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VARIABILITY OF THE MECHANICAL PROPERTIES OF FLAX FIBERS FOR COMPOSITE REINFORCEMENT

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Natural Fibers for Composite Reinforcement

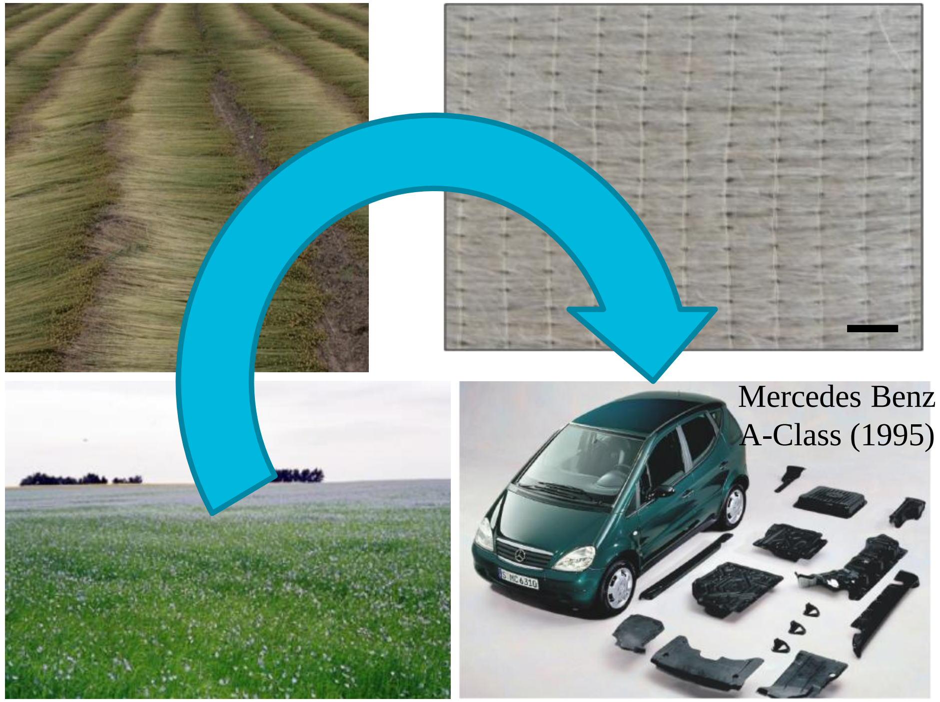
Natural fibers are environmentally-benign alternatives to glass (or aramid) fibers for composite reinforcement.

Pros

- Can meet the requirements of environmental regulations (e.g. REACH).
- Flax and hemp are promising (E/ρ ~ glass fiber).
- France is No 1 producer of flax and hemp in Europe (80%).
- Currently, the 3rd technical fibers (after glass and carbon fibers).

Cons

- Poor wettability between fibers / polymer: surface treatments !
- Life Cycle Assessment: Land use ? Water consumption ?
- Availability of high performance biobased (or biodegradable) thermoplastic matrices ? (Mostly, with PP or PLA so far)
- Thermal degradation of fibers: Use of High Tm thermoplastics ?
- Hygrothermal ageing ?
- High price of natural fiber textile reinforcement ?
- **Variability of fiber properties ?**



Natural fiber properties depend on

- ✓ ***Growing condition (Weather, Land, etc.)***
- ✓ ***Variety (genetics)***
- ✓ ***Fiber extraction/production parameters***
- ✓ ***Composites processing conditions***

etc.

Natural Fiber Composites: Projects of IMT Lille Douai (2013~)

Optimization, Numerical modeling, Characterization of Manufacturing Processes and Mechanical Properties

FIABILIN (PSPC)

- Flax textile + Biobased PA11
- Direct impregnation process (CRTM)

SINFONI (PSPC)

- Characterization of fiber density distribution in flax preform
- Numerical simulation for resin flow

Current projects

BIOCOMPAL (INTERREG FWVL)

- Flax textile + Biobased Benzoxazine
- High temperature resistant biocomposites

SEABIOCOMP (INTERREG 2 SEAS)

- Flax fiber + Self-reinforced PLA
- Biodegradable composites for marine applications

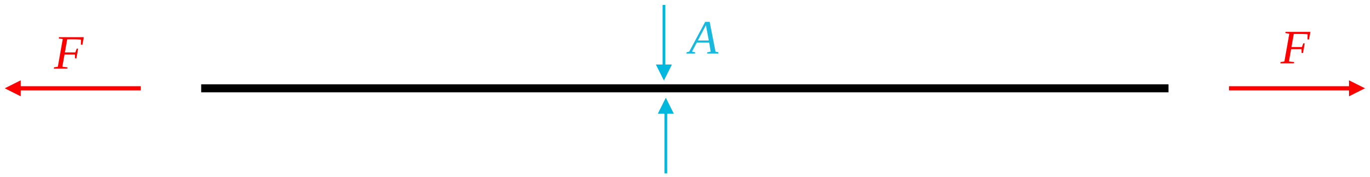
ATHENS (INTERREG FWVL)

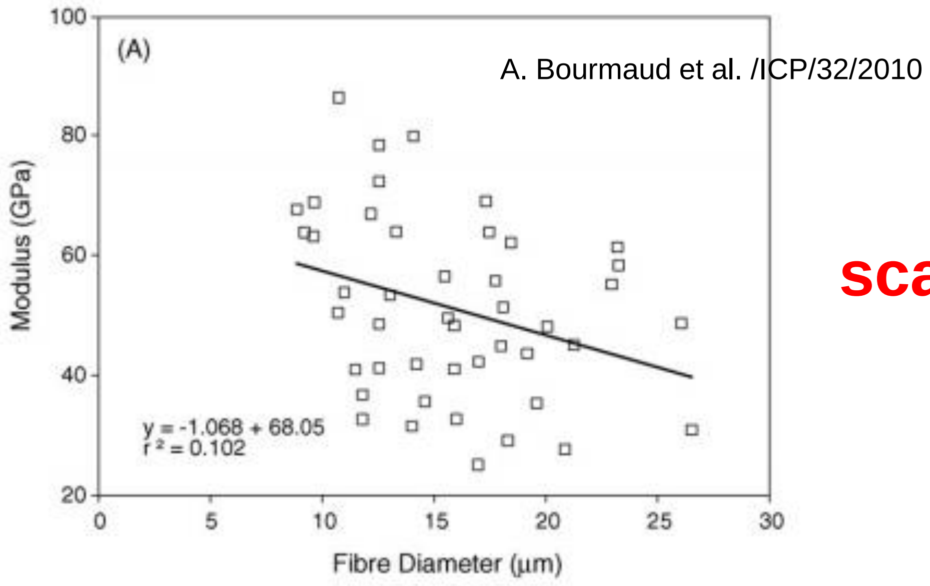
- Assembly technology for flax fiber composites
- Laser-welding for flax fiber reinforced PP or PLA

