KU LEUVEN

MATERIALS ENGINEERING

Composite Materials Group

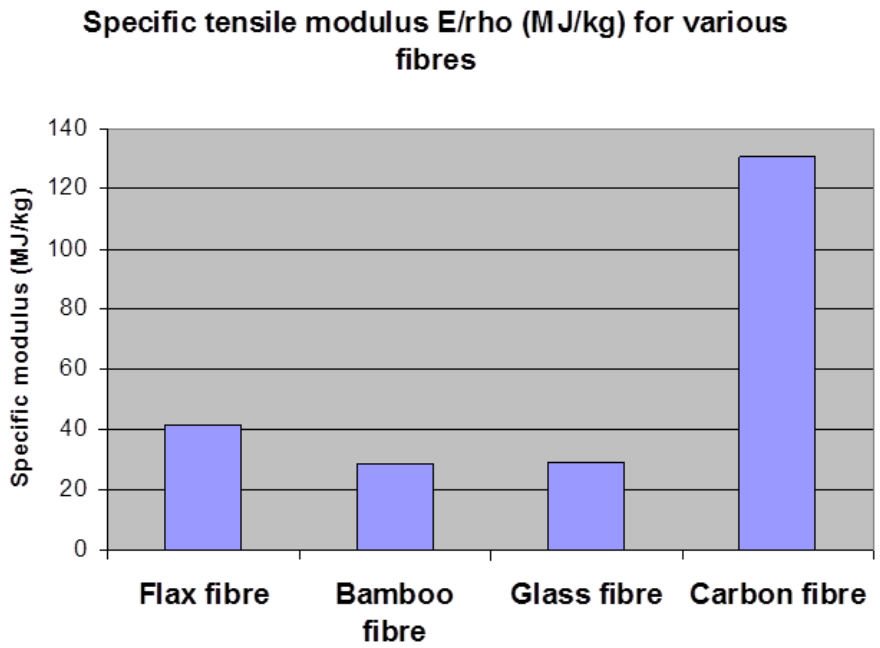
On the road to durable and affordable natural fibre composites, examples from the FlaxPreComp and other projects

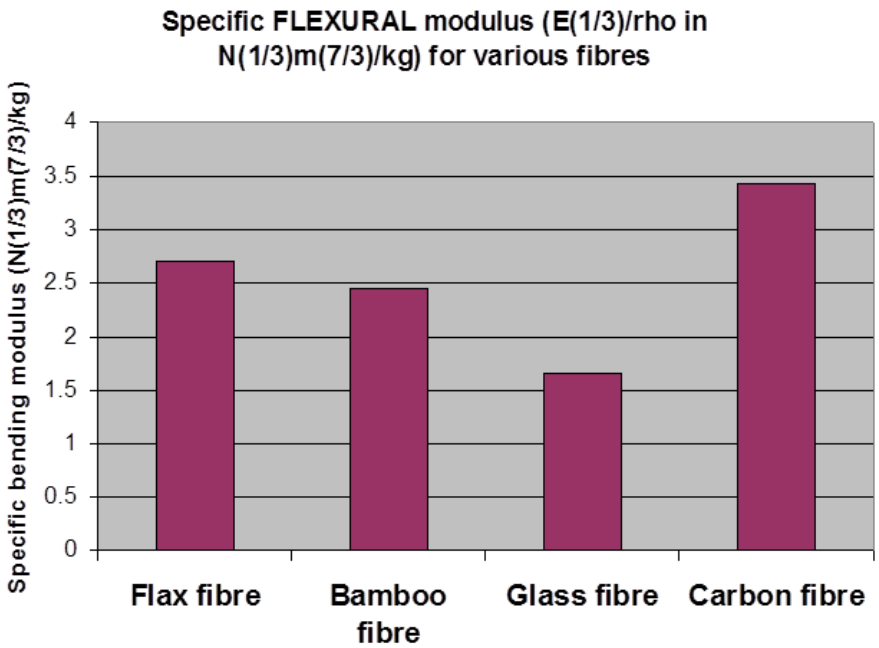
December 2018

Aart W. van Vuure

Department of Materials Engineering & Campus GroupT,
KU Leuven, Belgium

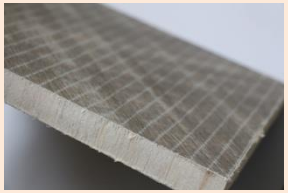
Natural fibres are also a light-weight alternative





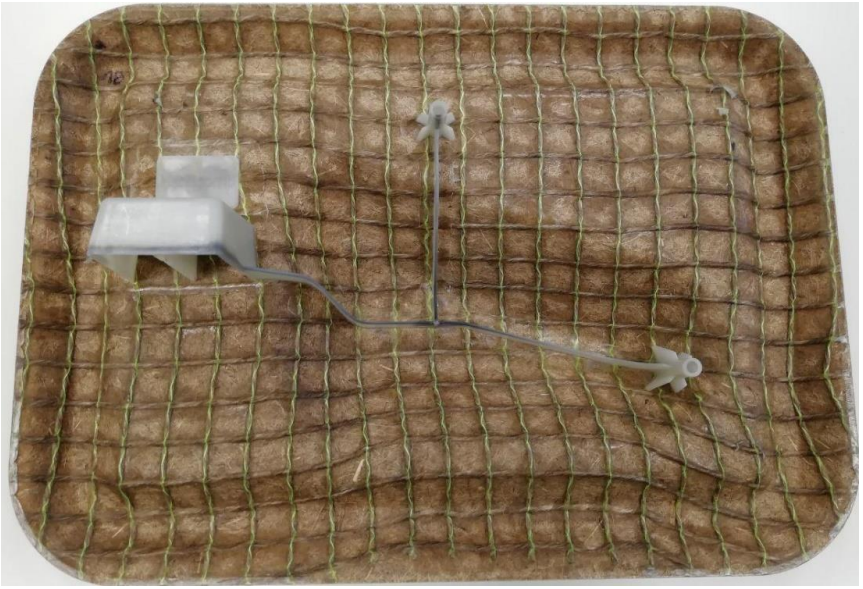
Material stiffness efficiency in tension

Material efficiency in (plate) bending (or buckling)



CELC: A MARKET REALITY

LIGHTWEIGHT AUTOMOTIVE INTERIORS



powerRibs® FOR MOTORSPORTS

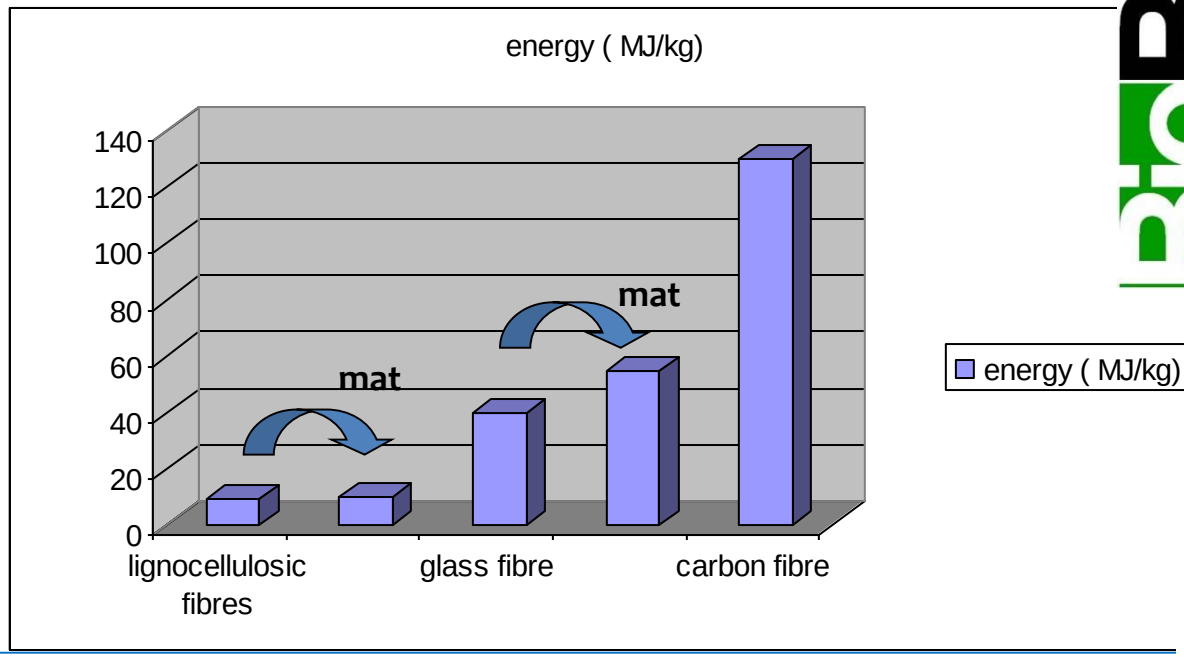
Electric GT Tesla with ampliTex™+powerRibs™ natural fiber bodywork

Automobiles Gillet, Pikes Peak 2018, with ampliTex™+ powerRibs ®body parts

And what about the embedded energy?

