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ANR-22-CE51-0001

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DAMPING PROPERTIES OF PLANT FIBRE COMPOSITES

Pauline BUTAUD – ESBBC 2023 Tarbes

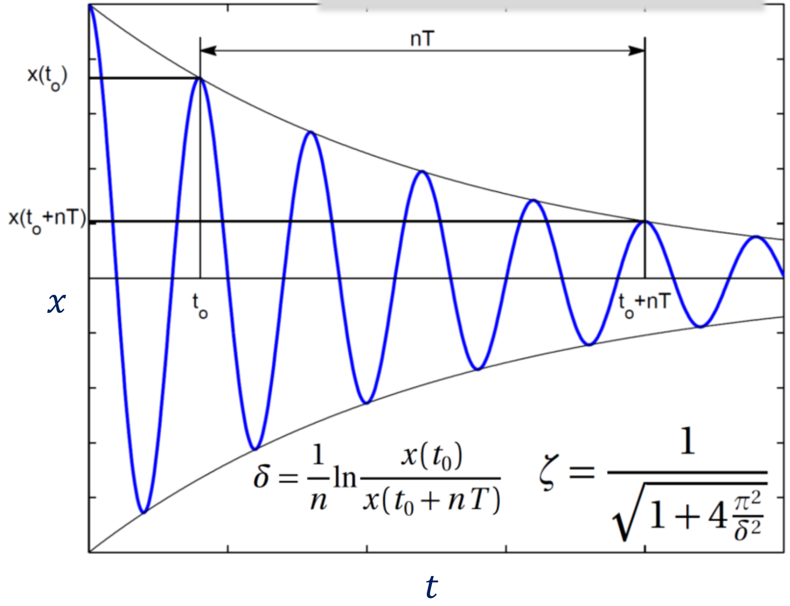
F. Pelisson, V. Placet, M. Ouisse,
T. Liu, Y. Gaillard, G. Bourbon, F. Amiot

cnrs UBFC UNIVERSITÉ BOURGOGNE FRANCHE-COMTÉ UNIVERSITÉ DE FRANCHE-COMTÉ SUP MICROTECH ENSMM utbm

DAMPING BASICS – VIBRATION TESTS

Damping identification in free vibrations

Logarithmic decrement



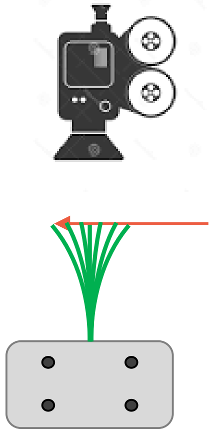
$$\delta = \frac{1}{n}\ln\frac{x(t_0)}{x(t_0+nT)} \qquad \zeta = \frac{1}{\sqrt{1+4\frac{\pi^2}{\delta^2}}}$$