Scattering of Flax Fiber Properties Measurement Results

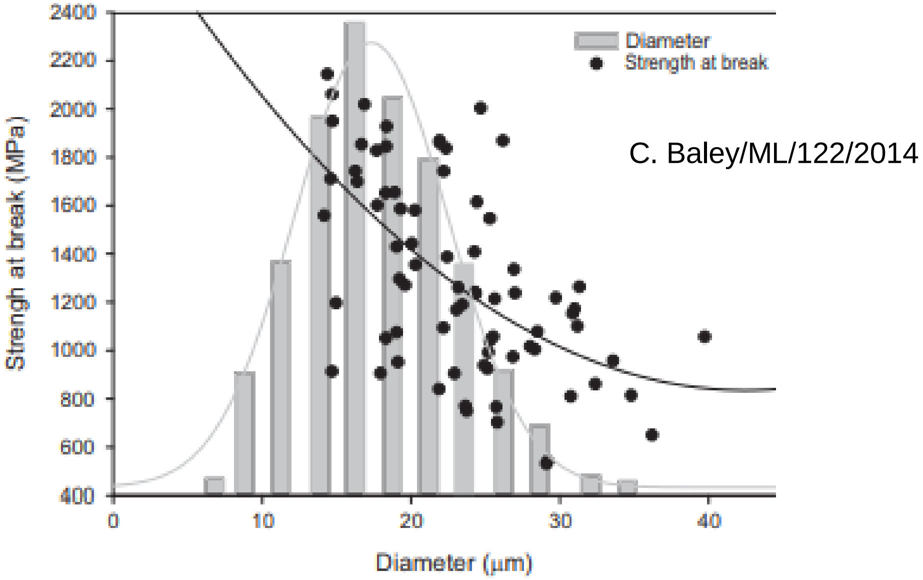
Single fiber test

$$\sigma = \frac{F}{A}$$





Big scattering!



- Requires high precision in extracting fibers without damage
- Intrinsic variation of fiber properties
- Non-uniform cross-section (diameter) of fibers: fiber to fiber, within a fiber

Impregnated Fiber Bundle Test (IFBT)

- Measurement of the mechanical properties of pure matrix and unidirectional composites
- Back-calculation of the mechanical properties of fibers

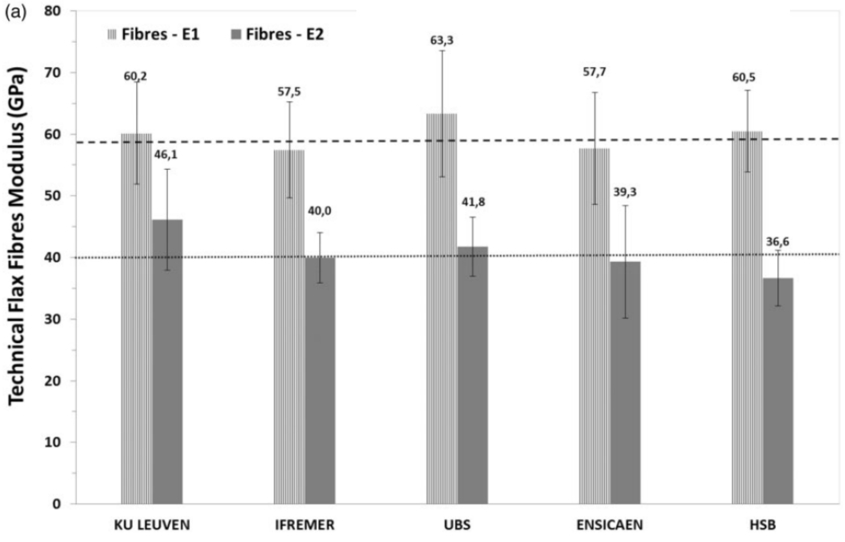
Statistical averaging

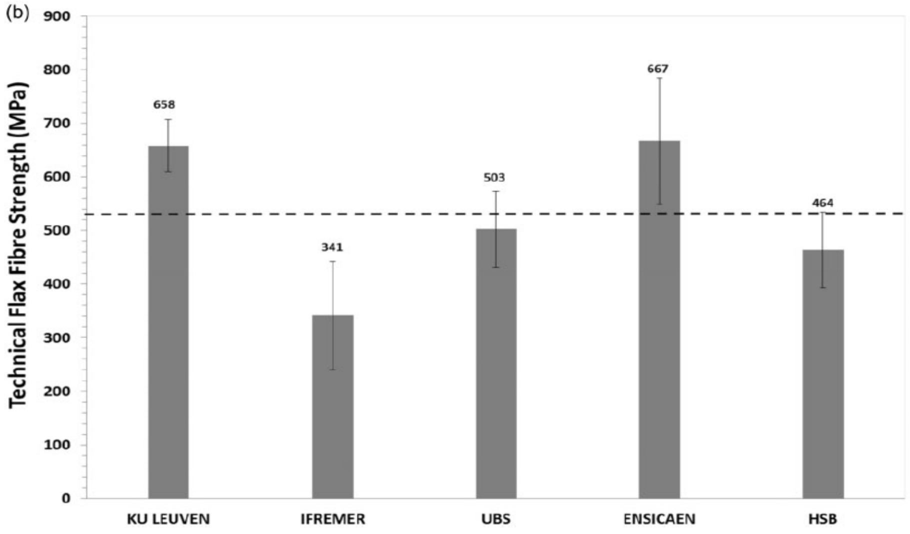
Benchmark tests by different labs Bensadoun et al./JRPC/2017

