length/diameter of the hole… a



$\frac{a}{L_0} \gg 1$

Small-scale bridging

Linear Elastic Fracture Mechanics (LEFM)

Important parameter: G_c

$\frac{a}{L_0} \approx 1$

Large-scale bridging

Cohesive Zone Model (CZM)

Important parameters: G_c **and** σ_0

- $L_0 \approx 1$ mm for thermosetting materials [Yang et Cox,2005]

➔ maybe large-scale bridging in our thermoplastic case

Simulations

2D model on Abaqus

- Symmetry ➔ ½ of the structure is simulated

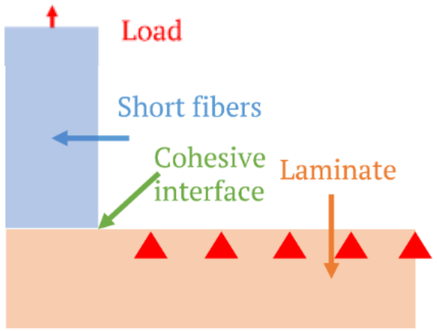
Variables

- Geometry: joint shape, laminate thickness, boundary condition
- Material: parameters of the cohesive law G_c, σ_0

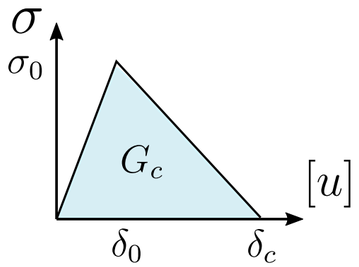
  Range: thermosetting, thermoplastic

  σ_0: 10 MPa~80 MPa
  G_c: 350 J/m^2 ~1050 J/m^2

Available experimental data [CETIM]