Composite Materials Group

Some data on energy utilisation for fibre production:



SEVENTH FRAMEWORK PROGRAMME

BioBuild

Interreg North Sea Region BIOCAS

European Regional Development Fund

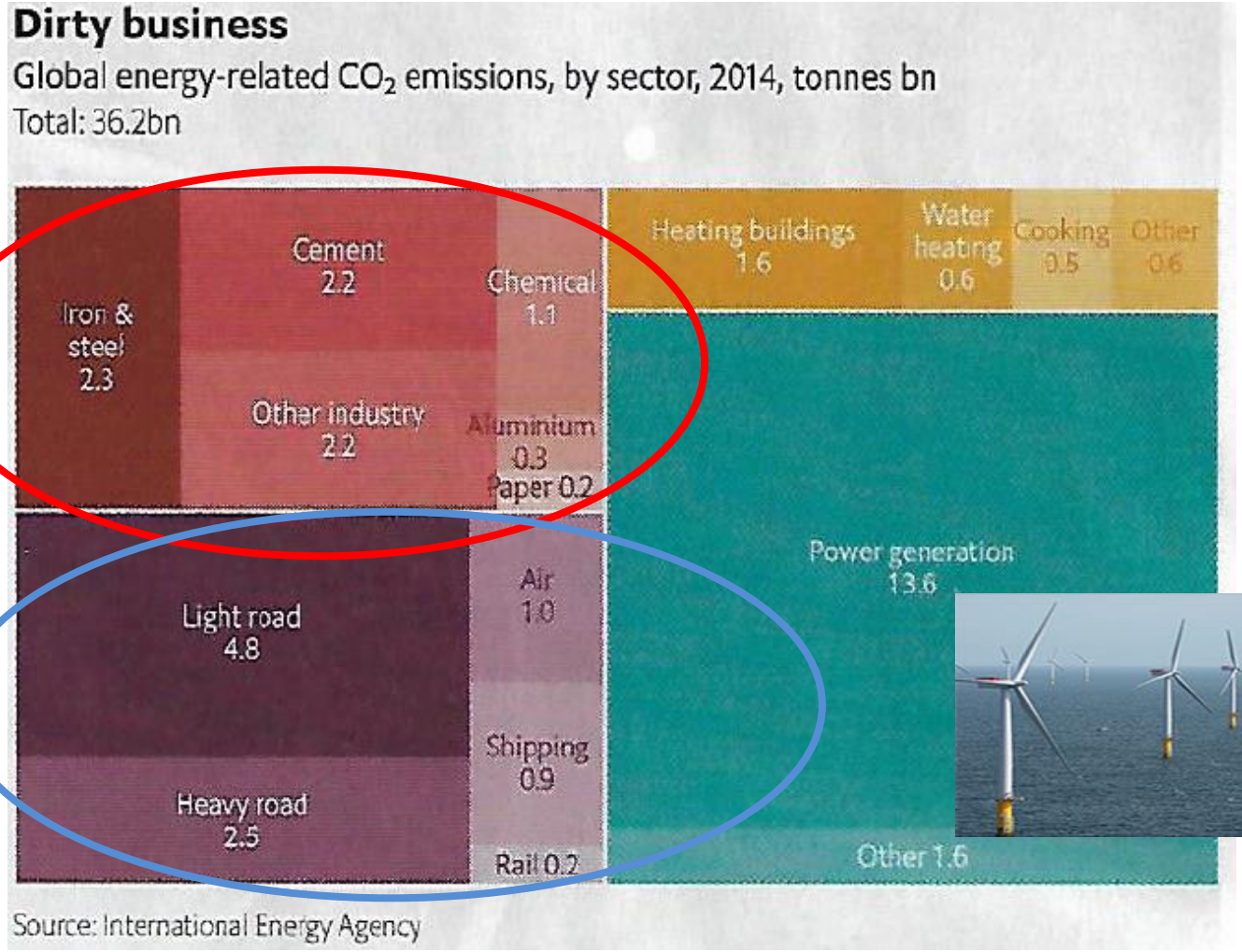
EUROPEAN UNION

KU LEUVEN MATERIALS ENGINEERING

Impact on global warming mitigation

Low-Carbon Materials

Less energy usage from light-weight

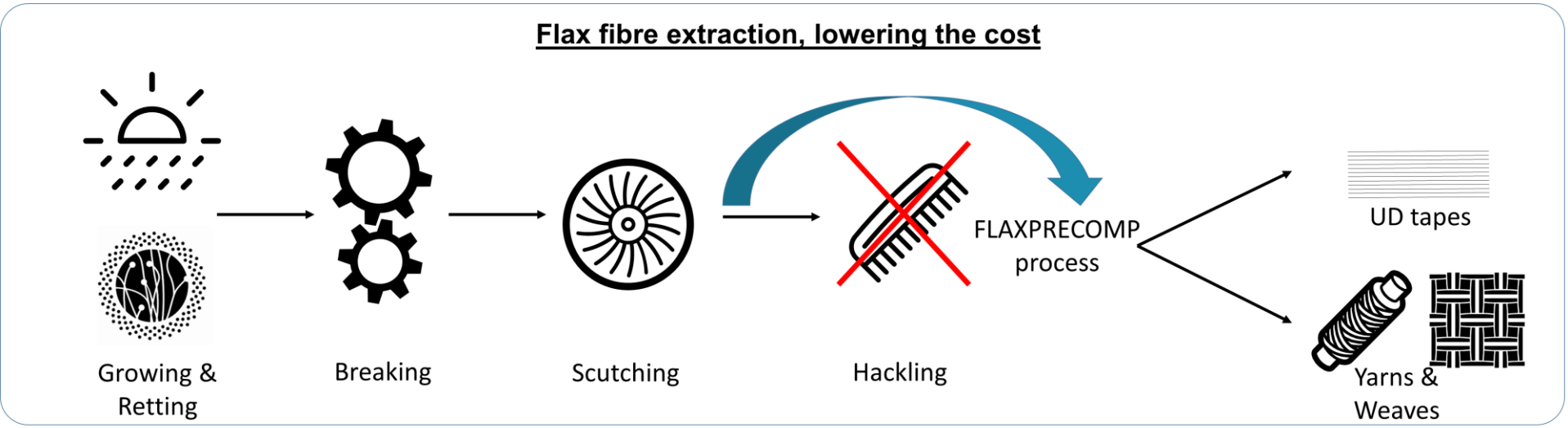


The Economist, Dec 1, 2018

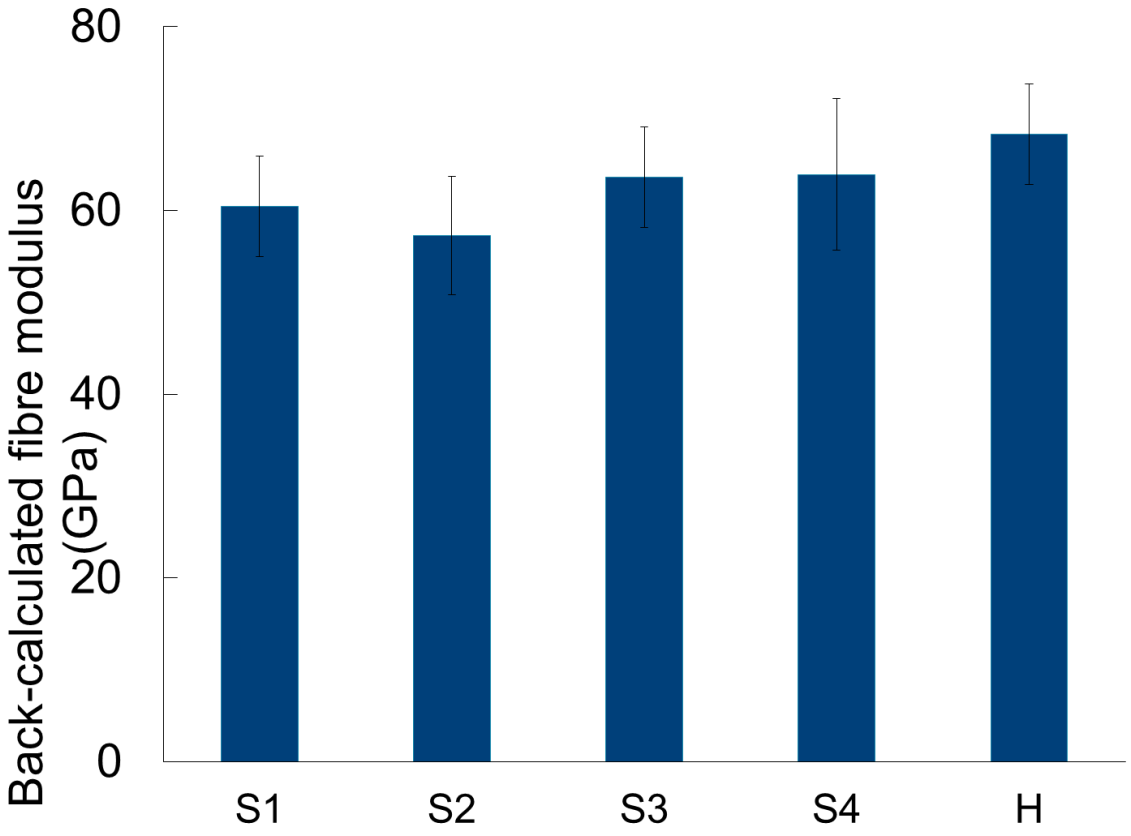
Natural Fibre Composites; Strengths and weaknesses

STRENGTHS	WEAKNESSES
Renewability	Moisture sensitivity / **Durability**
Low Carbon footprint	Variability?
Moderate cost	Not-optimized interfaces
Low abrasiveness	Thermal degradation