Modulus $\mathbf{E_f} = \frac{\mathbf{E_C - E_m * (1 - V_f)}}{\mathbf{V_f}}$

Strength $\sigma_{u,f} = \frac{\sigma_C - \sigma'_m * (1 - V_f)}{V_f}$ $\sigma'_m = E_m \times \varepsilon_c$

f: fiber
m: matrix
c: composite





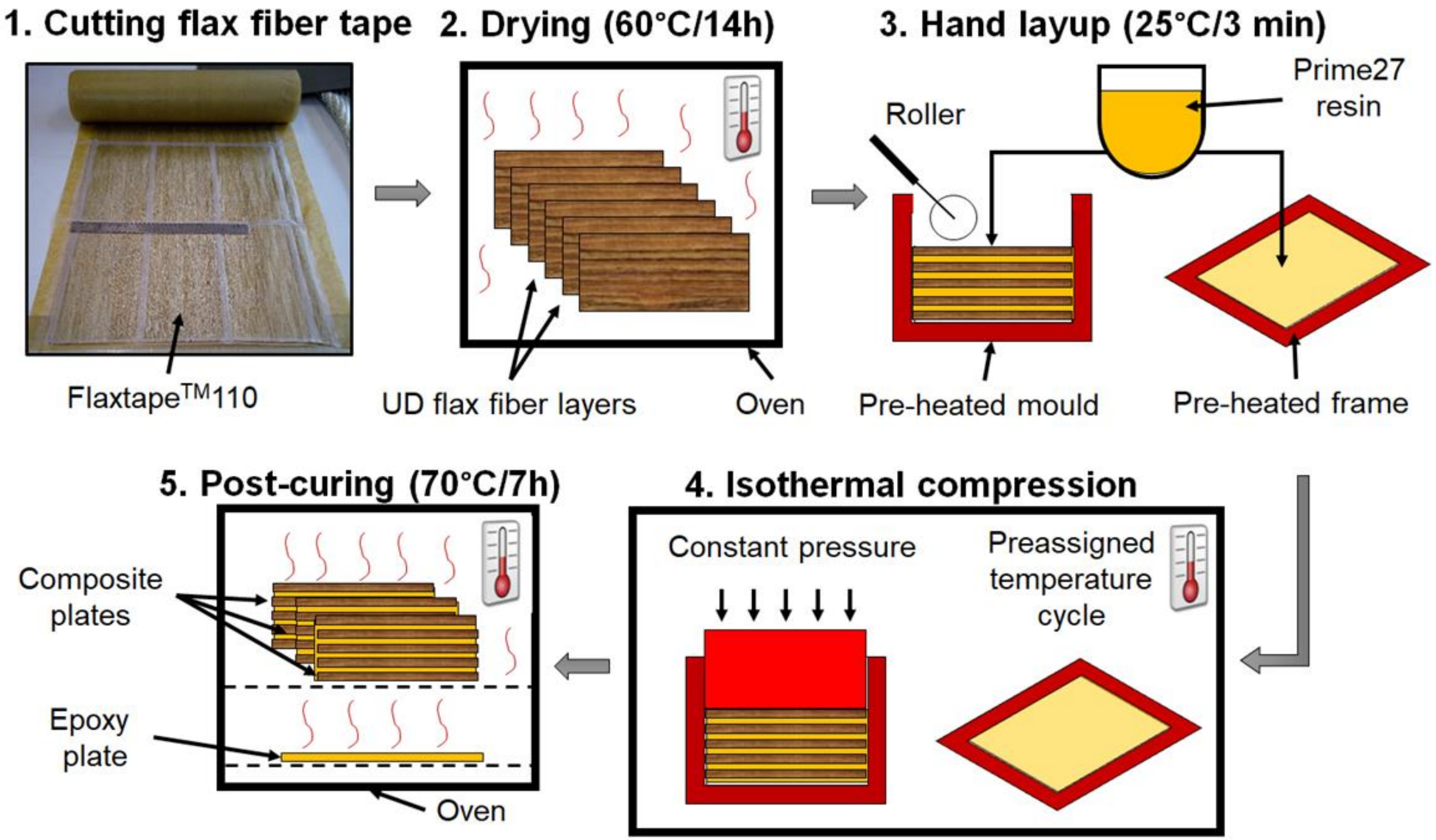
Constant fiber modulus

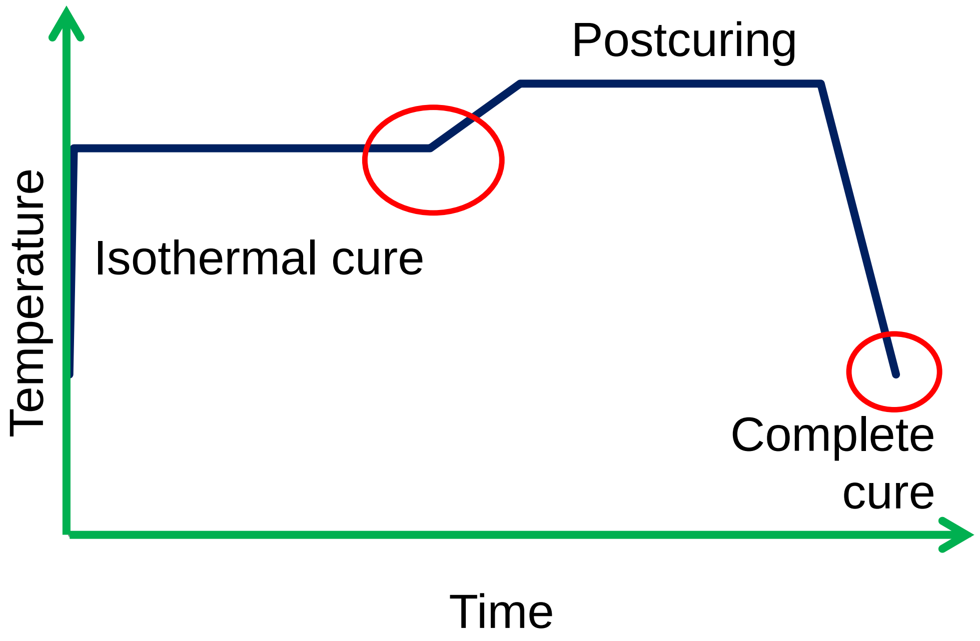
Variable fiber strength

Influence of manufacturing conditions (void content, cure cycle) ?