Free test example on fibre

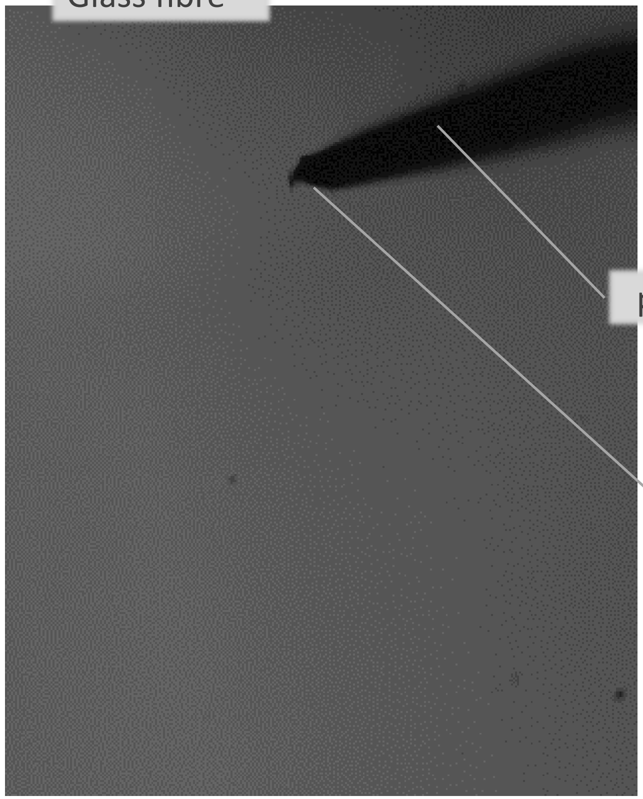
camera

fibre

clamp



Glass fibre

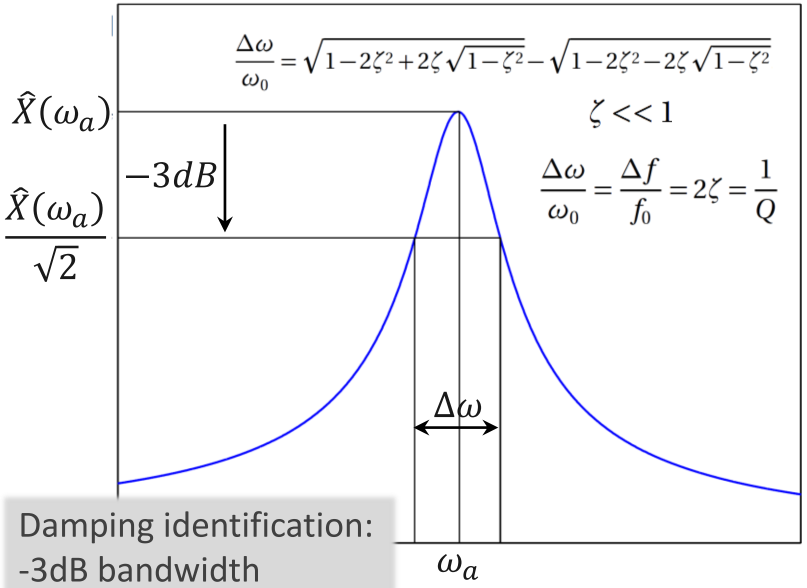


probe - excitation

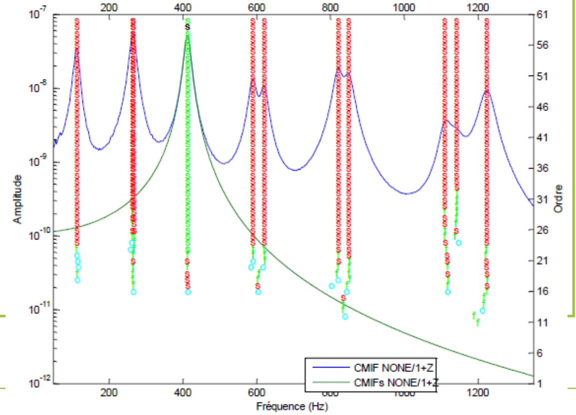
fibre

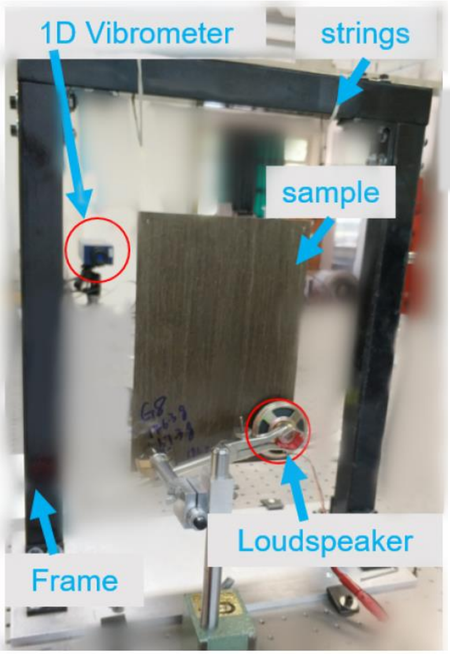
DAMPING BASICS – VIBRATION TESTS

Damping identification in forced vibrations



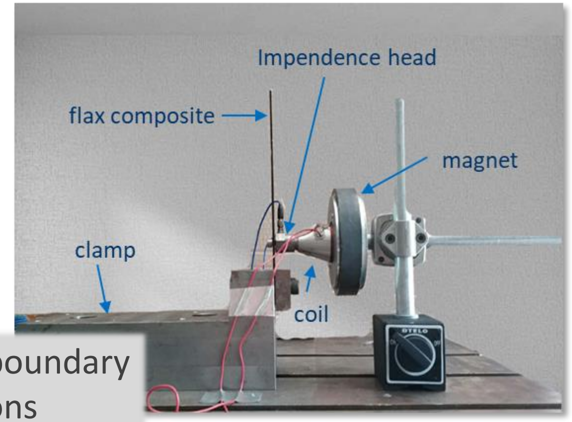
Damping identification: -3dB bandwidth





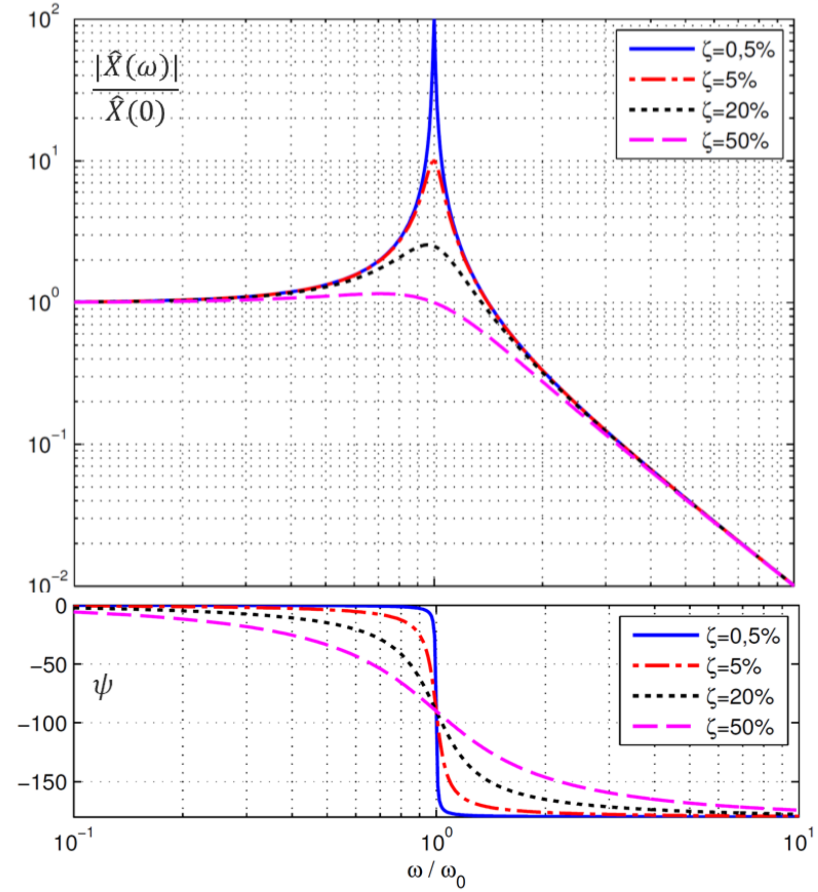
Free boundary conditions

Liu, 2021



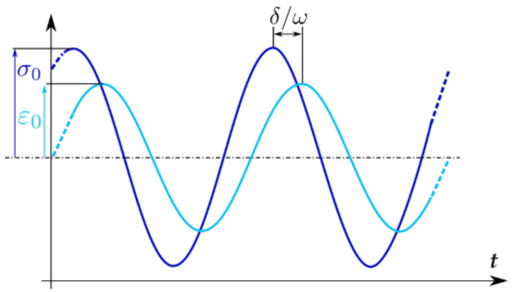
Clamp boundary conditions

Damping effect is only observable at resonance!



DAMPING BASICS – HARMONIC TEST

Damping identification in DMA



complex modulus:

$$E^* = \frac{\sigma_0}{\varepsilon_0}\exp(i\delta)$$

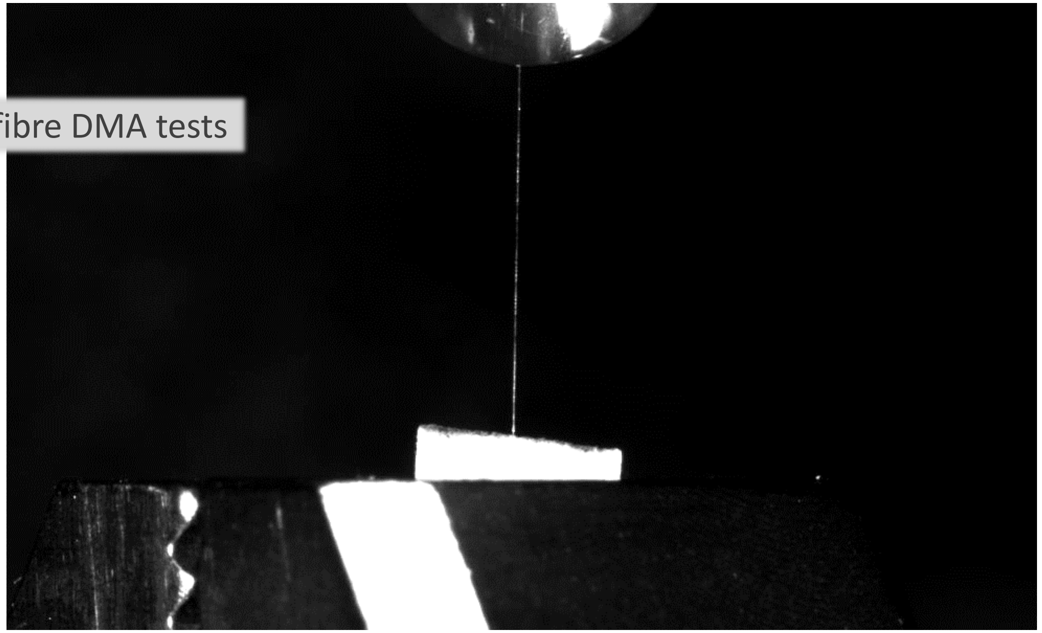
storage and loss modulus:

$$E^*(\omega) = E'(\omega) + iE''(\omega)$$

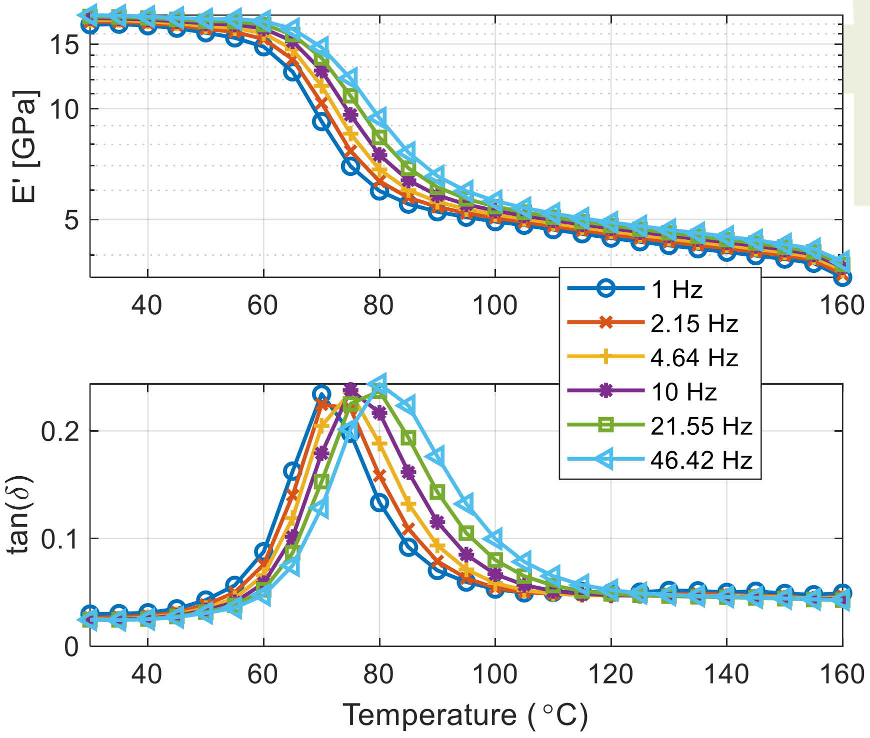
loss factor:

$$\eta = 2\zeta = \tan(\delta) = E''(\omega)/E'(\omega)$$

hemp fibre DMA tests



temperature and frequency scanning



Liu, 2021

UD flax composite

Storage modulus : 18 GPa in glassy state
to 3,8 GPa in rubbery state

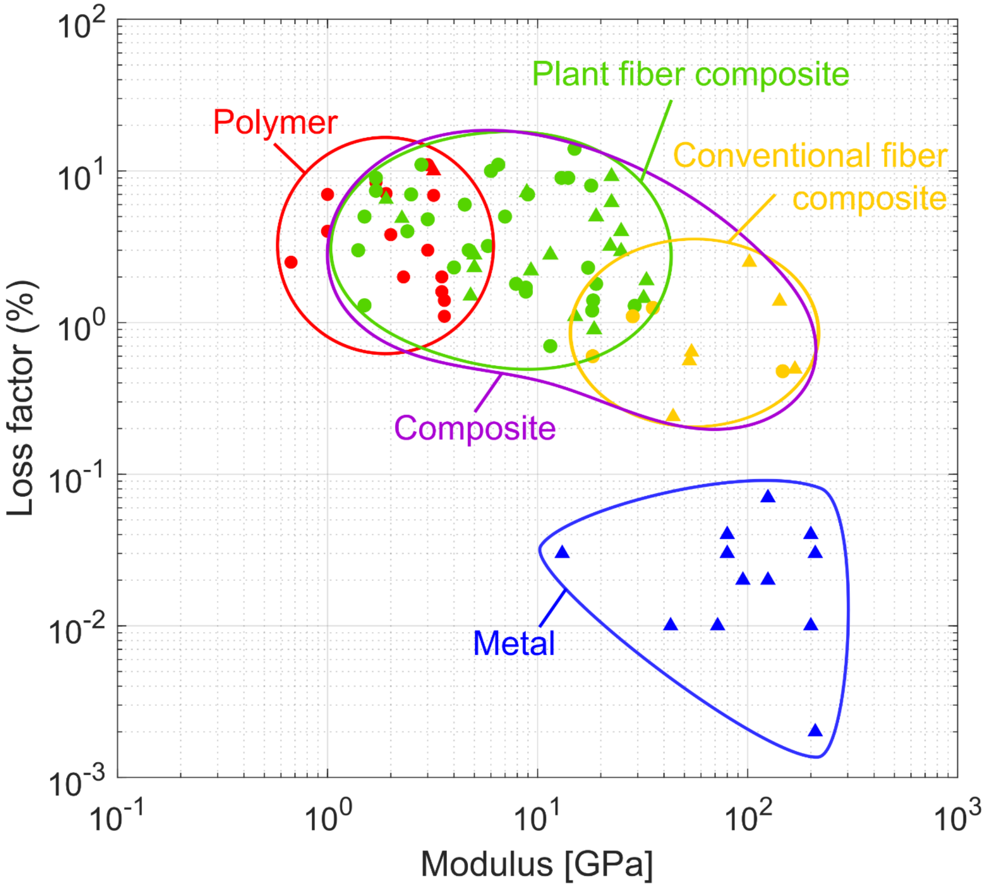
Loss factor : 2,5 to 24% according to the temperature and the frequency