Healthier?	Non-linear stress-strain behaviour ?
Good specific mechanical properties (longitudinally)	Low transverse and shear properties
Acoustic and vibrational damping	Water during processing
Low CTE	Not optimized fibre preforms
Natural look and feel	Extraction without damage

Lower the cost of flax fibre preforms – the SIM FlaxPreComp project

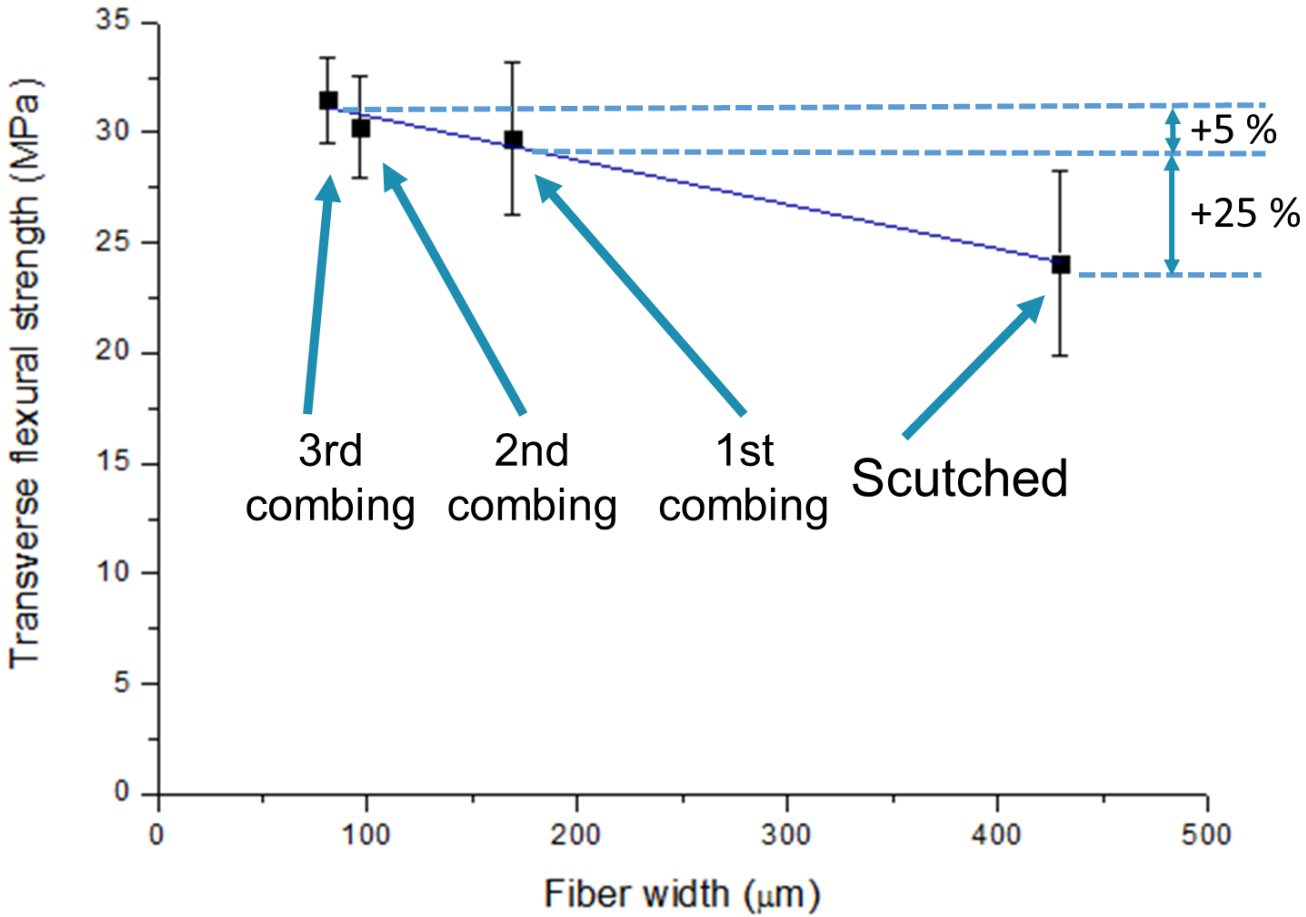


Performance of scutched fibre composites



S = scutched fibre, H = hackled fibre

Benefit of added combing steps



Enzymatic treatments, a.o. to replace dew retting

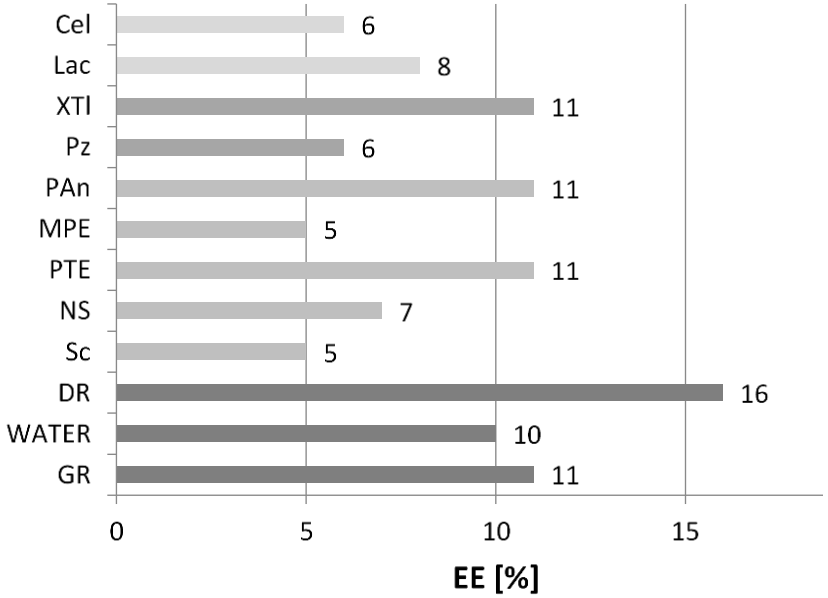


Figure 1. Extraction Efficiency of enzymatic treatments at pH 5.0

$$FE = \frac{\text{Amount of long fibers extracted (g)}}{\text{Total amount of flax stems (g)}}$$