Manufacturing of UD Composite Specimens for IFBT

Different cure cycles, $T(t)$





Cycle reference	Temperature(°C)
RT	25
60	60
80	80
80S	80

Temperature

Time

Hand lay-up to minimize the void content (<1% except 80S)

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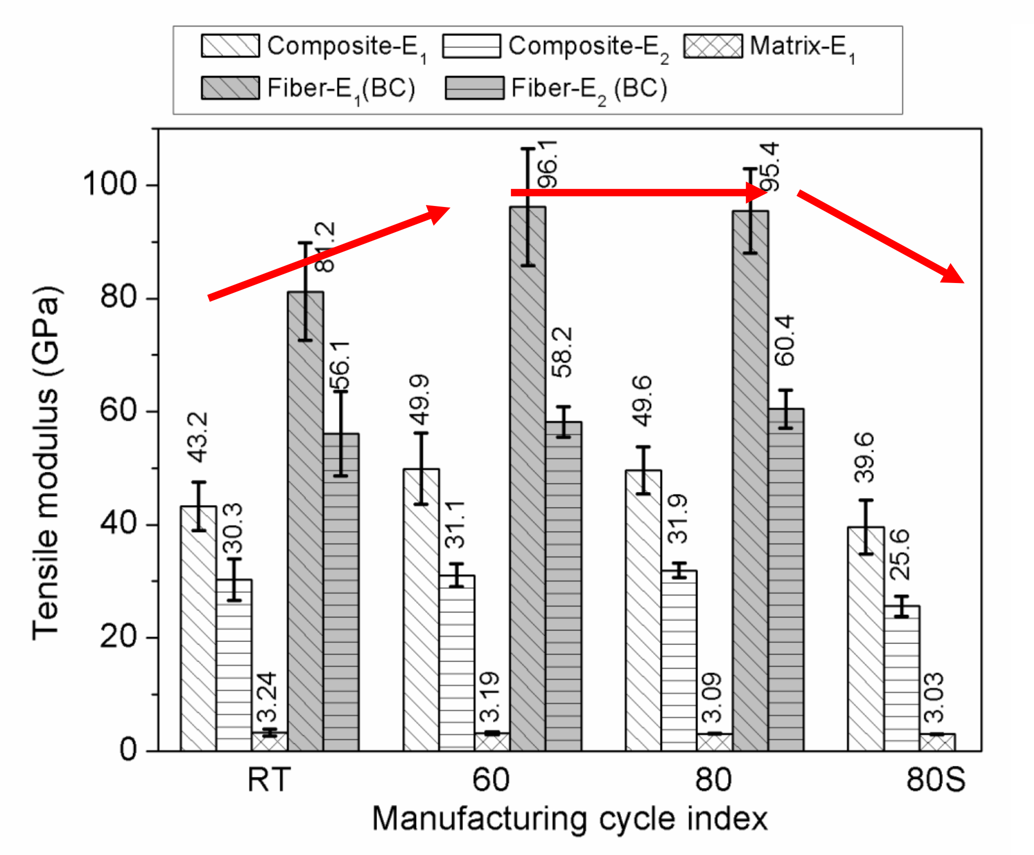
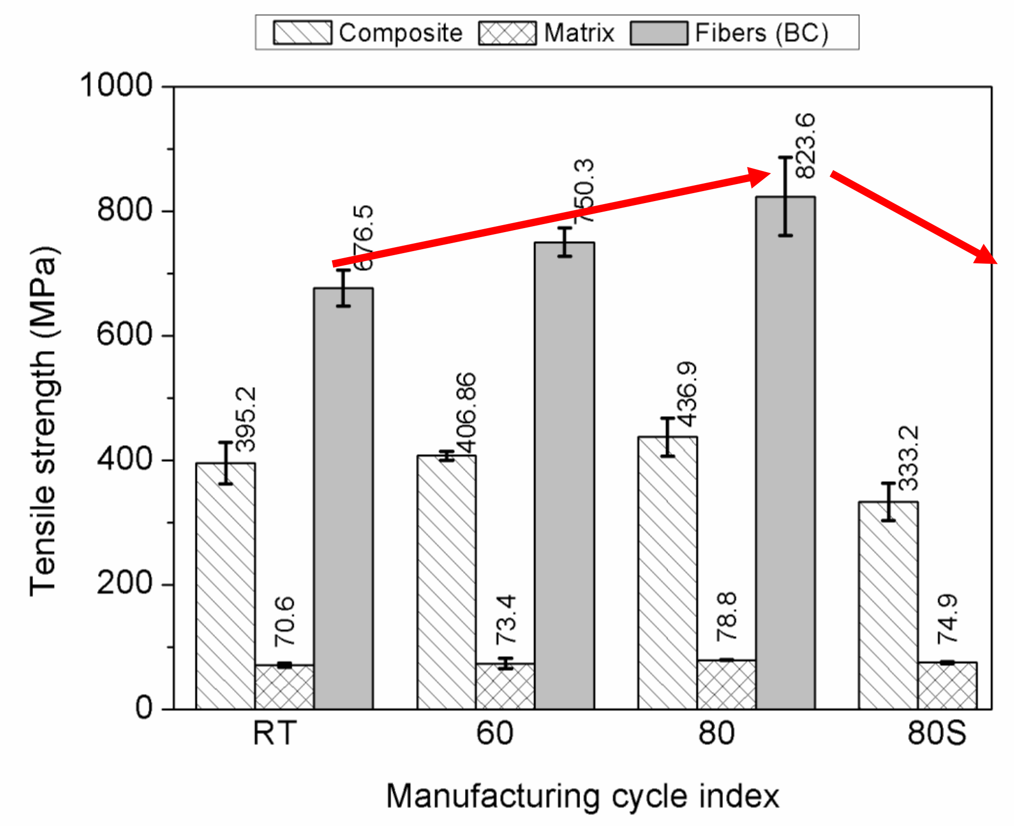
Results for Tensile Modulus and Strength of Flax Fibers

- As the temperature increases, the fiber modulus/strength increases.
- At the same temperature, the strength is greater for a longer duration of cure (and impregnation).