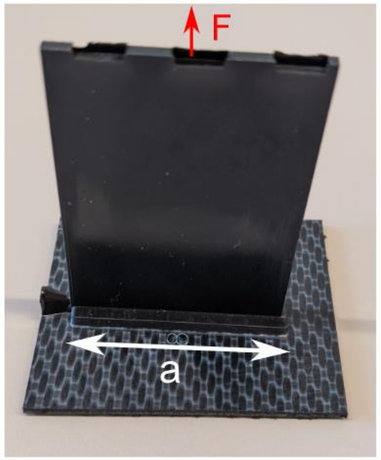
2D model on Abaqus



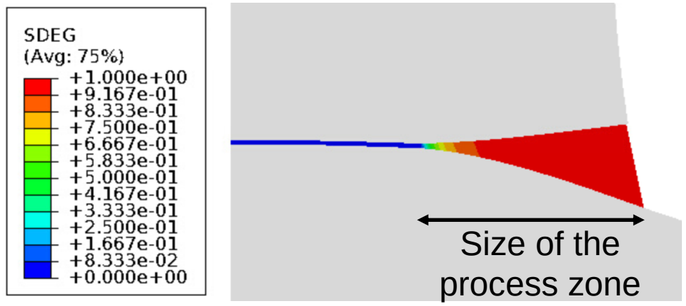
Triangular cohesive law

Evaluation criteria

- Maximum force flux=maximum load/out-of-plane thickness=F/a



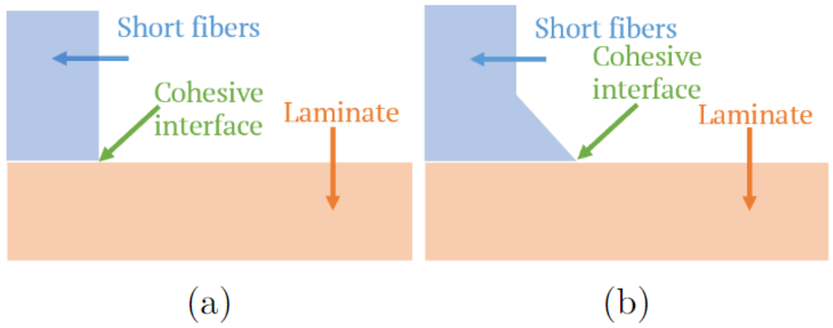
- Size of the process zone L_0



- Global stiffness: slope of force-displacement curve

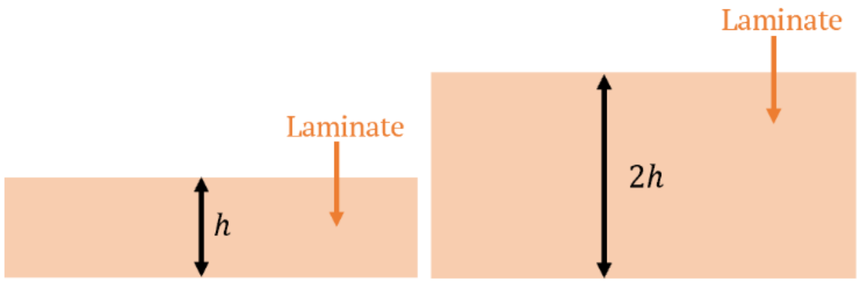
Definition of the geometrical variables

Definition of joint shape



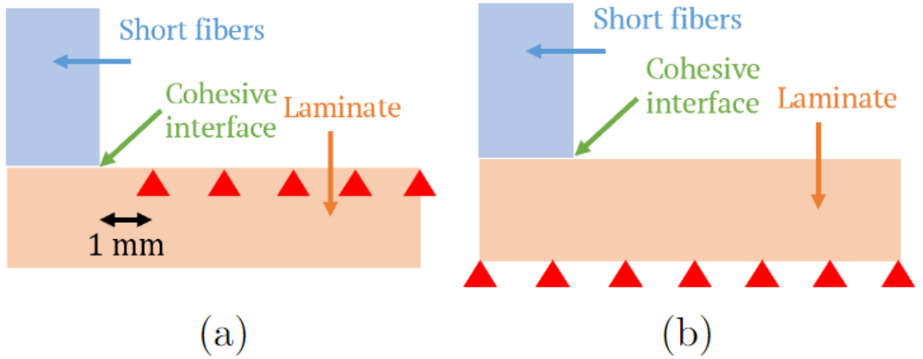
(a) (b)

Definition of thickness

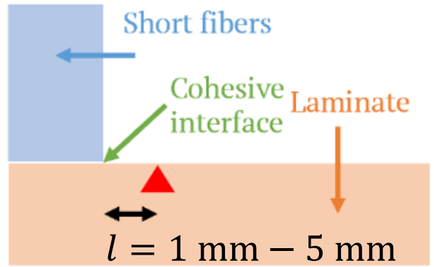


(a) Simple (b) Double

Definition of boundary conditions



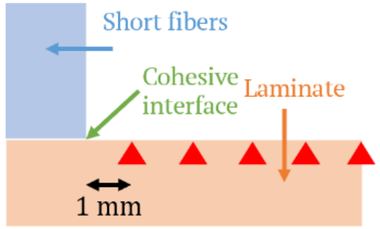
(a) (b)



(c1)