$$TE = \frac{\text{Amount of long fibers extracted (g)}}{\text{Time needed for extraction (min)}} * 2$$

$$EE = FE * TE$$

PhD Jana De Prez 2019

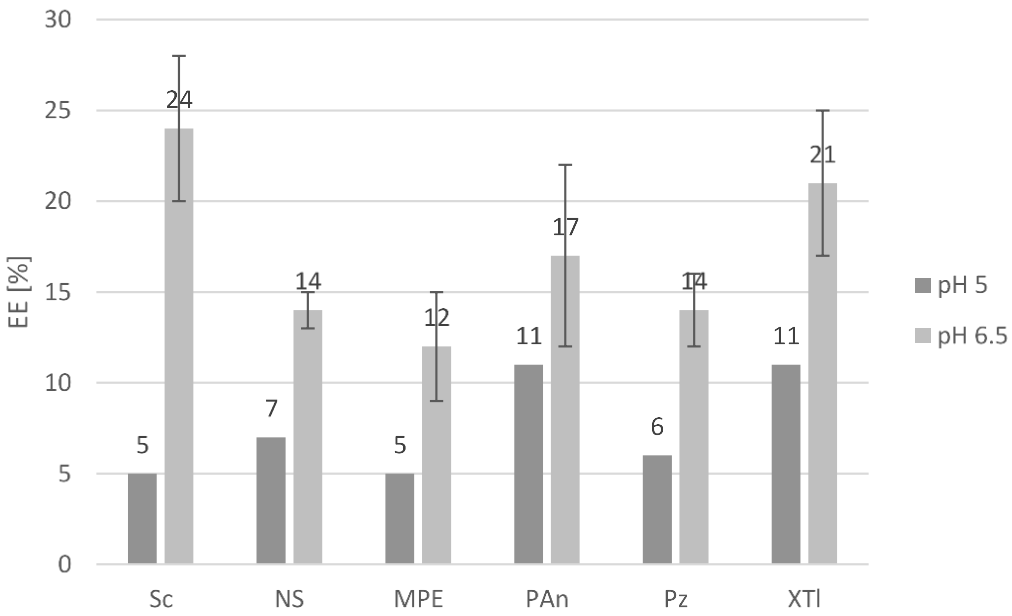
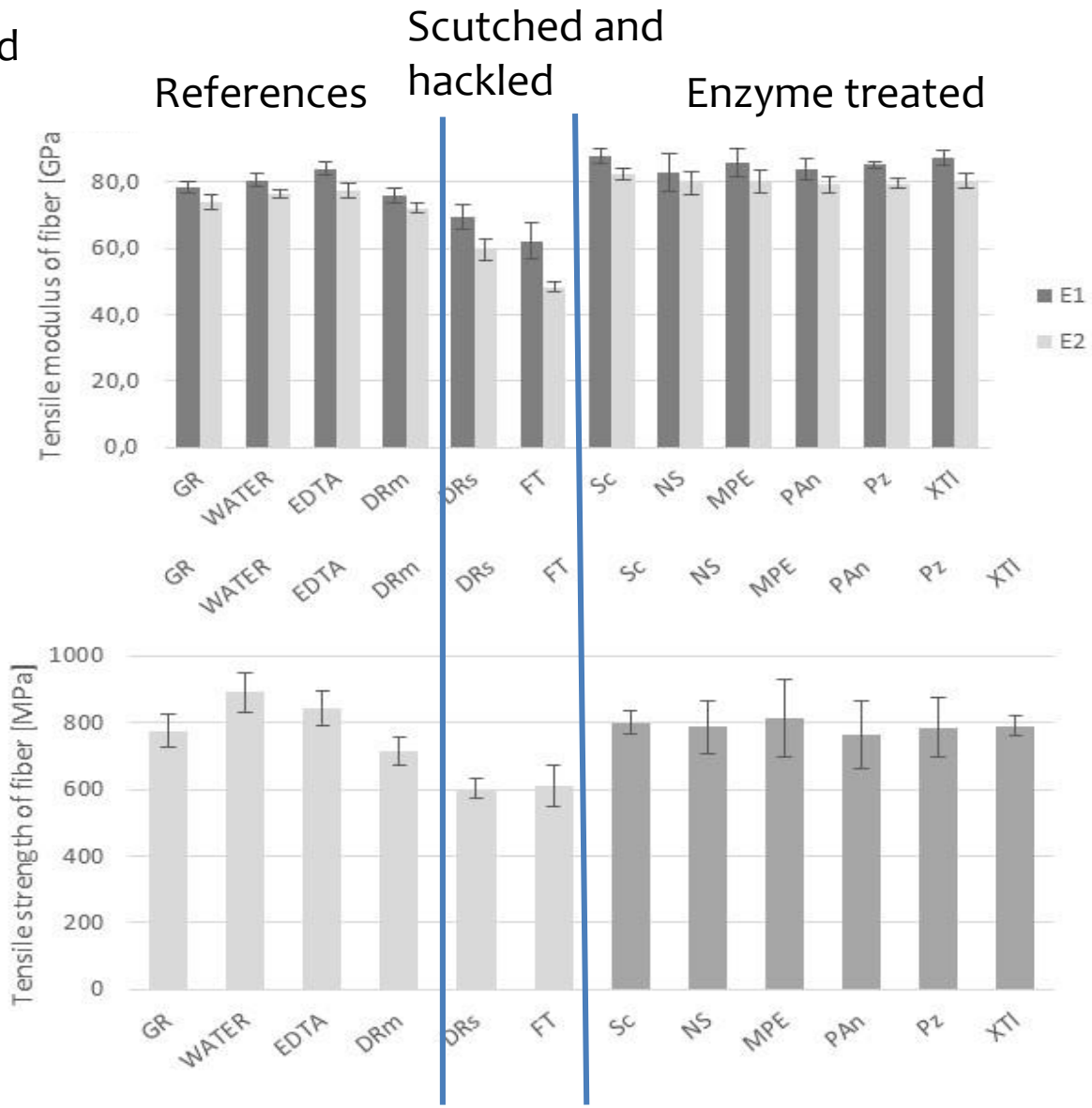


Figure 1. Comparison of Extraction Efficiency of enzymatic treatments at pH 5 and pH 6.5

Hand extraction limits damage

Impregnated fibre bundle tests (IFBT)