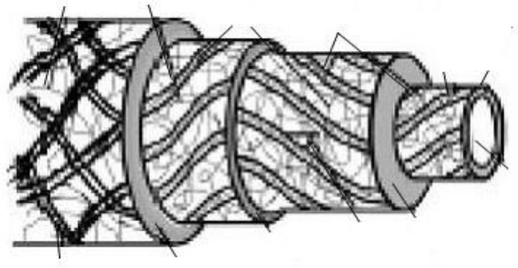




Process optimization: Minimal temperature and duration

Multi-scale Porosity of Flax Fiber Reinforcement

Elementary fiber



Porous fiber cell walls

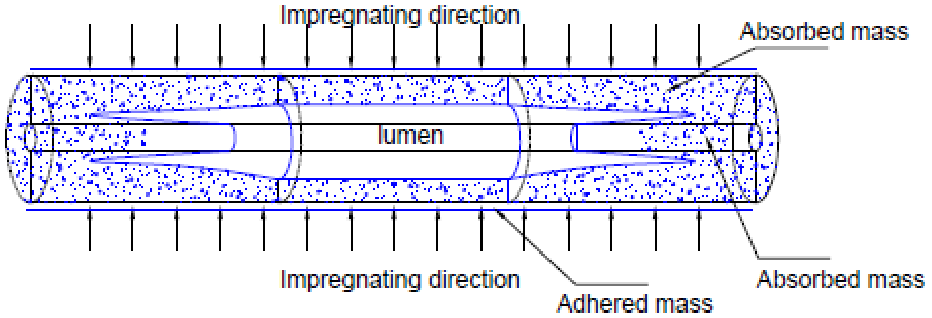
Yarn

Textile

Flax fiber in contact with the liquid resin

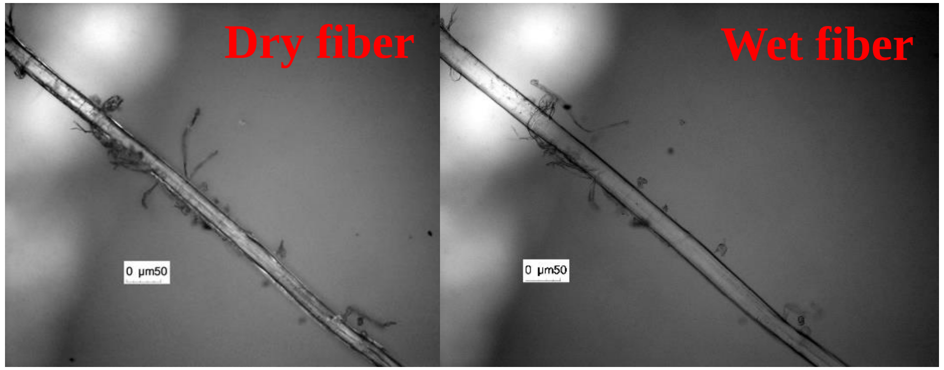
- **Liquid absorption**

Liquid absorption into the fiber cell walls

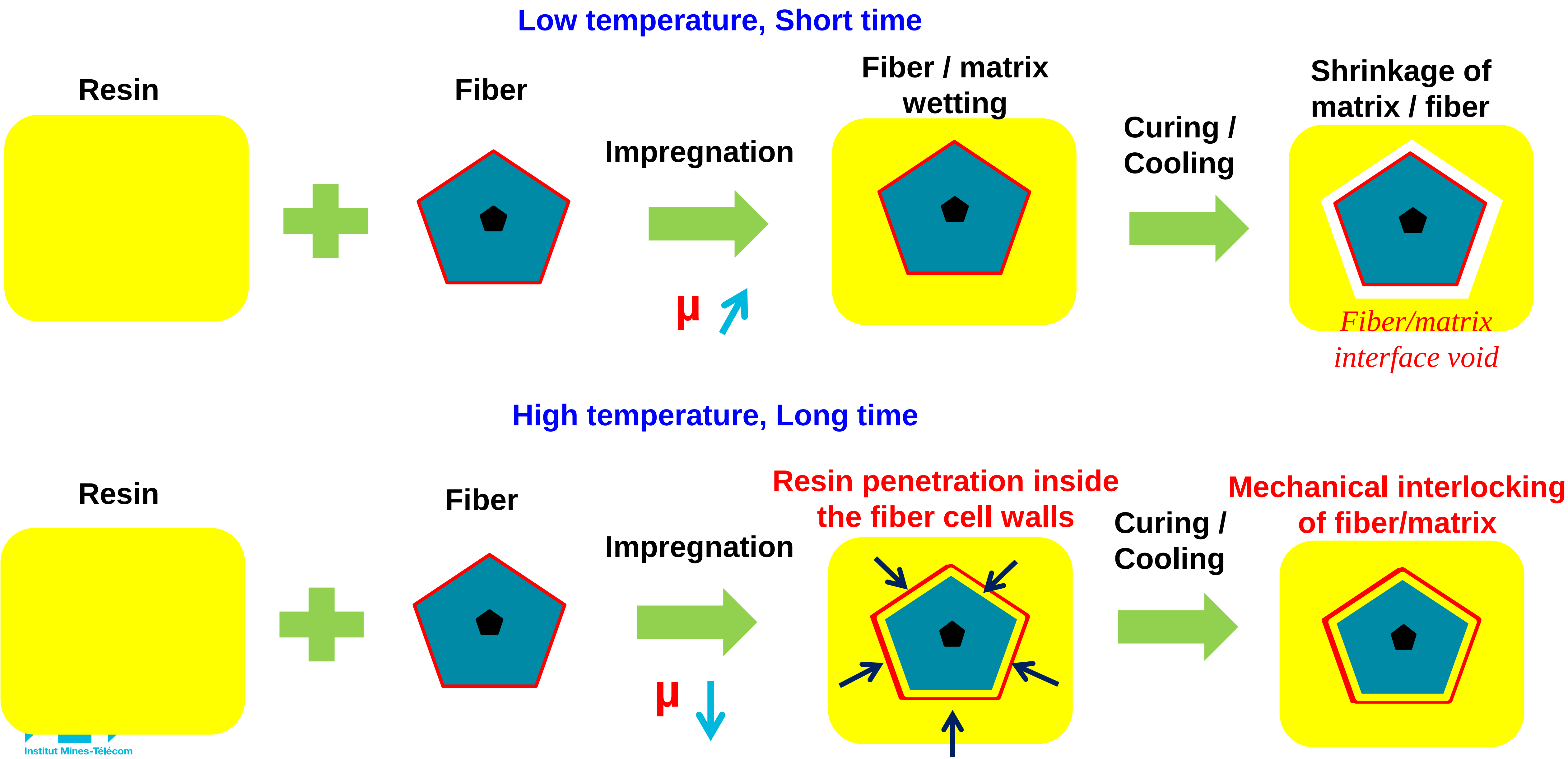


- **Fiber swell**

Increase of fiber diameter (cross-section)