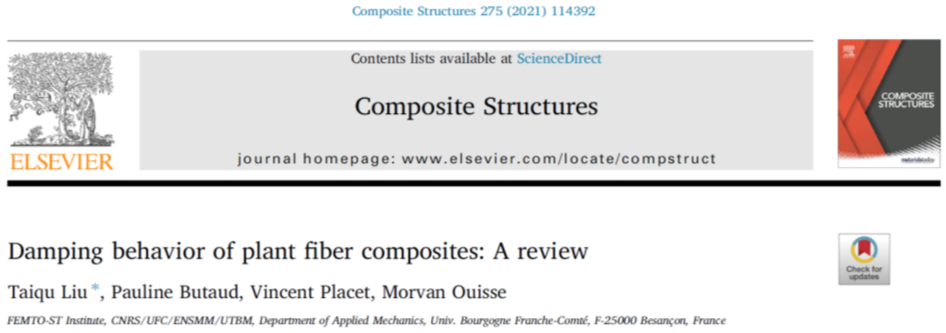
CONTENT

- Context and challenges
- Micro-scale properties of bio-based composites: state-of-the-art
- *In situ* testing
- Single fibre testing
- Conclusions and outlooks

DAMPING BEHAVIOR OF PLANT FIBRE COMPOSITES

Ashby diagram
Loss-modulus map from literature





Composite Structures 275 (2021) 114392

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Damping behavior of plant fiber composites: A review

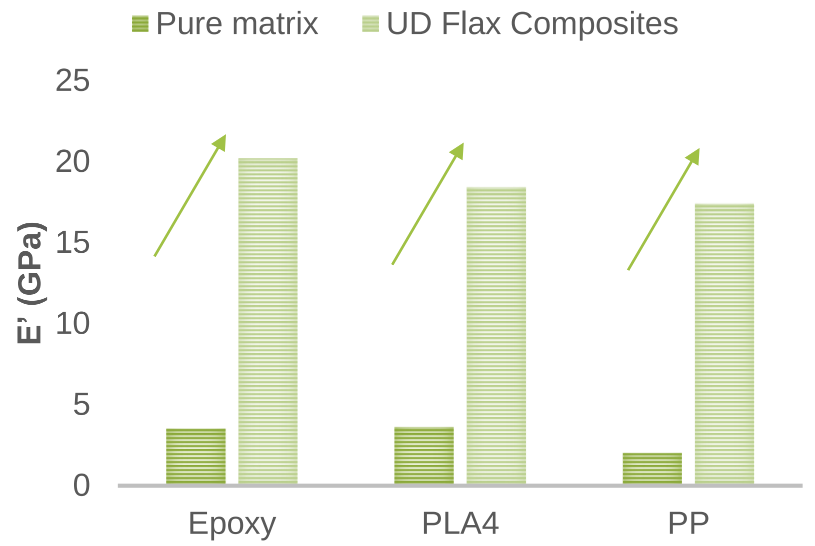
Taiqu Liu *, Pauline Butaud, Vincent Placet, Morvan Ouisse

FEMTO-ST Institute, CNRS/UFC/ENSMM/UTBM, Department of Applied Mechanics, Univ. Bourgogne Franche-Comté, F-25000 Besançon, France

- **Loss factor** of PFCs is generally much **higher** than that of synthetic fibre composites
- **Origin not clearly elucidated** / contradictory reports are found in literature
- Knowledge on the damping behaviour of PFCs is sometimes **deficient or ambiguous**
- **Hierarchical aspects** have to be considered

IMPACT OF FIBRES REINFORCEMENT ON COMPOSITE PROPERTIES

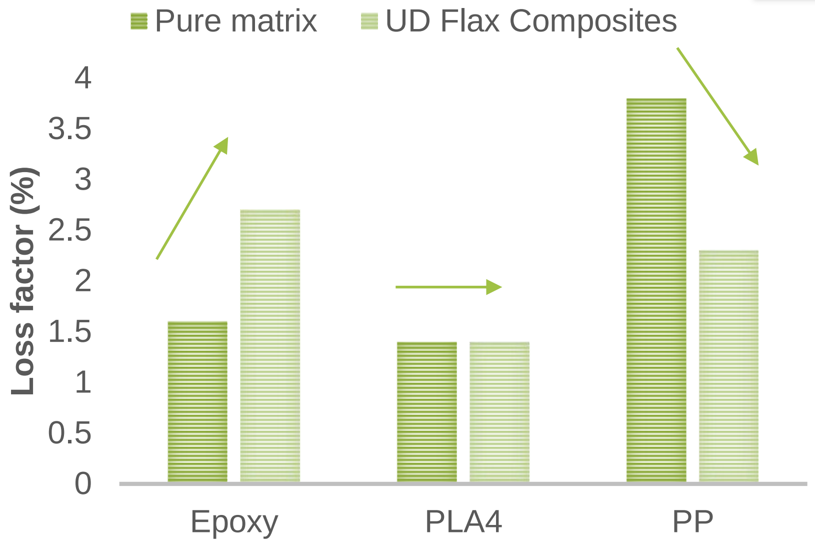
Stiffness



Flexion – 1 Hz – 25°C

Contrary to the modulus of rigidity which responds to a law of mixture, the **loss factor** is **more difficult to predict**

Damping



Impact of **flax fibres reinforcement** on polymer composite properties:

- **stiffness**: the storage modulus increases
- **damping**: the loss factor evolution is depending on the matrix…

Damping of thermoset and thermoplastic flax fibre composites, F. Duc et al. Composites Part A, 2014

DAMPING APPLICATIONS

Musical instruments & acoustics

Guitar (Blackbird)

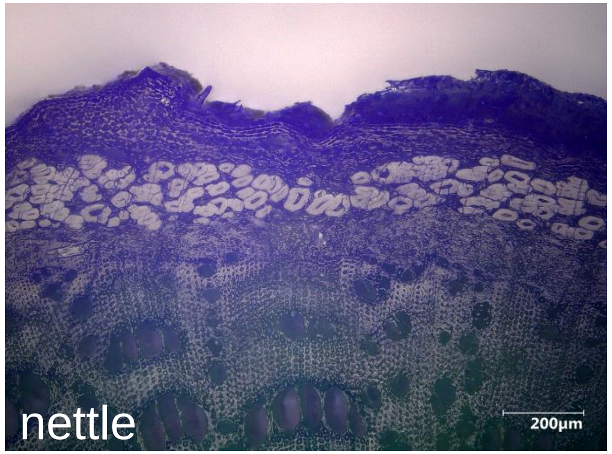
Violin soundboard

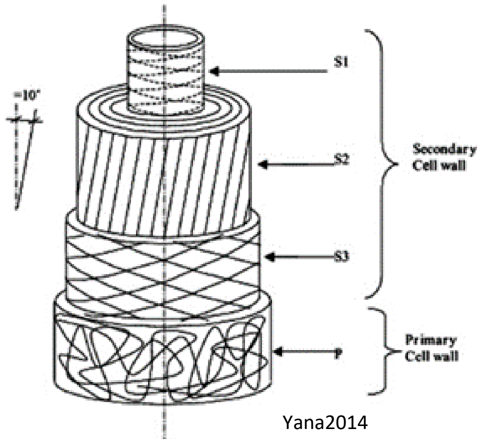
High-end loudspeakers (Wilson Benesch)

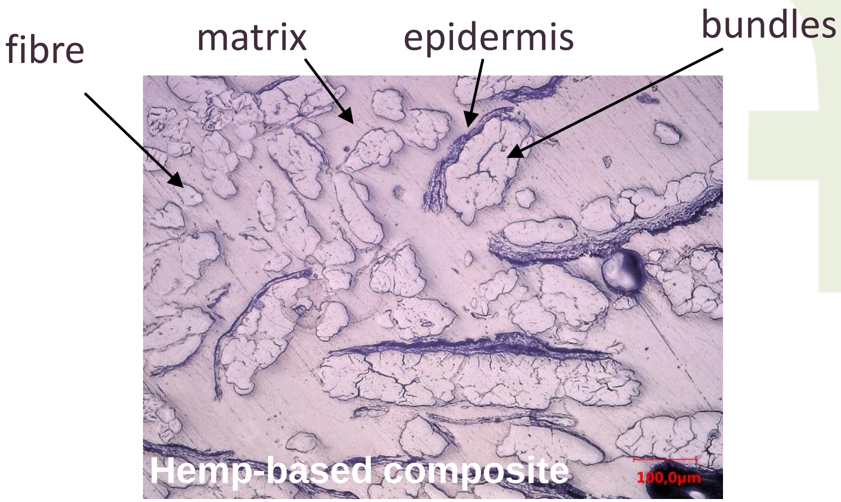
Field of sports

Even if their **origin are not yet fully understood** and elucidated, the **damping** properties of PFCs are already **exploited in various products**

ENERGY DISSIPATION SOURCES







Energy dissipation could come from :

- **fibre** properties: polymeric and hierarchical
- **interface** fibre/matrix
- interface in fibre bundles (**friction**)
- **damage**
- **matrix properties**

Difficulties to study bio-based material

- variability
- hierarchical
- sensitivity

Environment influence

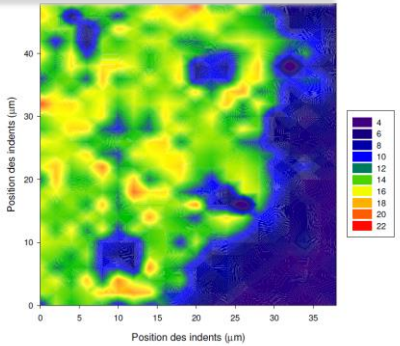
- humidity
- temperature
- frequency
- fibre type