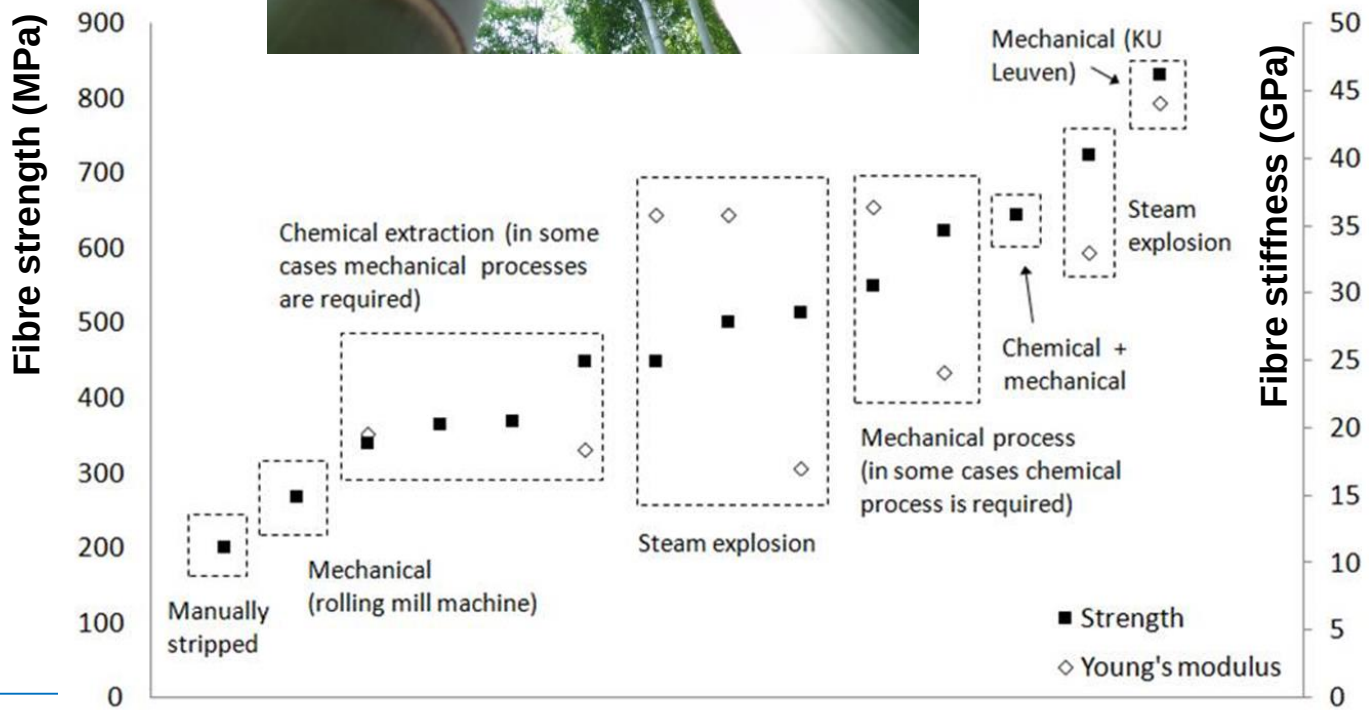
E up to 84 GPa !

Strength up to 800 MPa

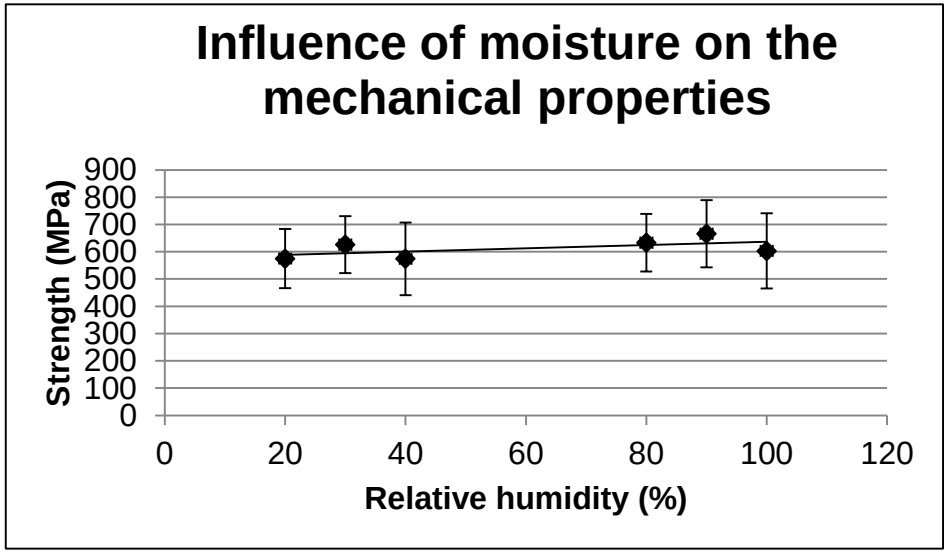
Ways to improve Durability, particularly moisture sensitivity

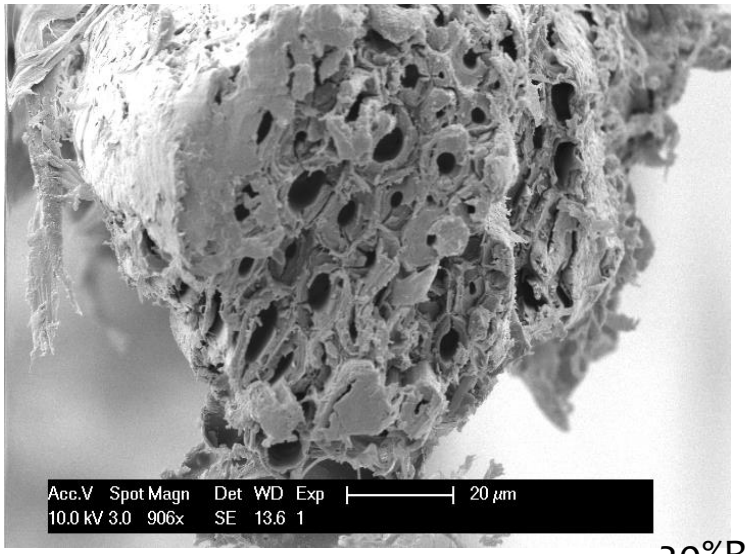
1) Choose less moisture sensitive natural fibres, e.g. bamboo fibre
2) Lower the Equilibrium Moisture Content (EMC) of the fibres; chemical treatment (EU H2020 BBI Ssuchy)
3) Reduce the swelling of the fibres; constraint from the matrix? (EU Marie Curie FibreNet)
4) Turn water inside the fibres into an advantage, process with water inside the fibres; pre-swollen fibres (Ssuchy)
5) Coatings (of fibres or composite); slow down water diffusion and mitigate peak loads (Ssuchy)