Example of simulation results

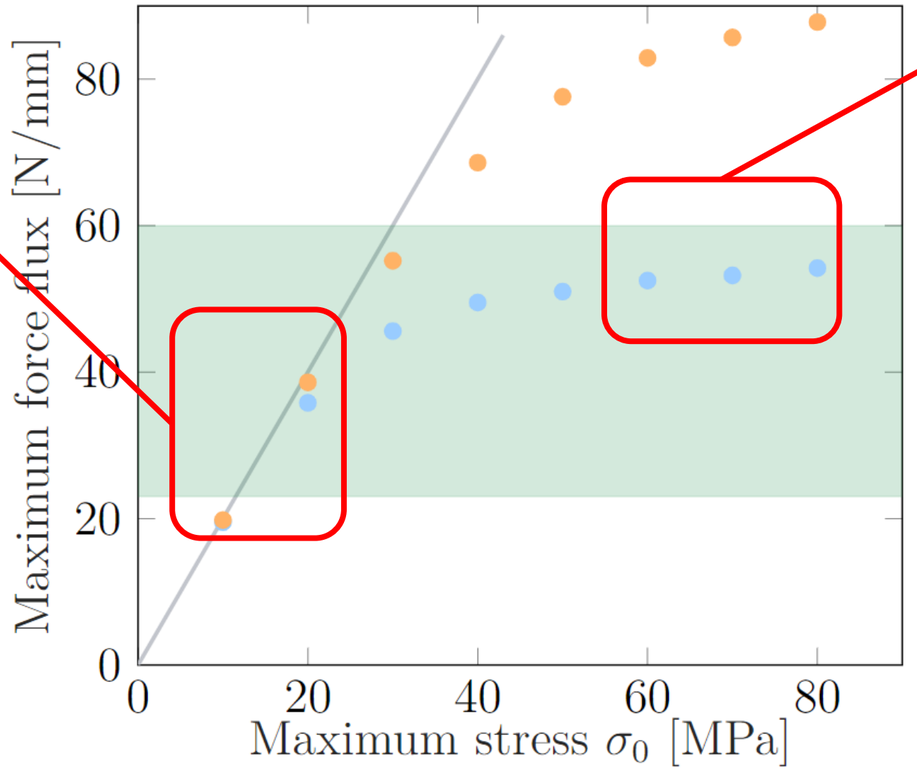
- **Configuration**

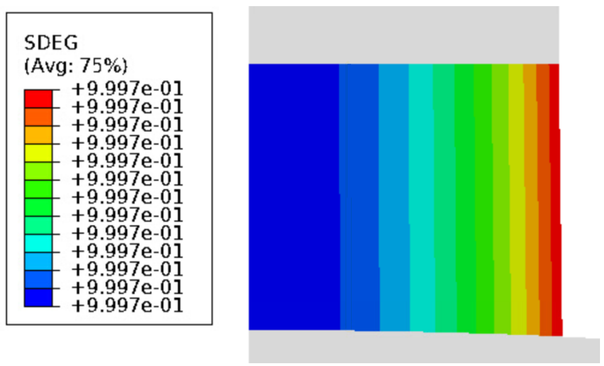


- **Variables**
  - G_c, σ_0
- **Results**

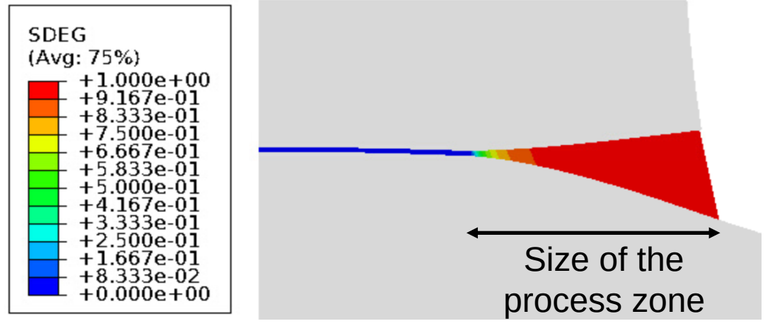
Large-scale bridging:
G_c has no influence

LEFM :
σ_0 has no influence





Size of the process zone>width



Summary of simulation results

Material

❖ **Two regimes observed:**

LEFM & large-scale bridging

➔ Consistent with [Bao and Suo, 1992]

❖ **Orders of magnitude** ☺

Consistent with experimental range, especially when bending is added

Geometry

❖ **Joint shape**

Chamfer: ⊕ Higher force flux

❖ **Thickness of the laminate:**

Thicker laminate➔Stiffer in bendng➔better perfomance

❖ **Boundary condition:**

Less bending➔better perfomance

Example of bending influence

- $G_c = 1050\ \mathrm{J/m^2}$, $\sigma_0 = 80\ \mathrm{MPa}$,

Same laminate thickness & joint shape

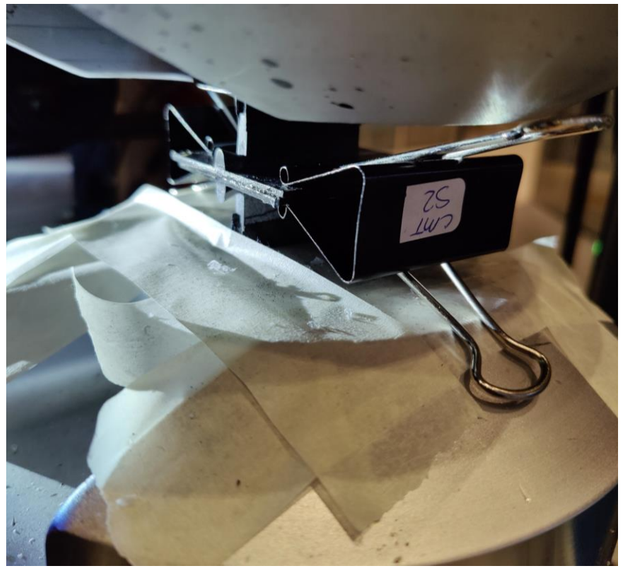
Boundary condition	Maximum force flux $(\mathrm{N/mm^2})$
Bending	87.8
No bending	136.7