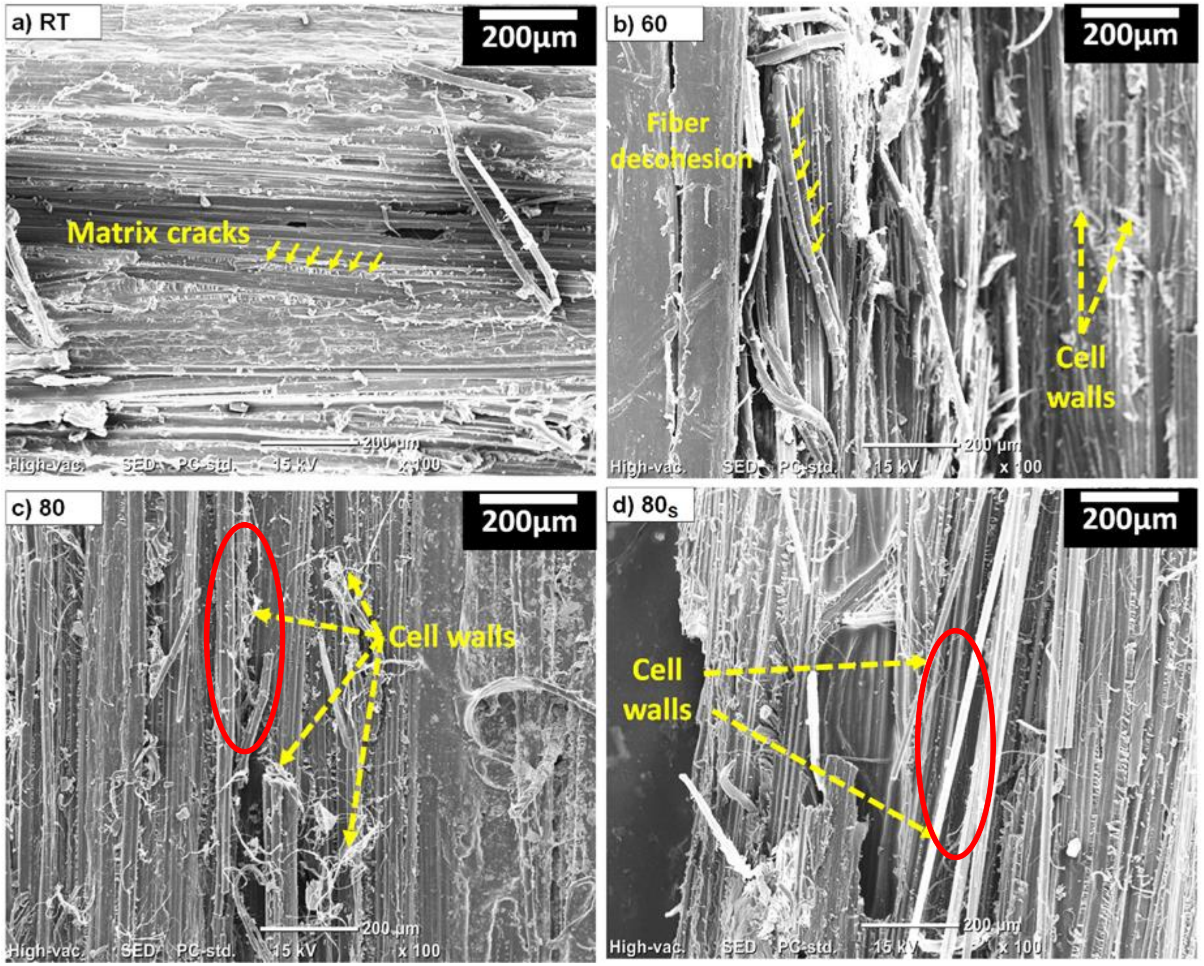


Resin Penetration into Flax Fiber Cell Walls

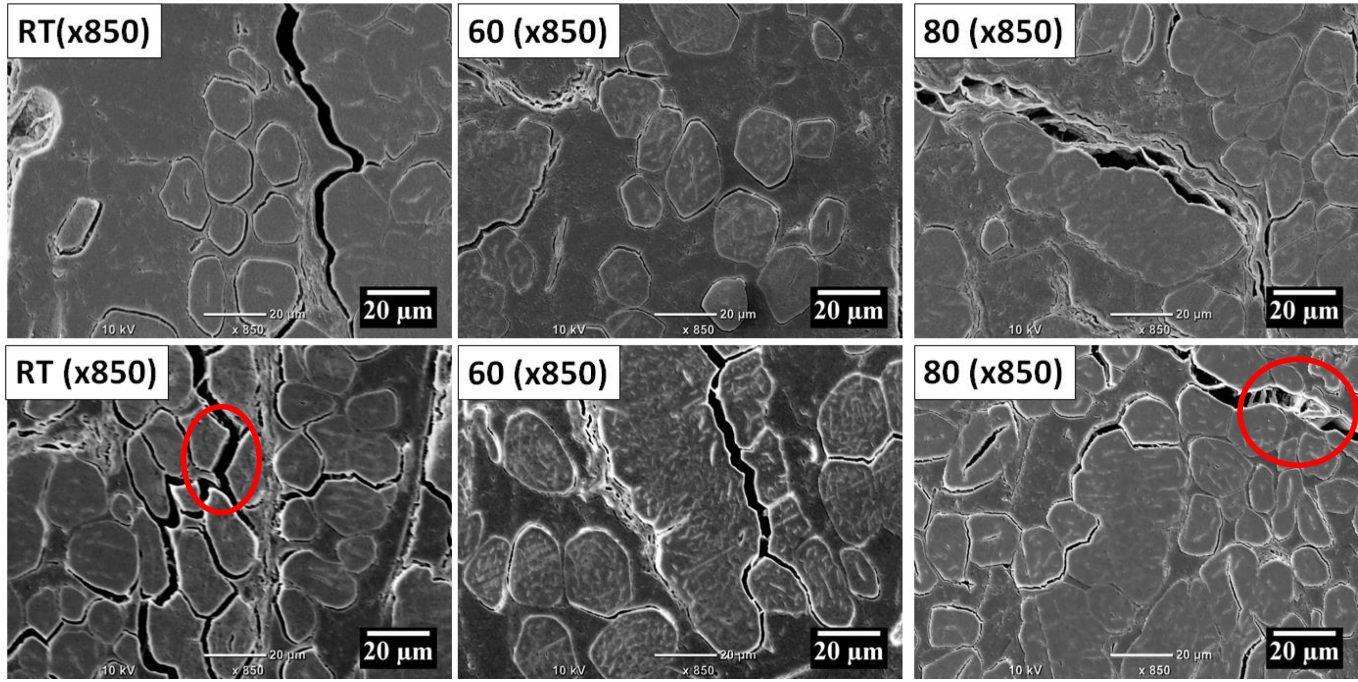


Fractography

- At low temperature (and short duration), fiber/matrix separation at the interface.
- At high temperature (and long duration), fiber cell walls are torn off by the matrix.



SEM images of fractured surfaces of composite samples



SEM images showing the interfacial cohesion and decohesion for different cure cycles at the scale of individual fibers