Bamboo Fibre Extraction

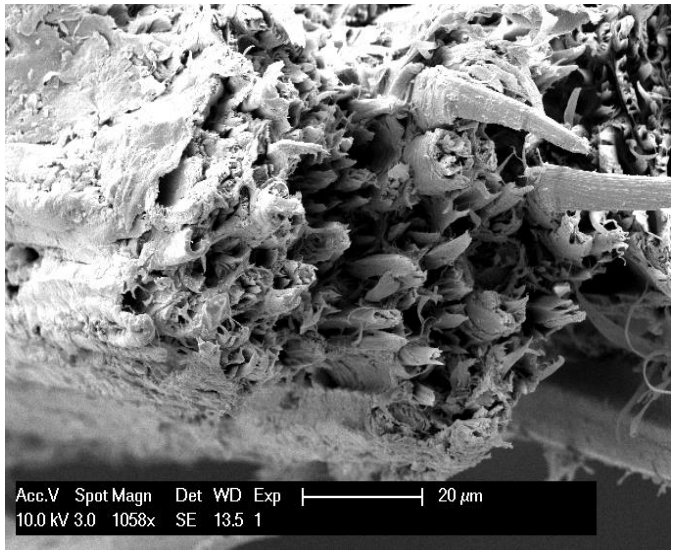


Moisture sensitivity of technical bamboo fibres

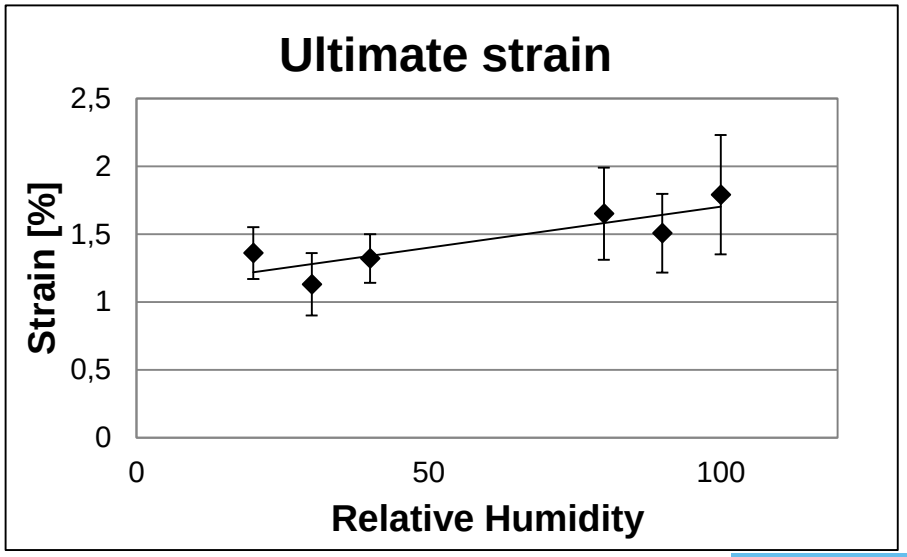




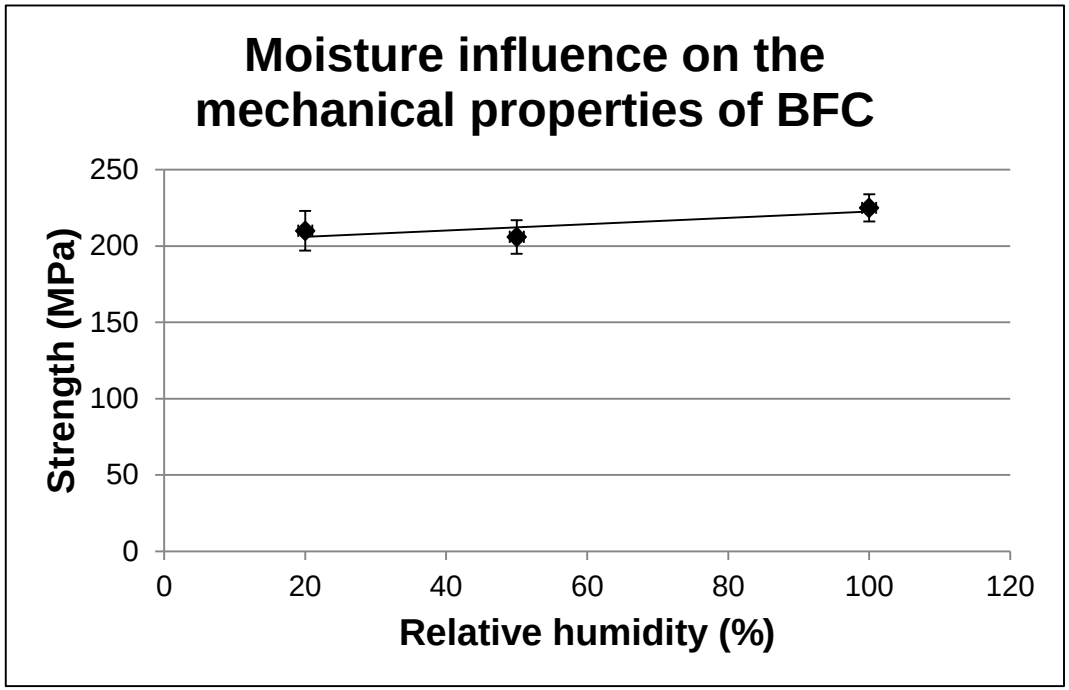
20%RH



80%RH



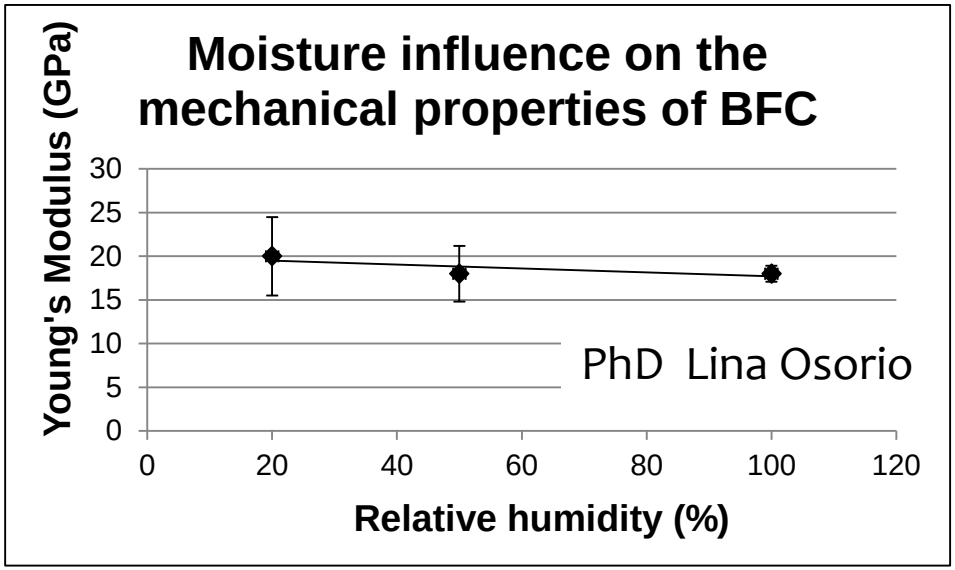
Moisture Sensitivity of Bamboo Composites

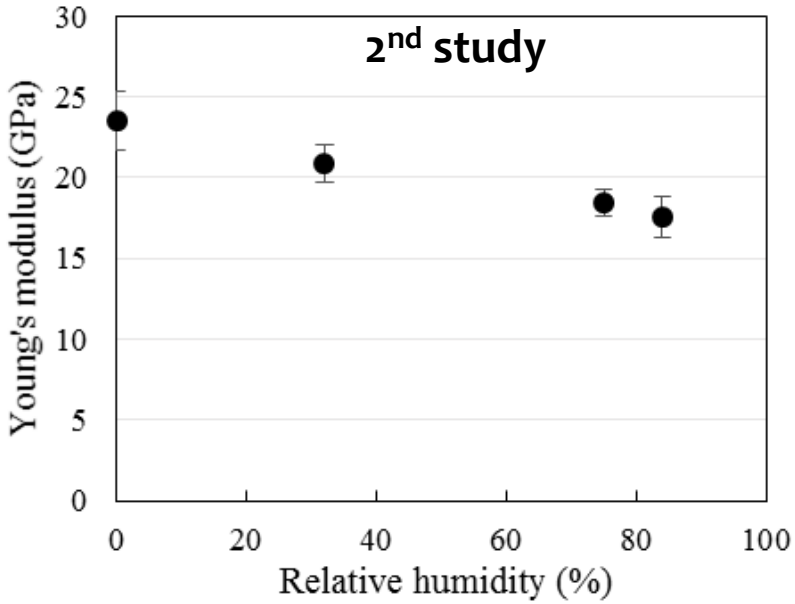


(epoxy matrix)

Moisture sensitivity of bamboo fibre composites

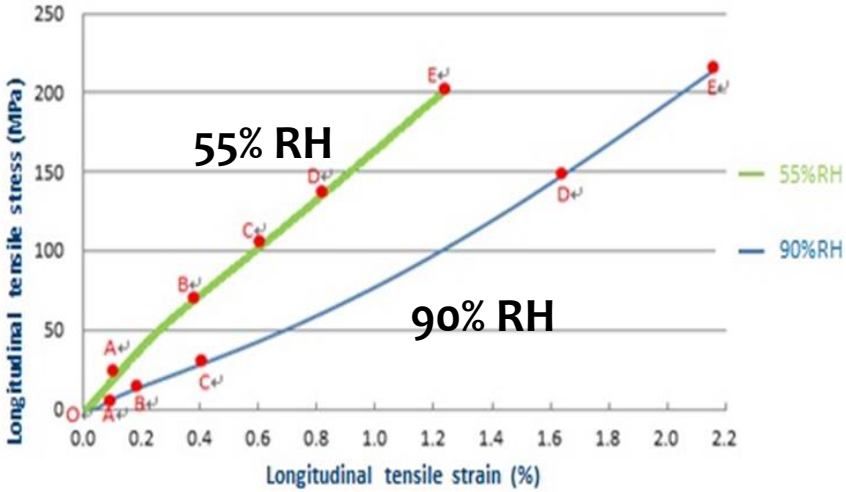
Modulus does not decrease much!