Microscale dynamic characterization and identification

CONTENT

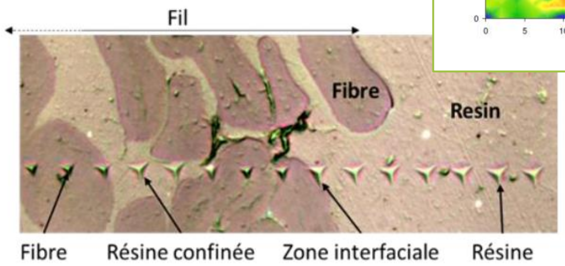
MODULUS AT THE FIBRE-SCALE

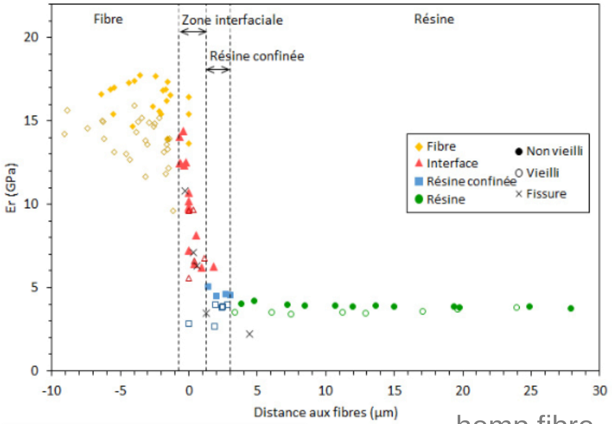
Bourmaud et al, 2009



flax fibre

Nanoindentation test: modulus identification

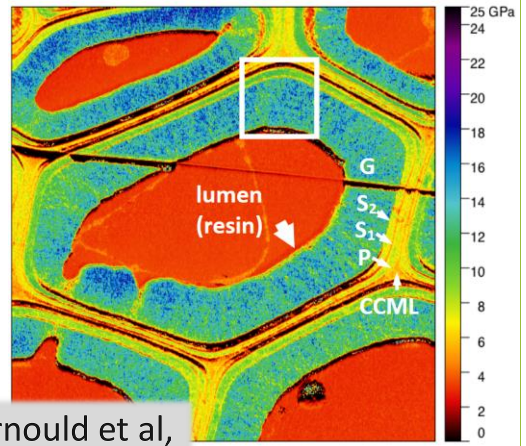




hemp fibre

Perrier et al, 2016

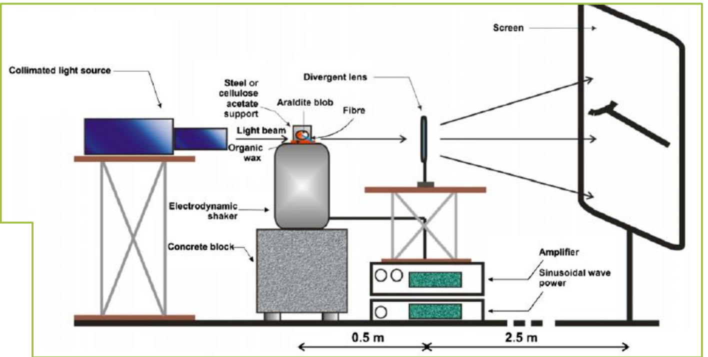
Atomic Force Microscopy, indentation modulus



Arnould et al, 2022

Wood fibres

glass fibre



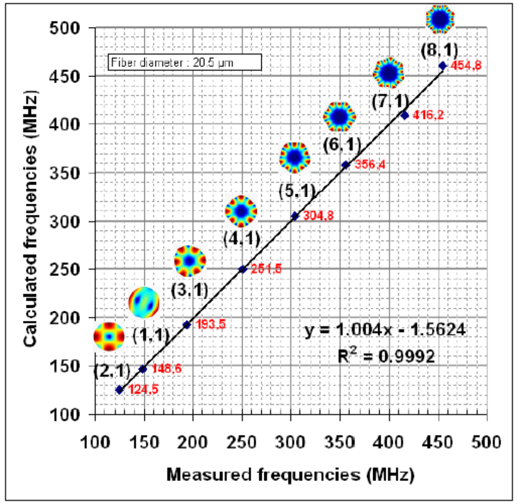
Determination of the elastic moduli of glass by forced vibrations

Perrin et al. 2007

MODULUS AT THE FIBRE-SCALE

Mounier et al. 2012

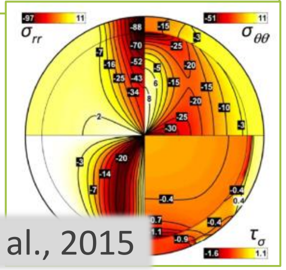
Determination of the transverse elastic properties of by laser resonant ultrasound spectroscopy



glass fibre and carbon fibre

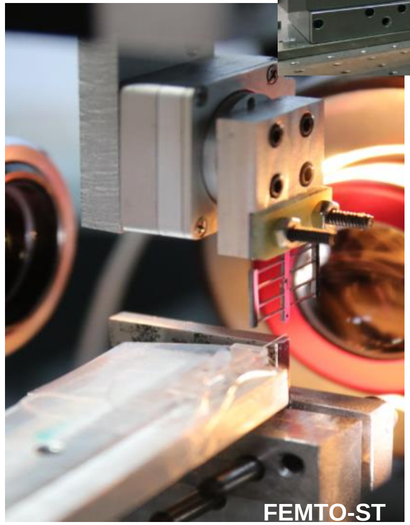
Single fibre transverse compression testing

aramid fibre



Wollbrett et al., 2015

Single plant fibre transverse compression



Flax, hemp, aramid fibres

Govilas et al., 2022

DAMPING AT THE FIBRE-SCALE

Torsion pendulum for elementary fibre: determination of the modulus and the loss factor under vacuum.

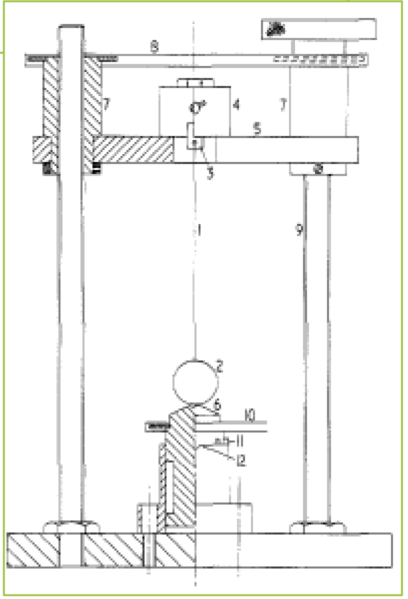
Adams et al. 1975

carbon fibre

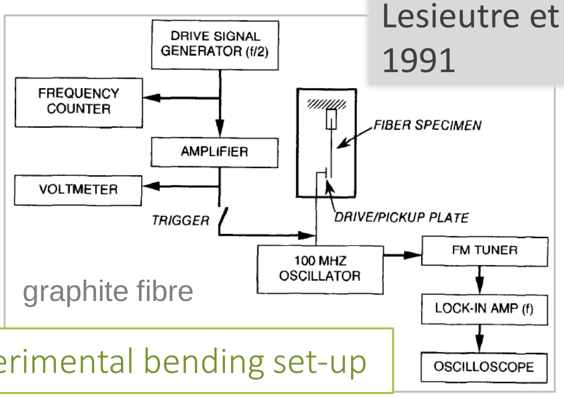
Yu et al, 2016

wool fibre

Philips et al, 1987



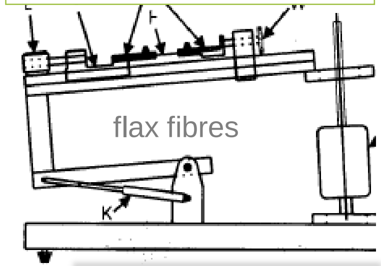
Lesieutre et al. 1991



graphite fibre

Experimental bending set-up

Dynamical traction



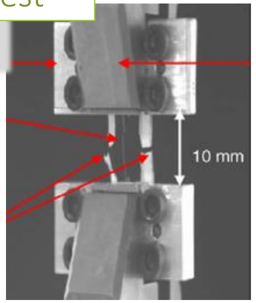
flax fibres

Davies et al. 1998

DMA tensile test

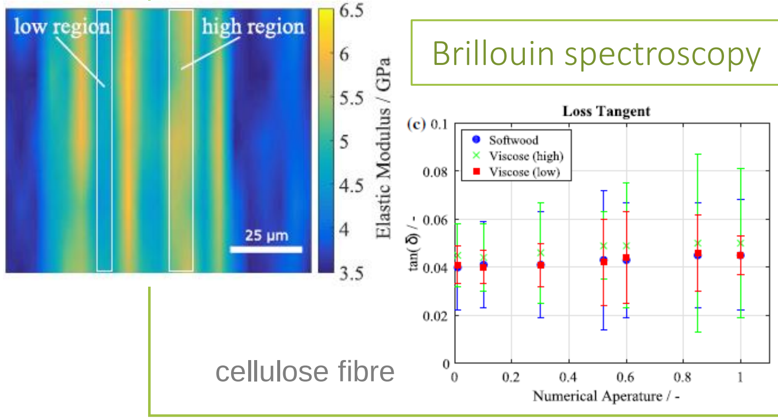
Placet et al. 2009

hemp fibres



Elsayad et al, 2020

Brillouin spectroscopy



cellulose fibre

Key points to measure the damping at the microscale:

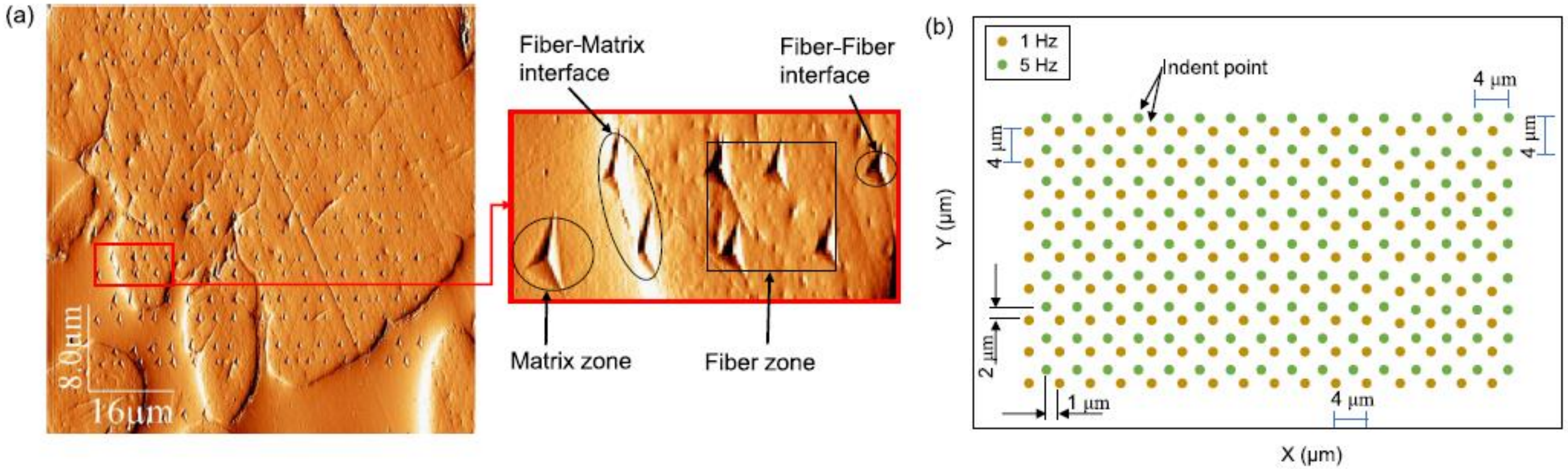
- To quantify the aerodynamic effect
- To control of the boundary conditions:
  - Clamp design
  - Measure method
  - Excitation mode
- To know the sample (geometry, density…)

carbon/graphite: $\eta \approx 10^{-2} - 10^{-1}$ %
wool: $\eta \approx 20 - 80$ %
flax/hemp: $\eta \approx 10^{-1} - 10$ %
cellulose: $\eta \approx 10^{0} - 10$ %

CONTENT

DYNAMIC NANOINDENTATION (DNI) – TESTING FIBRE WALL PROPERTIES IN COMPOSITE

Unidirectional flax/GreenPoxy composites



Contents lists available at ScienceDirect

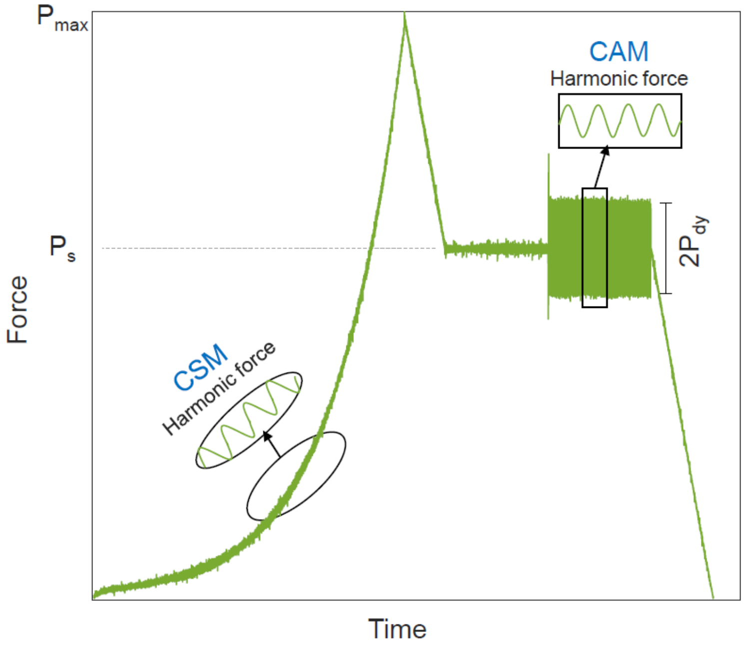
Composites Part A

journal homepage: www.elsevier.com/locate/compositesa

ELSEVIER

In situ damping identification of plant fiber composites using dynamic grid nanoindentation

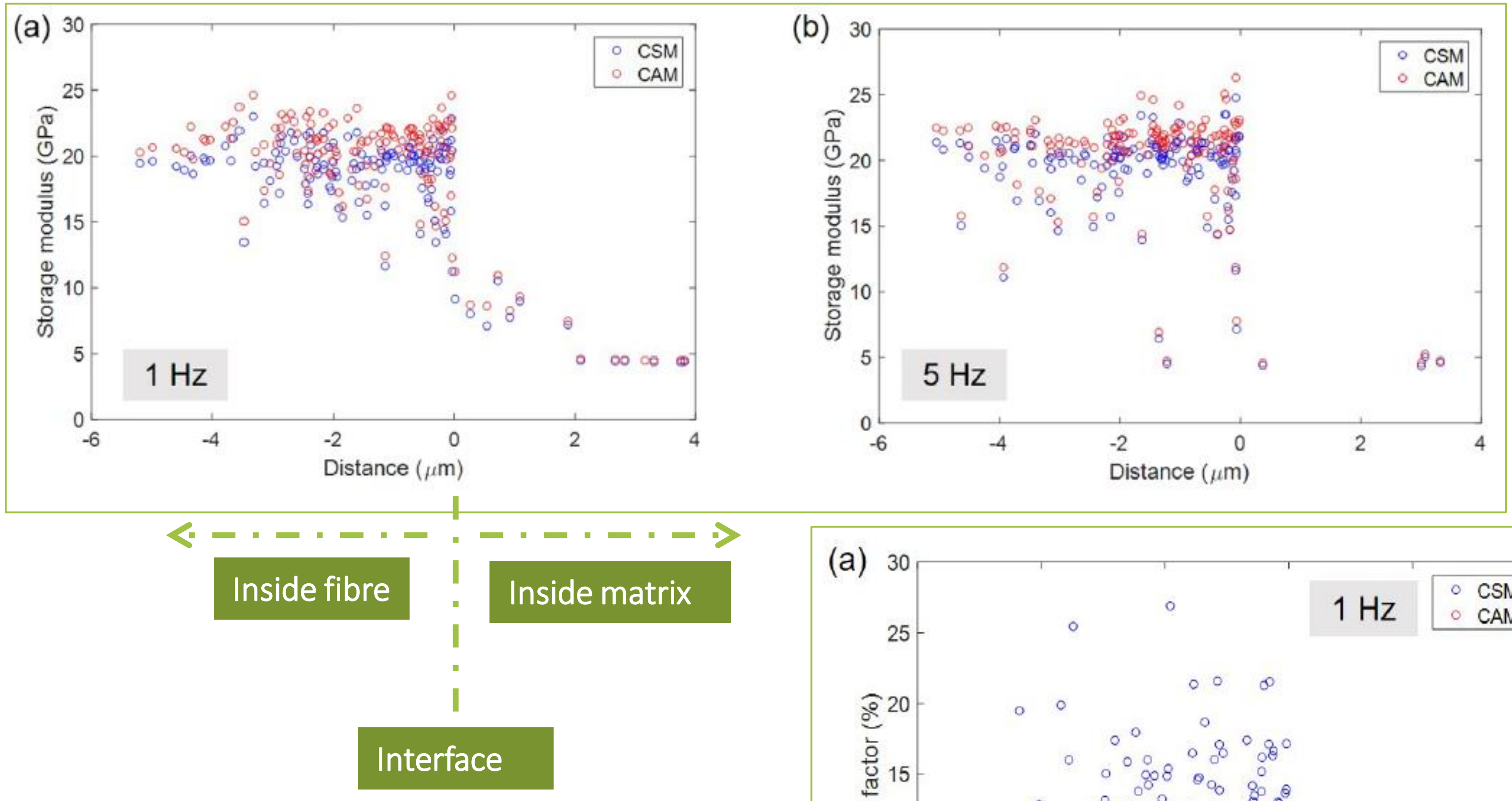
Taiqu Liu *, Yves Gaillard, Pauline Butaud, Vincent Placet, Morvan Ouisse