56% higher

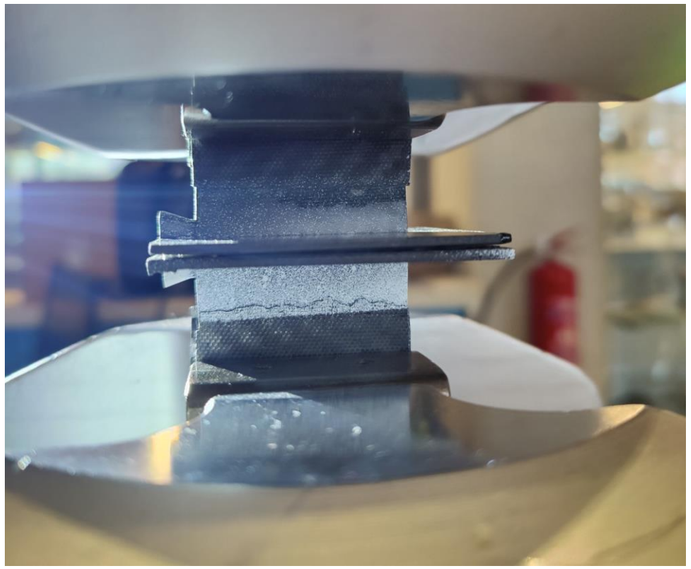
1. Importance of being able to control the bending in future tests
2. Joint shape ➔ Attention is needed during the design stage

Experiments: validation test

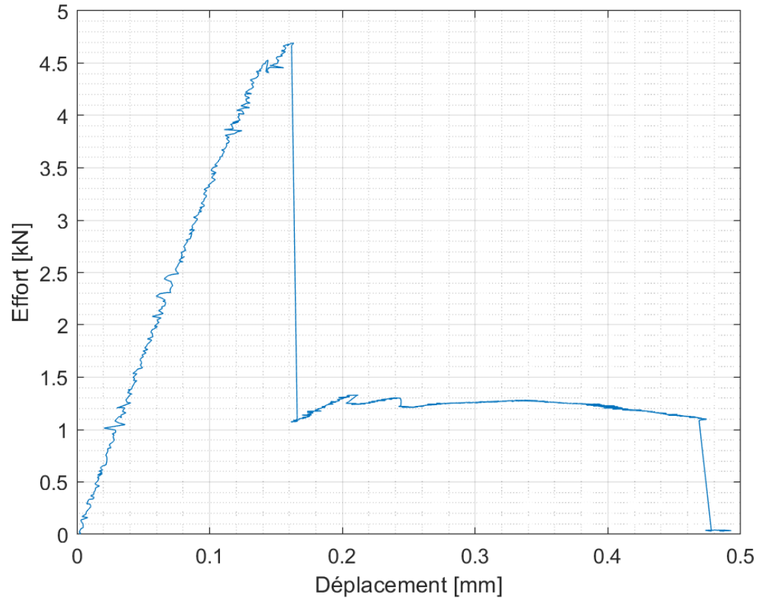
- **Tensile test**
  - Two T joints glued together to **remove the bending**
- **Results**
  - Glue failure
  - Stiffness >> CETIM experiments
  - Same order of magnitude in force reached ☺
    > *2-5 kN in CETIM experiments with difficulties in the control of bending*
  - Confirmation of simulation results



Glue setting



Test setup



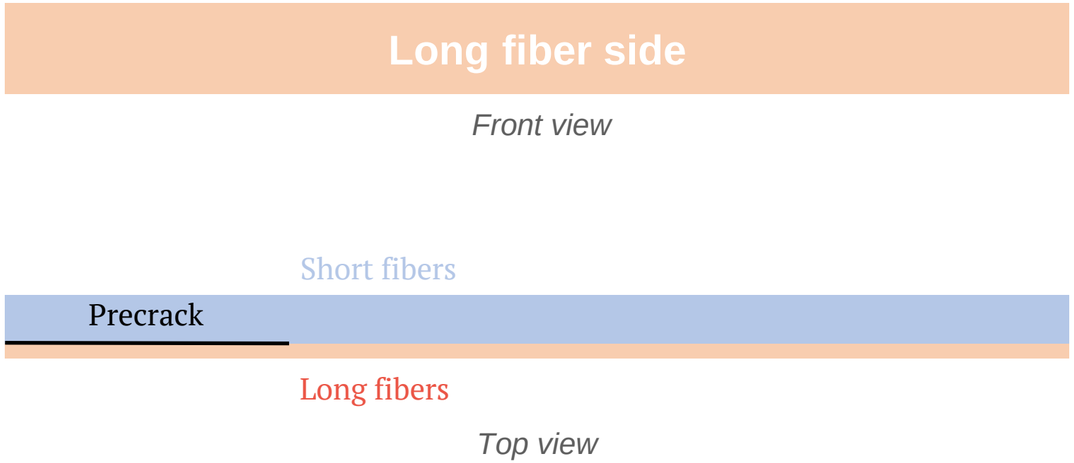
Force-displacement curve

Microscopy & CT scan: plane samples

Observation of plane samples for CDP tests:

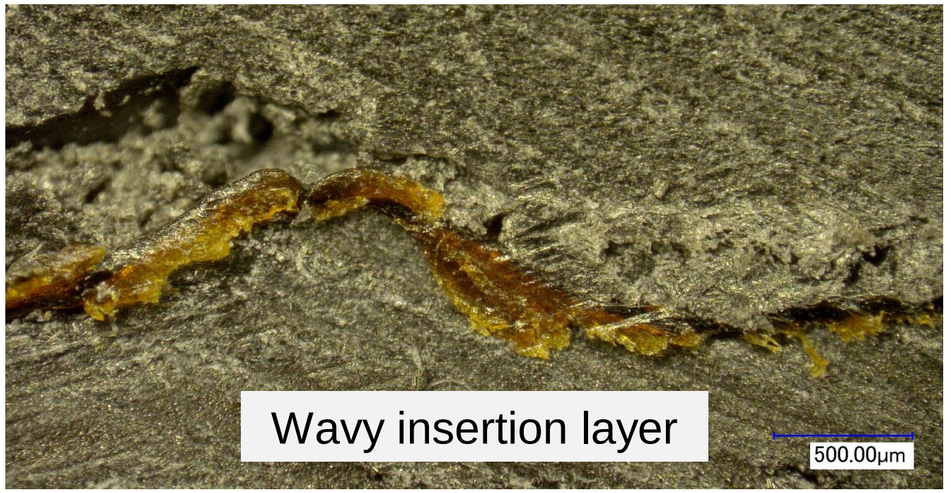
L210 mm×W20 mm

Different views of the sample



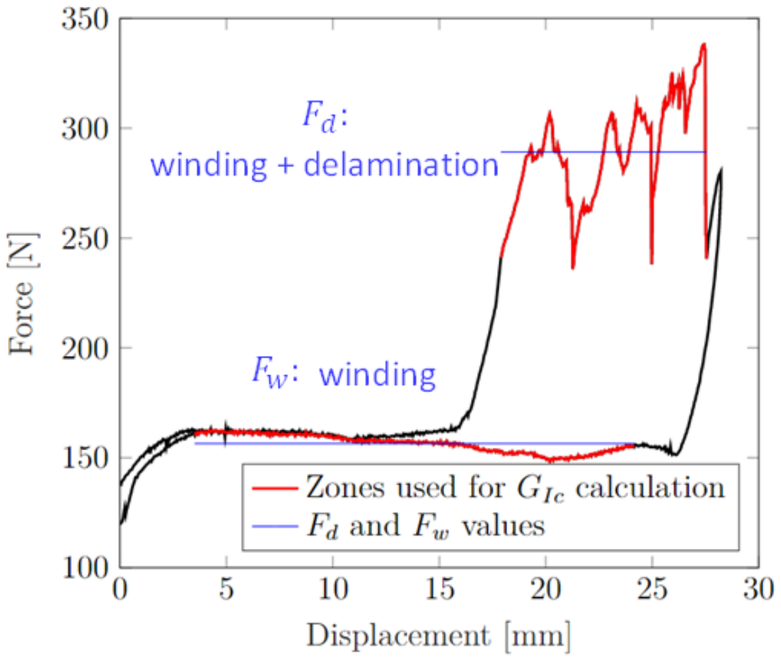
Typical defects

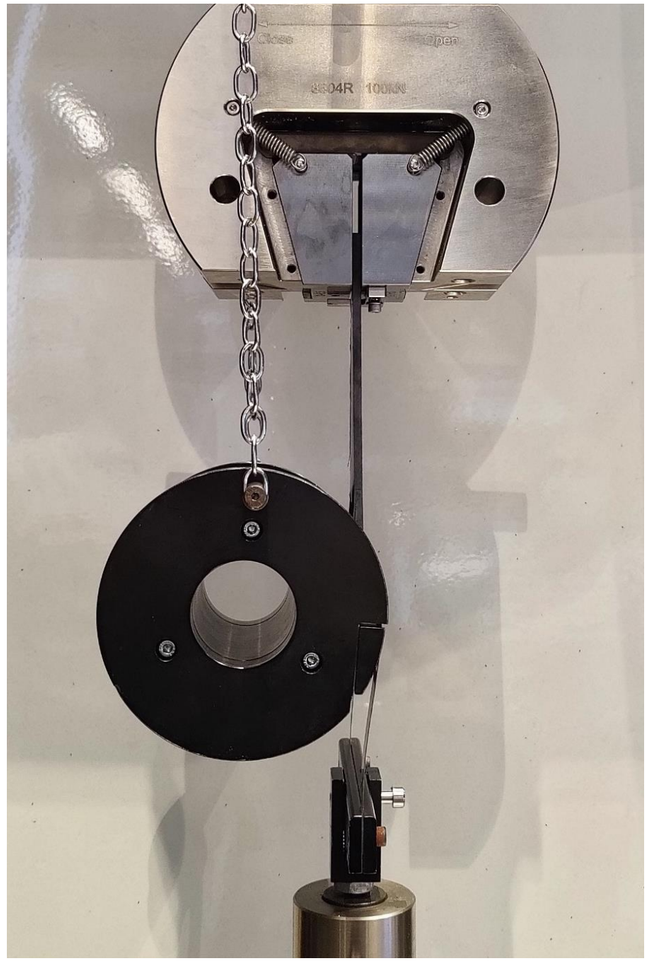
- Due to manufacturing difficulties



Experiments: characterization tests

- **Climbing Drum Peel (CDP) test**
  - Failure mostly in mode I
  - Initially designed for sandwiches and adapted to monolithic composites [Daghia and Cluzel, 2015]
  - Imposed kinematics ➔ more stable crack propagation compared to classical DCB test
  - Typical force-displacement curve:





CDP test setup

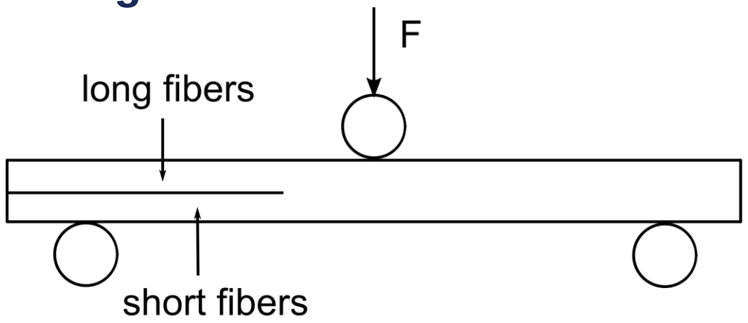
Experiments: characterization tests

- **Climbing Drum Peel (CDP) test**