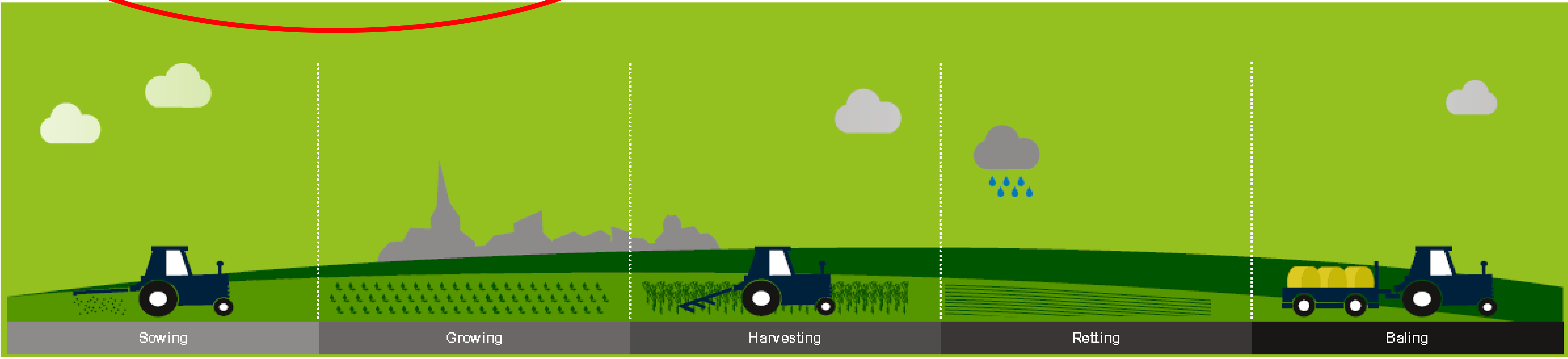
Different parameters may have an influence on the quality of flax fibers.

Variety

Growing conditions

Date of pulling

Retting degree



Comparison of Different Flax Varieties for Different Growing Conditions

Growing trials were carried out in the same field near Houtem, Belgium for two consecutive years.

2017 (Unfavorable: Very dry)

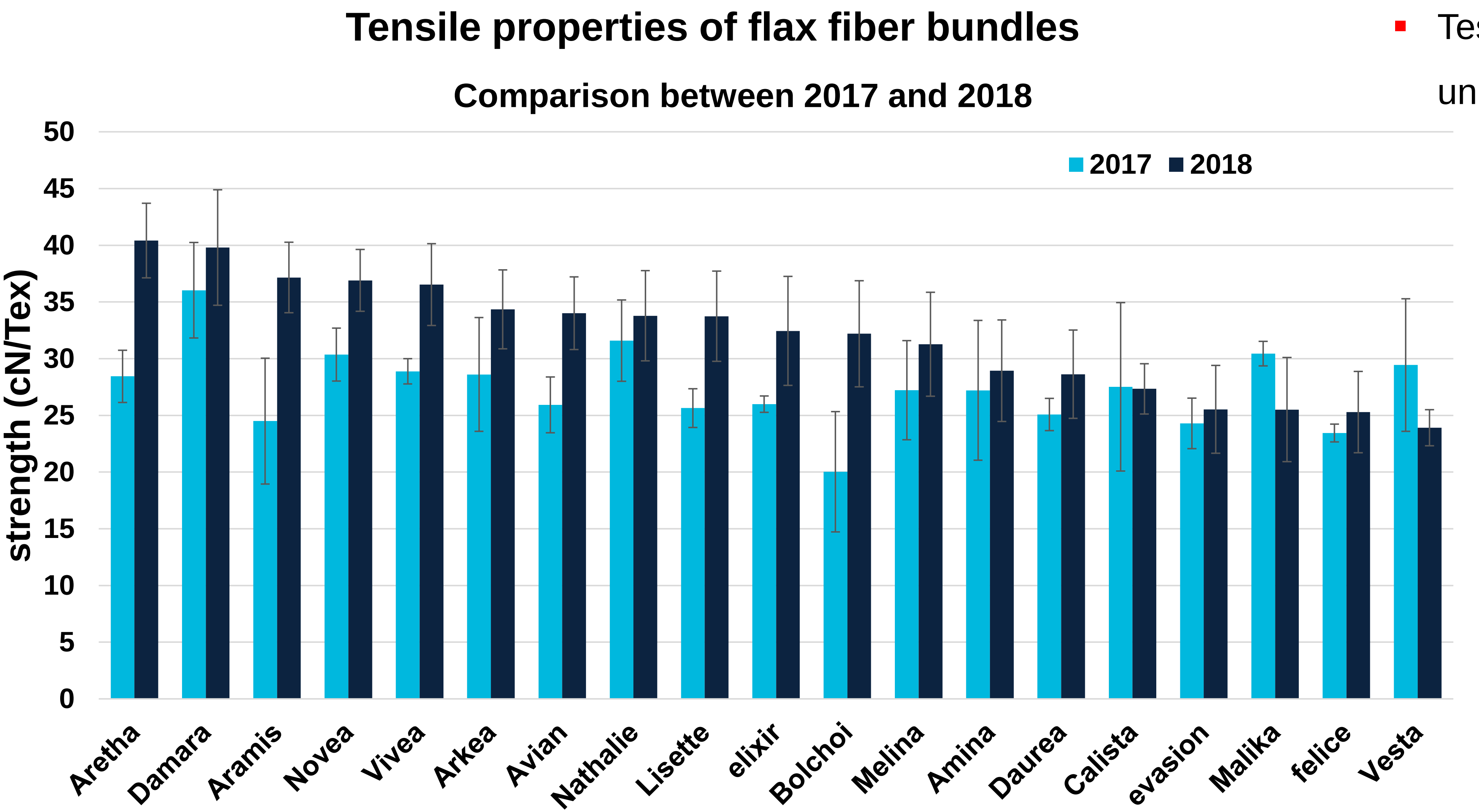
Activity	Timeline
Sowing	30/03/2017
Pulling	03/07/2017
Scutching	28/07/2017