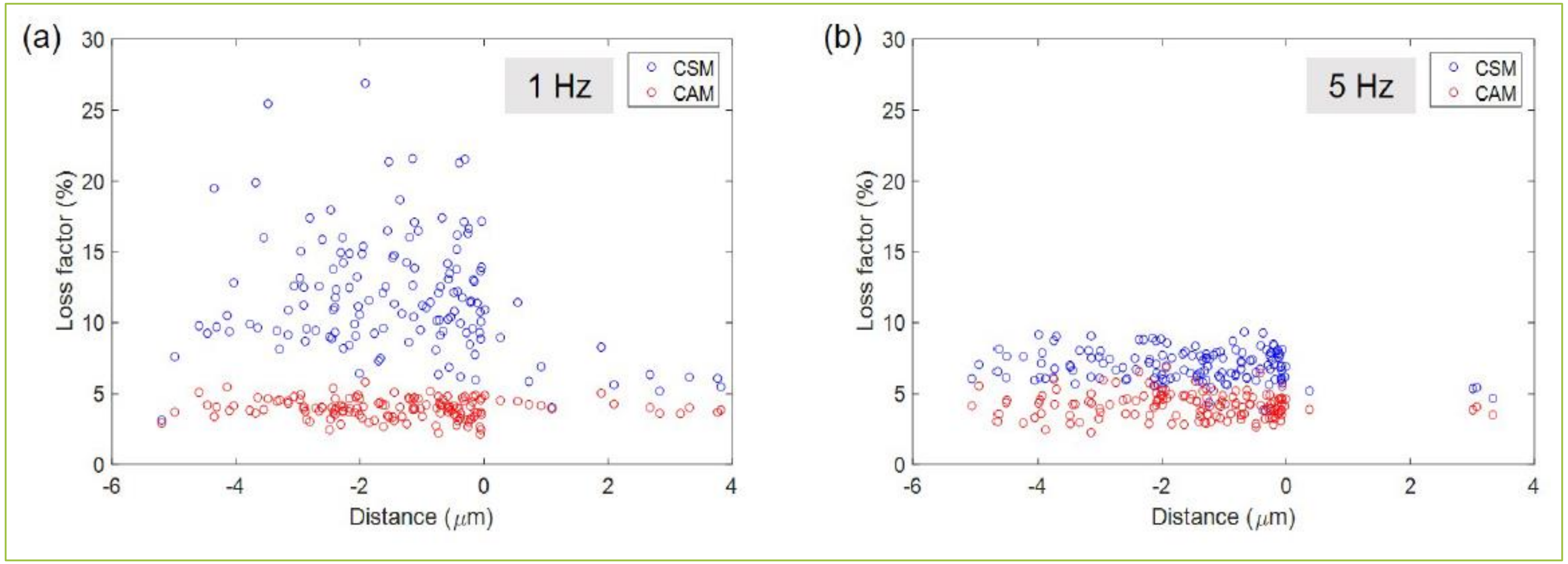
Continuous Stiffness Measurement method (CSM)
Constant Amplitude Measurement method (CAM)

DYNAMIC NANOINDENTATION (DNI) – TESTING FIBRE WALL PROPERTIES IN COMPOSITE

Liu et al. 2022

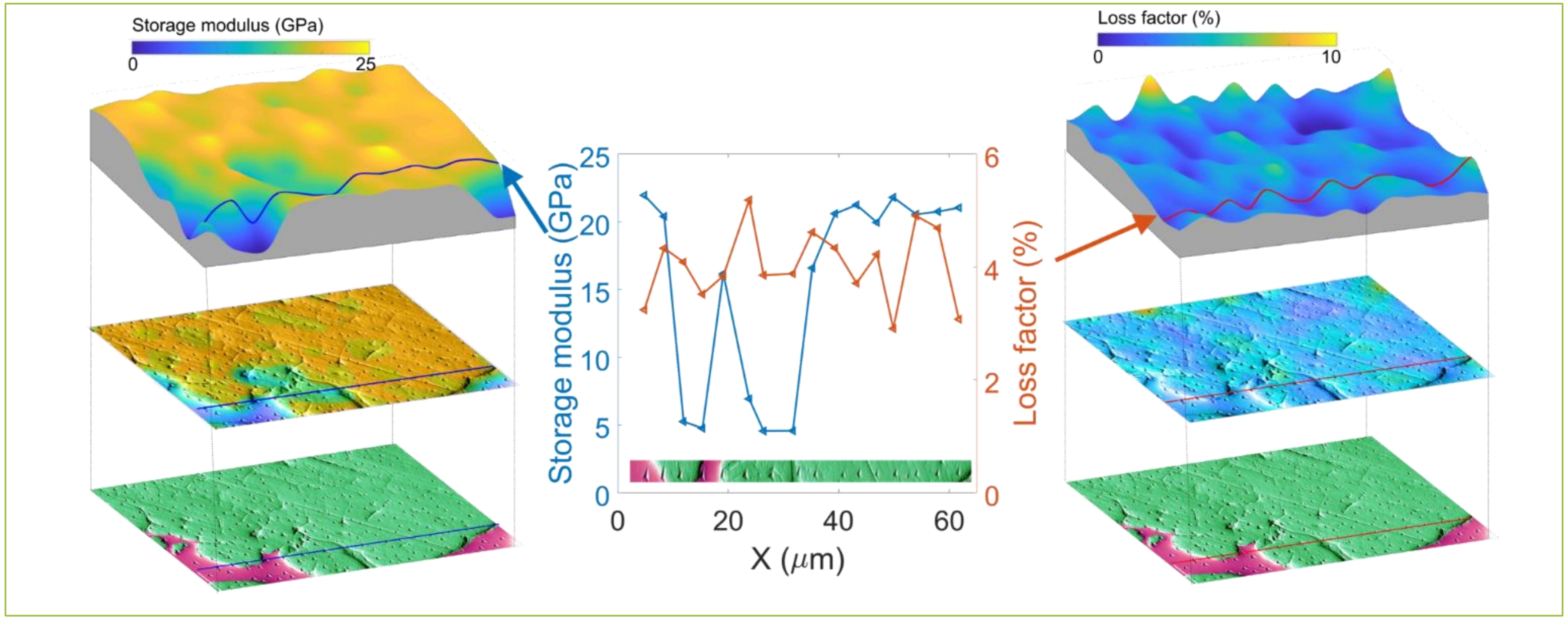


Unidirectional flax/GreenPoxy composites

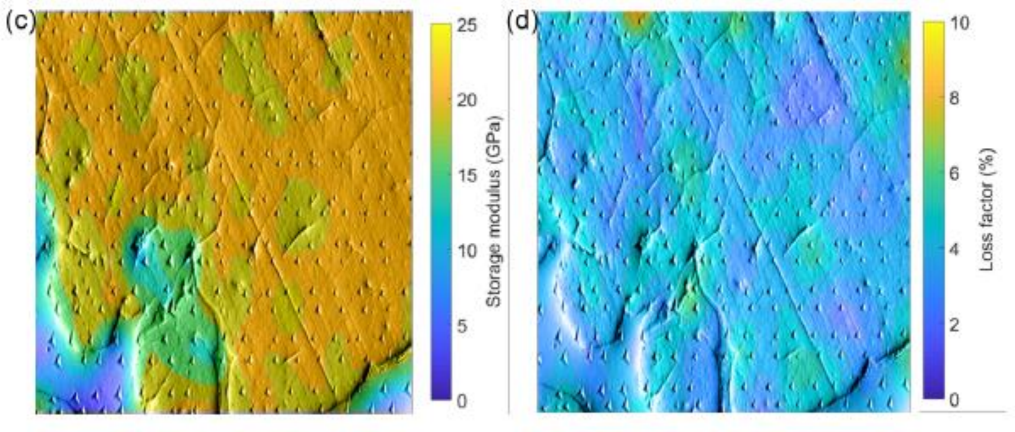


DYNAMIC NANOINDENTATION (DNI) – TESTING FIBRE WALL PROPERTIES IN COMPOSITE

Liu et al. 2022



CAM method



Unidirectional flax/GreenPoxy composites

CONTENT

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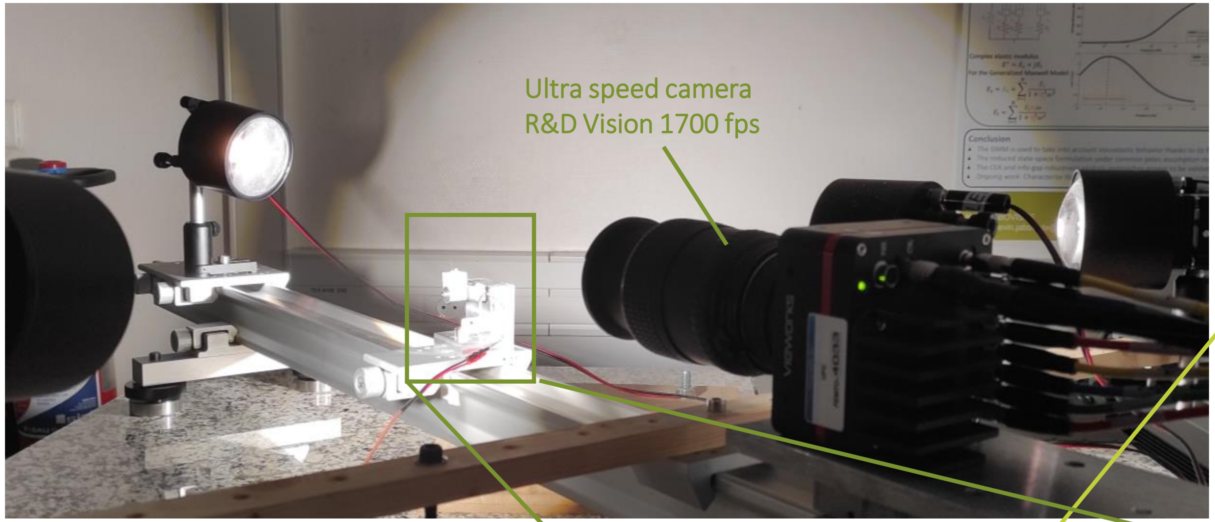
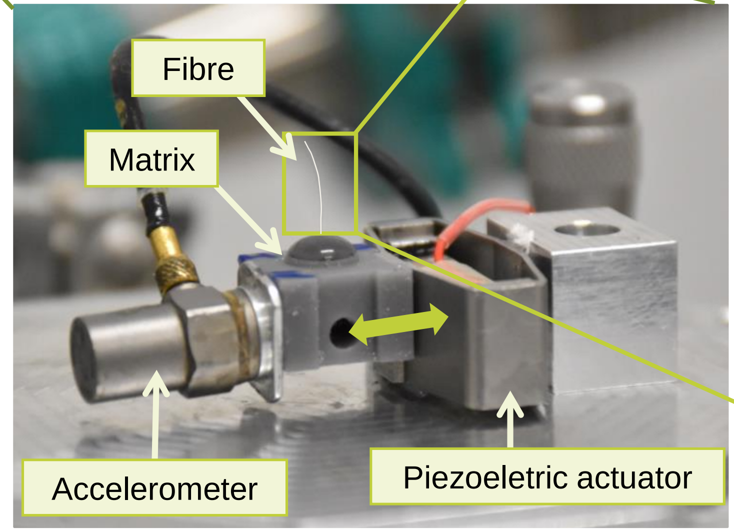
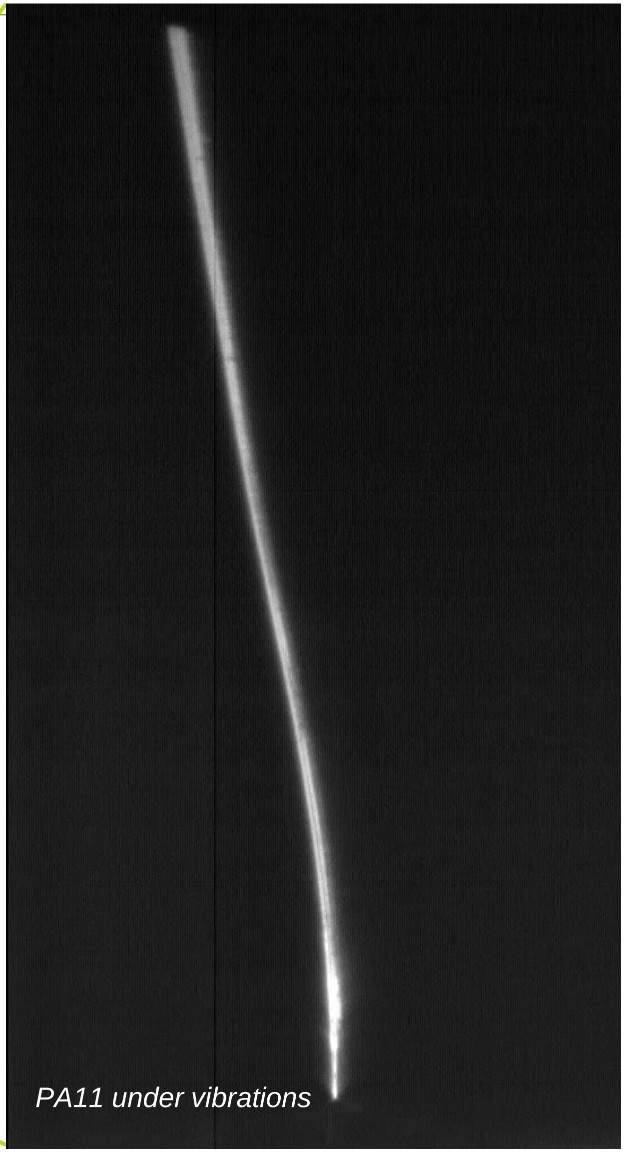
- Micro-scale properties of bio-based composites: state-of-the-art
- *In situ* testing
- Single fibre testing
- Conclusions and outlooks