  - **Orders of magnitude of G_c: $800 - 1000\ \mathrm{J/m^2}$ and $1500 - 1700\ \mathrm{J/m^2}$ depending on the stacking sequence**

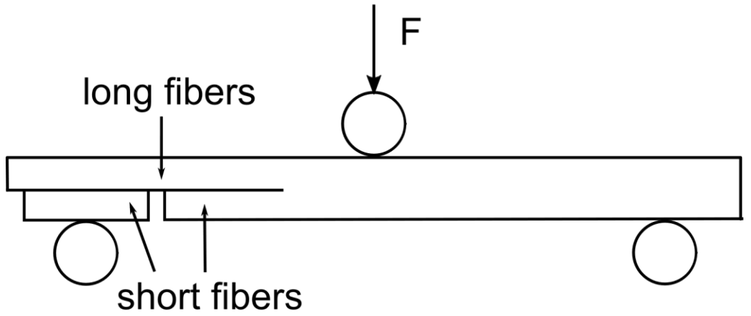
  ➔ Consistent with the chosen range in the simulations

  - **Robust test ☺**
- **End Notched Flexure (ENF) test (in progress)**
  - **Two configurations**

Classical



Proposed



➡

⊕ Reduces the friction between the two arms

⊖ More mode I involved

➔ Need to clarify the modal participations

Perspectives

- CDP/ENF tests in progress

- Test setup design for tensile tests in progress
- Tensile tests on T joint samples
- T joint samples with different joint shape
- ….

THANK YOU FOR YOUR ATTENTION!