2018 (Favorable: Enough rain)

Activity	Timeline
Sowing	20/04/2018
Pulling	14/07/2018
Scutching	16/08/2018

- A total of 20 varieties of flax were grown simultaneously.
- Based on screening (dry fiber bundle tests), only 10 varieties were selected for IFBT.

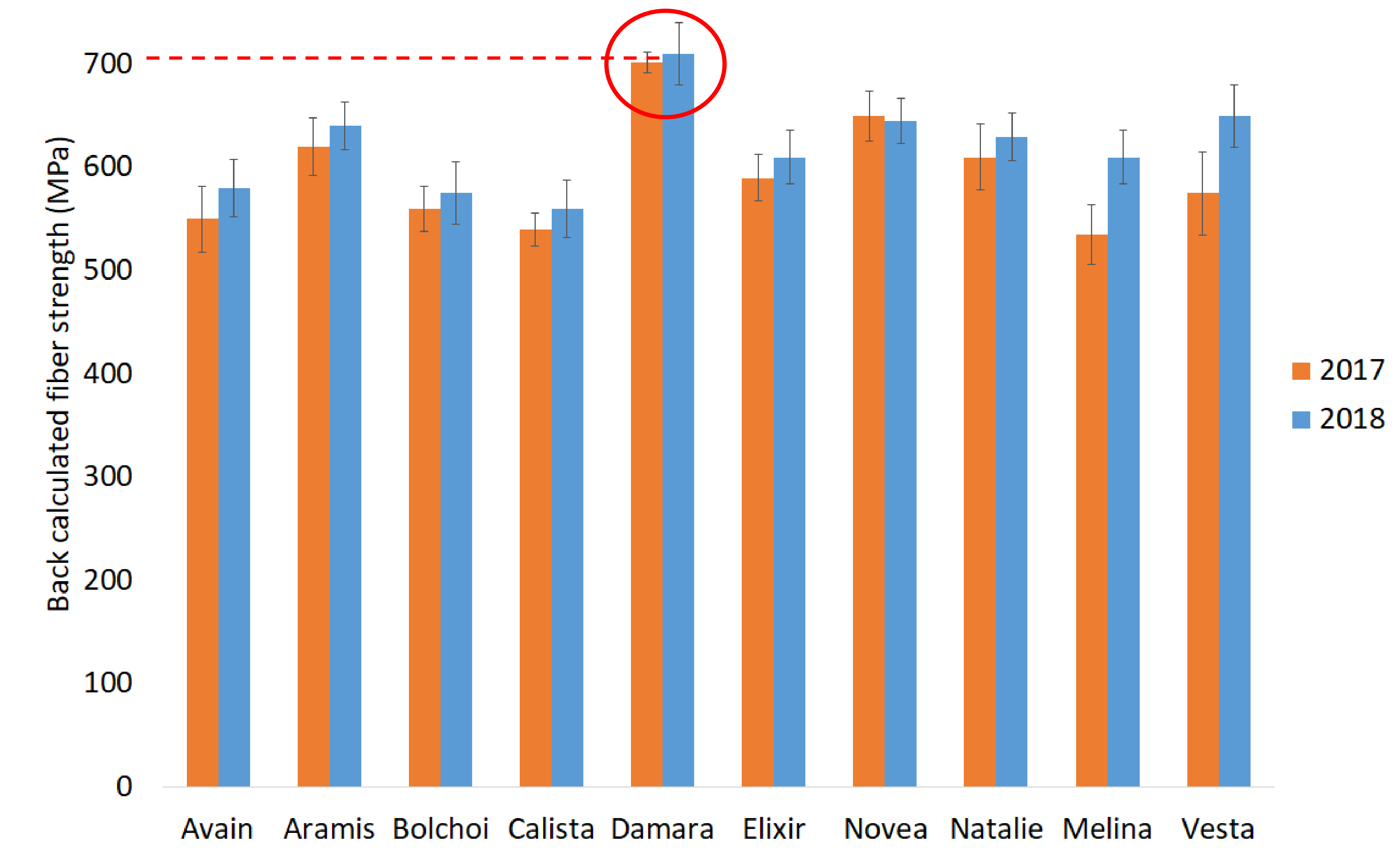
Tensile Test Results for Dry Flax Fiber Bundles



- Testing conditions: 15g of unhackled flax ISO/DP 4923
- Significant differences between two years
- Bad weather condition in 2017: More impurities in 2017 (stem residue)

IFBT Results of Flax Fiber Strength

- Similar trend as dry fiber bundle tests (but with smaller differences between 2017 and 2018)
- Damara has
  - ✓ *the highest average fiber strength*
  - ✓ *the smallest standard deviation*
  - ✓ *the smallest difference between 2017 and 2018*



Conclusions and Perspectives

- IFBT can be an effective method to characterize the mechanical properties of flax fibers. (But, improper processing conditions can lead to the underestimation of the flax fibers properties.)
- High temperature and long duration can lead to the resin penetration into flax fiber cell walls and the mechanical interlocking between the matrix and the fibers. (Optimal processing condition should include enough time for the resin to penetrate inside the fiber cell walls.)
- *The characterization of resin penetration depth inside the fiber cell walls and the modeling of the relation among the processing condition (T, t), the resin penetration depth and the mechanical properties are on-going.*

- There is a difference of the mechanical properties of flax fibers according to the flax varieties.
- The scattering of flax fiber properties can be minimized for industrial applications (at least aeronautic and railway sectors).
- *The influence of the pulling date, retting degree and growing region is under investigation.*