F. Pelisson

DYNAMIC MECHANICAL TEST AT FIBRE SCALE







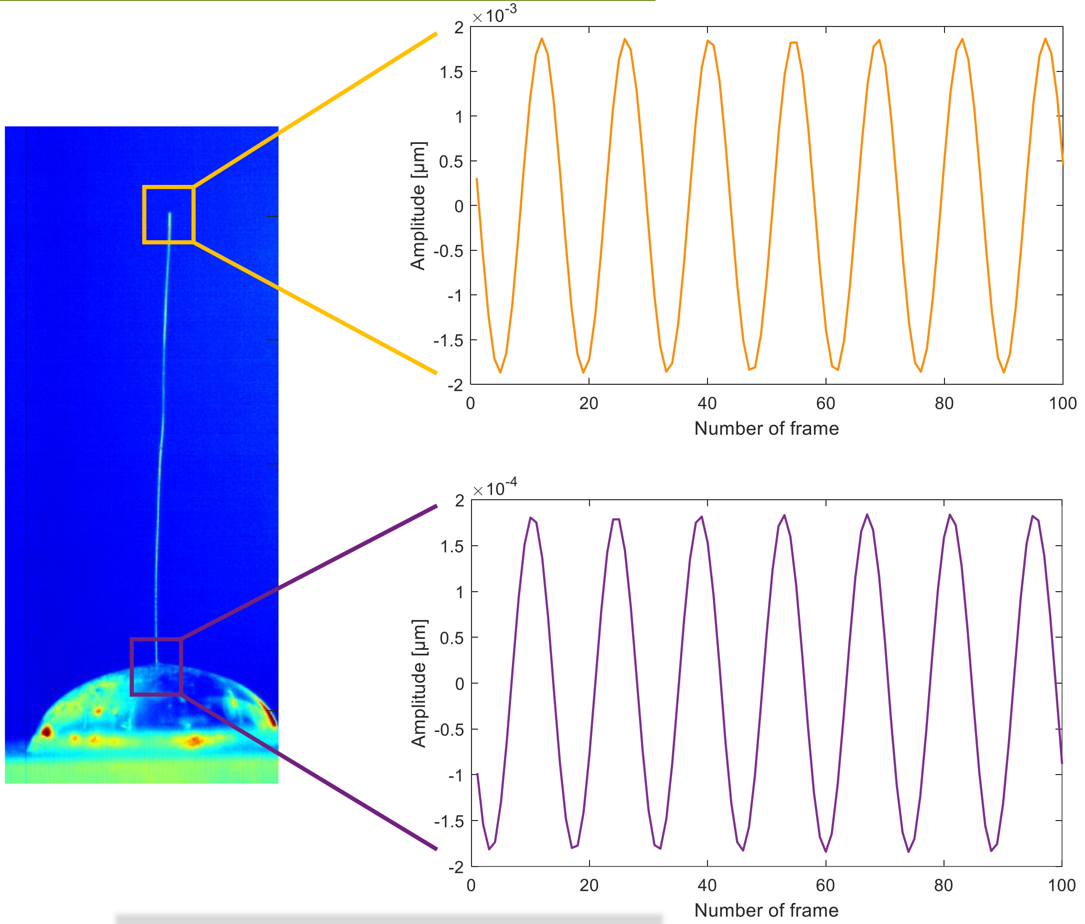
Vibration test on single fibre:

- Embedded in the matrix and excited at the base with a piezoelectric actuator
- Measurement by images tracking

F. Pelisson

DYNAMIC MECHANICAL TEST AT FIBRE SCALE

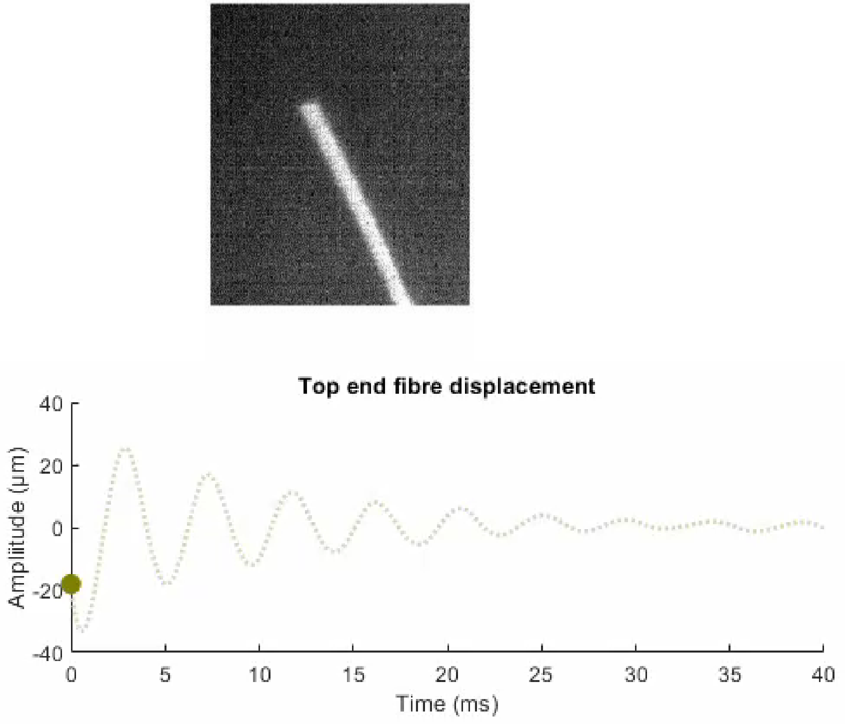
Damping identification in forced vibrations



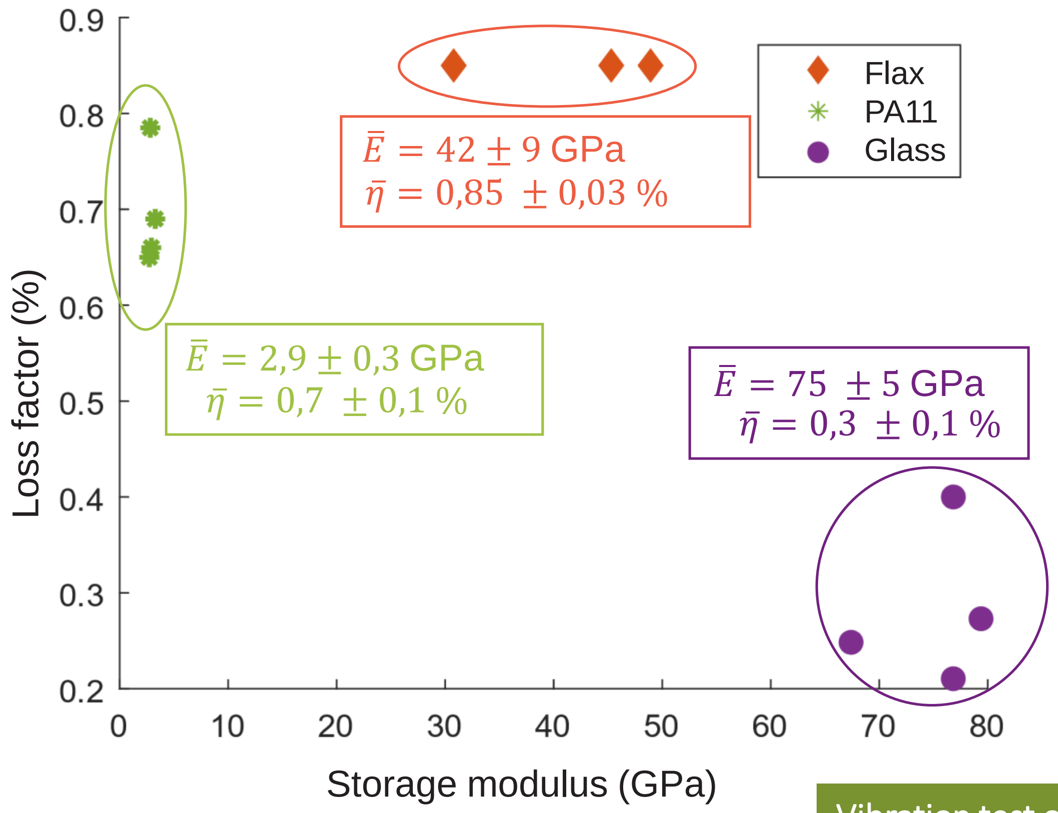
Storage modulus: linked to the resonance frequency of the fibre
Loss factor: linked to peak width

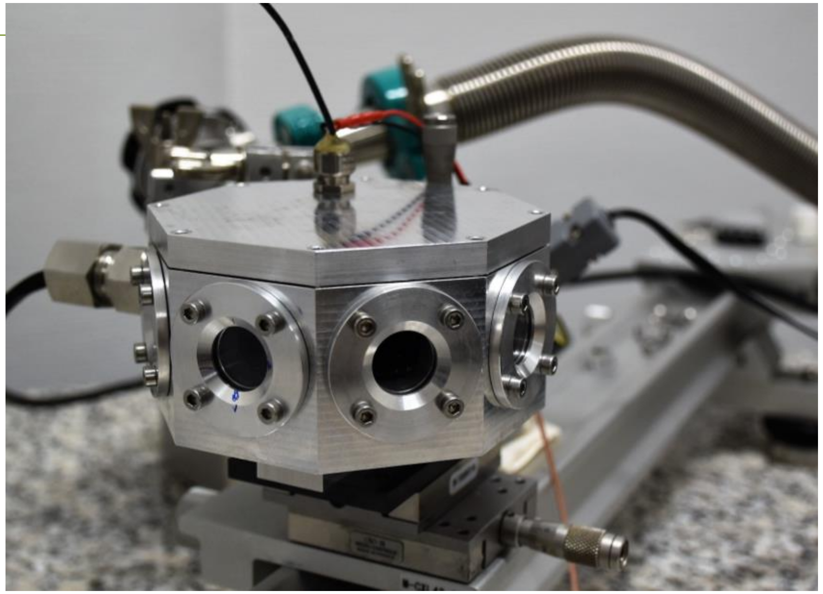
Damping identification in free vibrations

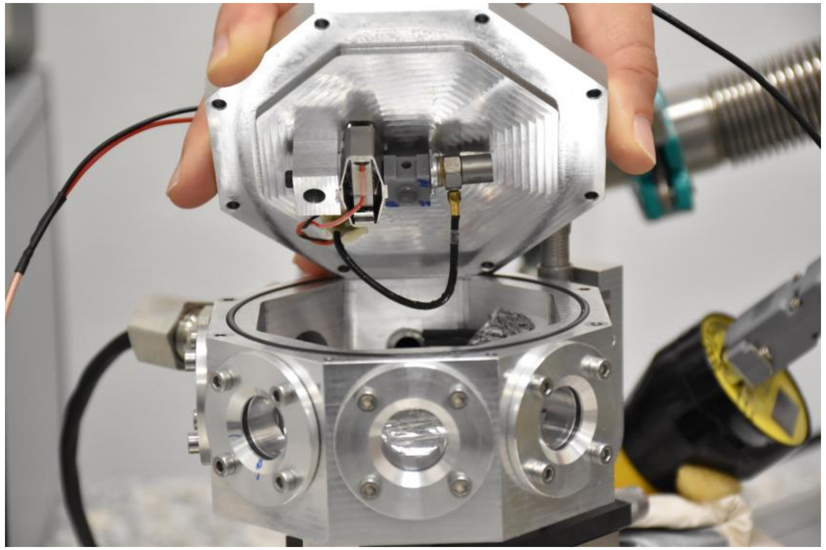
Storage modulus: linked to the resonance frequency of the fibre
Loss factor: linked to the logarithm decrement



DYNAMIC MECHANICAL TEST AT FIBRE SCALE







Vibration test on single fibre – limitations:
- Density and geometry of natural fibres difficult to evaluate
- High sensitivity to moisture/temperature variations and aerodynamic effects!?

CONTENT

- Context and challenges
- Micro-scale properties of bio-based composites: state-of-the-art
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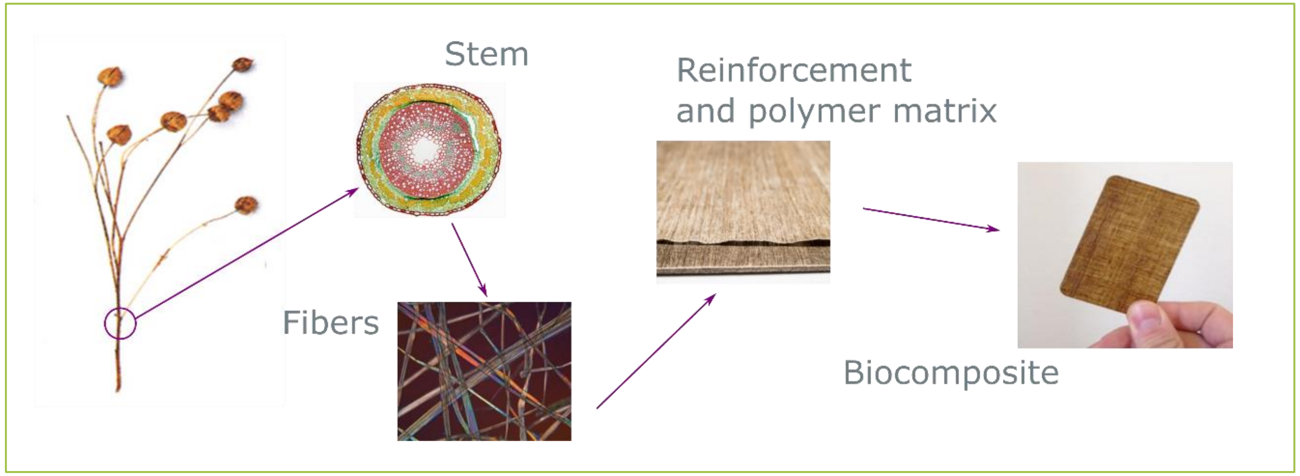
CONCLUSIONS & OUTLOOKS

- Better knowledge and **understanding of plant fibres damping capacity is cruci**al to design and **optimise** the new generation of PFC structures and implement new functionnalities in PFC products
- **Determination of damping** properties of (plant) fibres is **challenging**
- The classical techniques have drawbacks and the **uncertainty** of the identified properties is sometimes high
- The developement of **innovative and reliable experimental techniques** is ongoing in our team



MIcroscale characterization and modelling of energy DIssipation mechanisms to optimize damping of plant FIbres Composite structures

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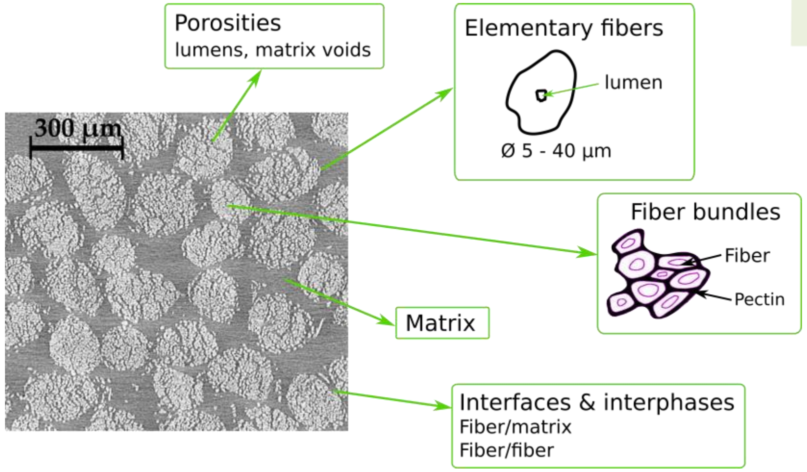
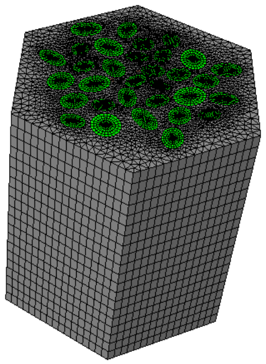
ANR JCJC (nov. 2022 – oct. 2026)

WP1: Fanny Pelisson PhD 2022-25



WP0: management		
WP1: microscale dynamic characterization and identification	WP2: composite damping multiscale optimization	Dissemination: publication, communication, vulgarization
Task 1.1: dynamic experimental development at fiber scale	Task 1.1: damping stochastic multiscale modeling development	
Task 1.2: dynamic properties of elementary fibers and bundles	Task 1.2: characterization and model validation	
Task 1.3: dynamic properties of the matrix/fiber interphase	Task 1.3: composite multi-objective optimization	
WP3: proofs of concept, demonstrators with low environmental impact		

WP2: Tsilat Shiferaw PhD 2023-26



Representative elementary volume (REV) of PFC

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