(Epoxy matrix, Vf 40%)

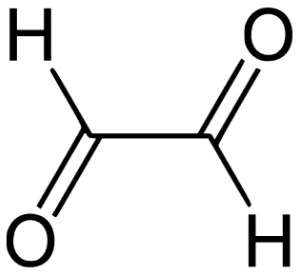
UD FLAX composite:



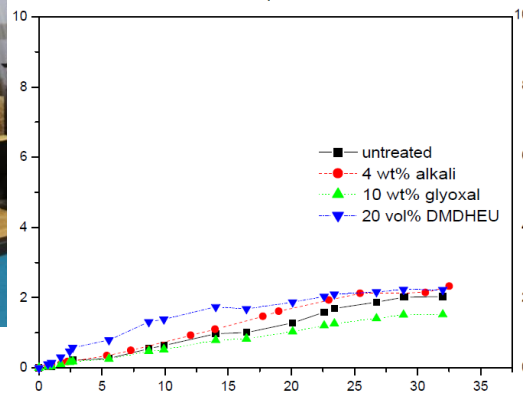
Linked to lignin content

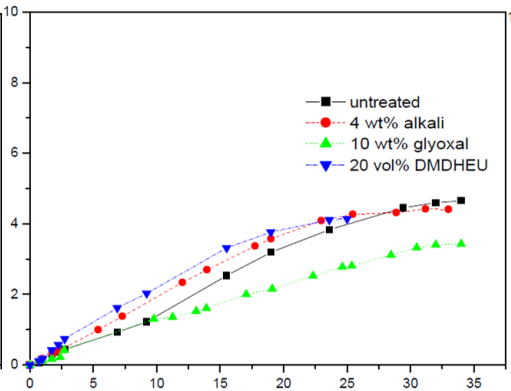
PhD Delphine Depuydt 2018

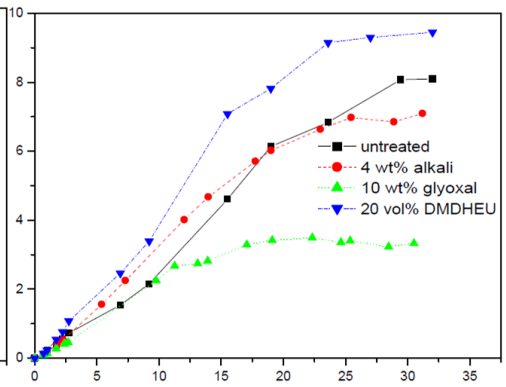
Flax fibre composites; treatments to lower the EMC



PhD Dieter Perremans



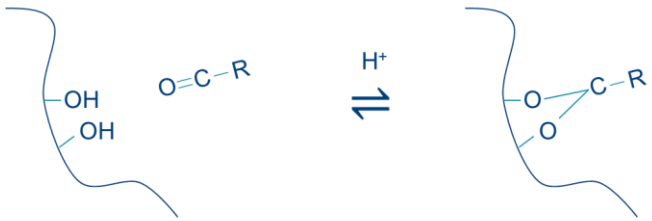




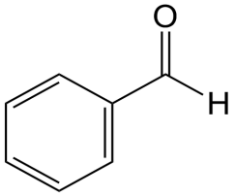
	50% RH	75% RH	90% RH
untreated	2%	4%	8%
4 wt% alkali	2%	4%	7%
10 wt% glyoxal	1.5%	4%	3.5%
20 vol% DMDHEU	2%	3%	10%

Aldehydes: A “new” class of treatments

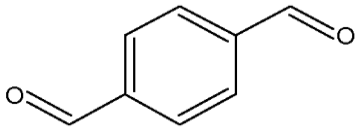
Acetal bond formation



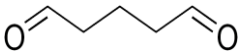
Benzaldehyde



Terephtaldehyde



Glutaraldehyde



Crosslinkers

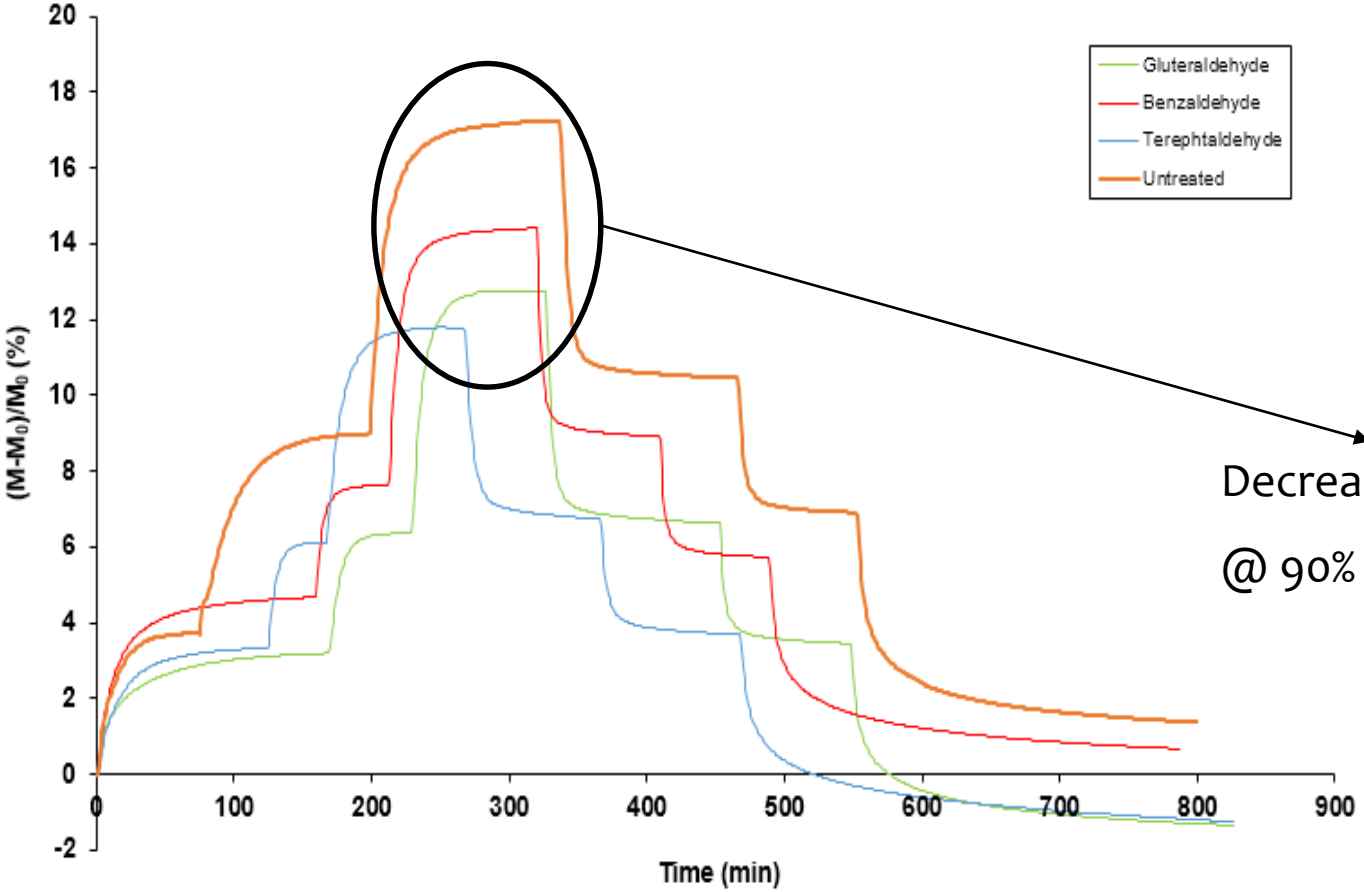
Conditions:

- 10 wt% in THF @ room temp.
- Fibres soaked for 10 min
- Dried in oven at 80°C

PhD Kevin Hendrickx, 2018

Dynamic vapour sorption – EMC

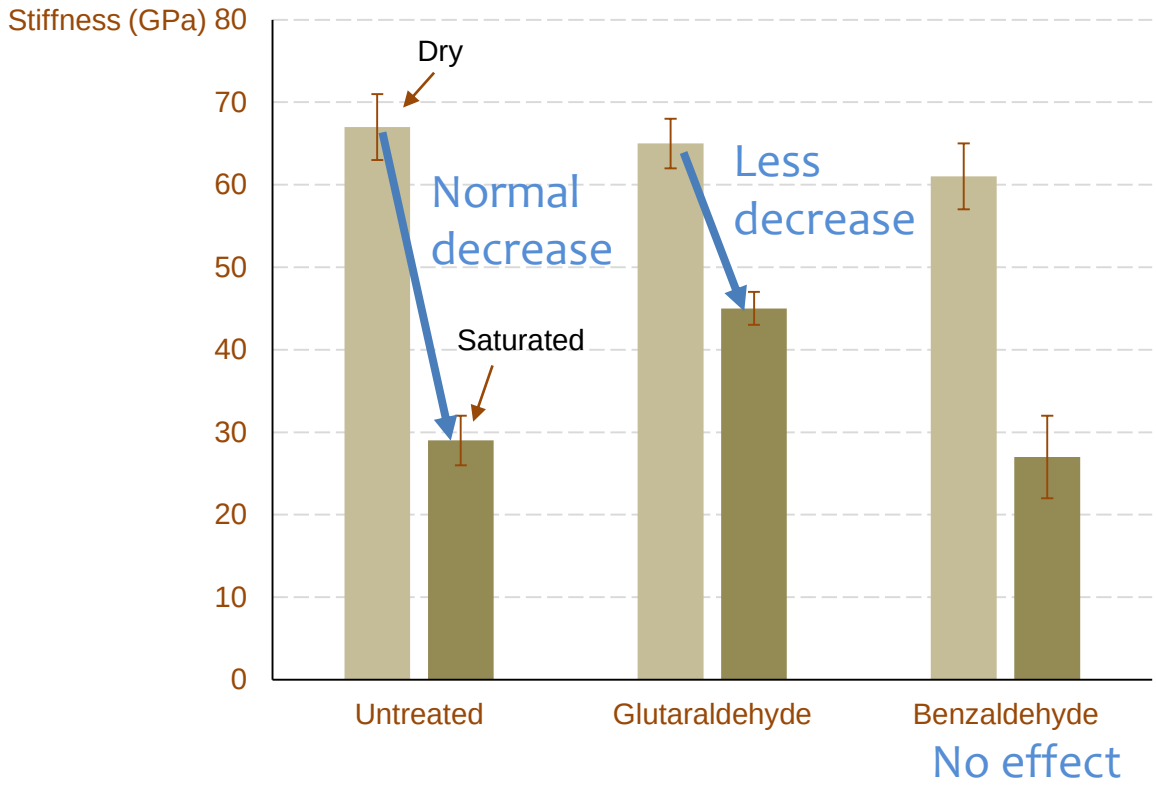
Di-aldehyde cross-linkers are more efficient



Decreased EMC

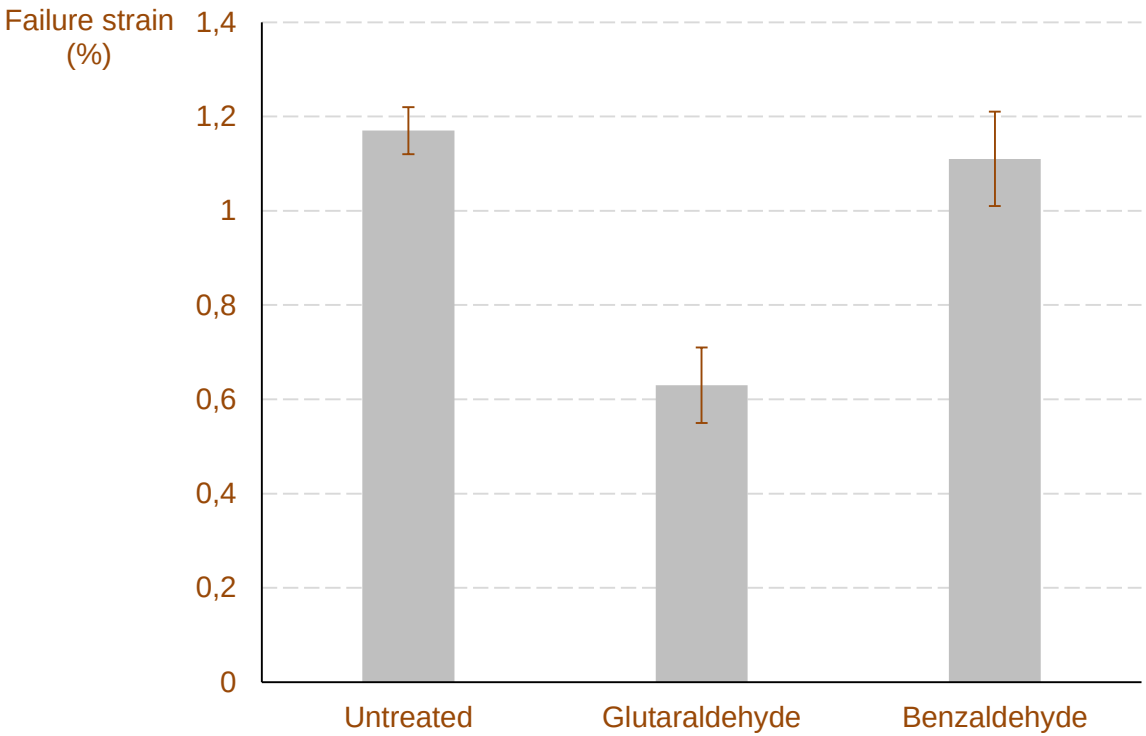
@ 90% RH

Backcalculated stiffness of UD treated fibre composites



Saturation @ 80%RH and 80°C

Embrittlement due to crosslinking



Failure strain of the composites severely decreased by glutaraldehyde

Fibres are likely embrittled due to crosslinking

Next: alternative treatments (PhD Gilles Koolen)

Enzymatic treatment can also lower water uptake

Table 1. Moisture absorption results of composites impregnated with enzymatically treated fibers compared to green flax fiber composites: equilibrium moisture content (%) and diffusion coefficient (mm^2/s)

Treatment	Equilibrium moisture content (%)	Diffusion coefficient (10^{-5} mm^2/s)
GR	6.05 ± 0.75	9.04 ± 1.05
Sc	4.55 ± 0.22	2.53 ± 0.19
NS	5.40 ± 1.35	1.68 ± 0.60
MPE	4.49 ± 0.16	1.92 ± 0.27
PAn	4.01 ± 0.15	1.00 ± 0.19
Pz	4.65 ± 0.17	5.39 ± 0.73
XTl	4.30 ± 0.51	3.39 ± 0.47

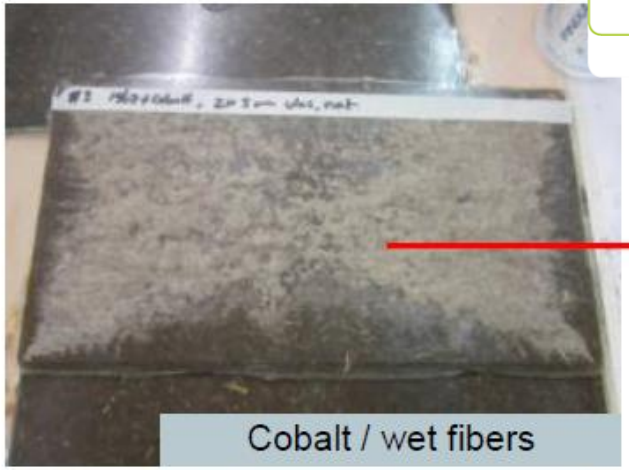
80% RH @ 80°C

Next: non-dried natural fibres

Novel water-insensitive curing systems for biofiber reinforced polyester composites

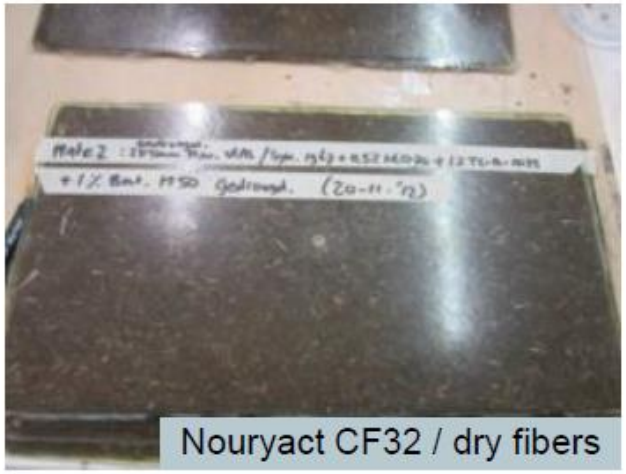
With Ssuchy partners Akzo Nobel and NPSP (Netherlands)

Cobalt / dry fibers

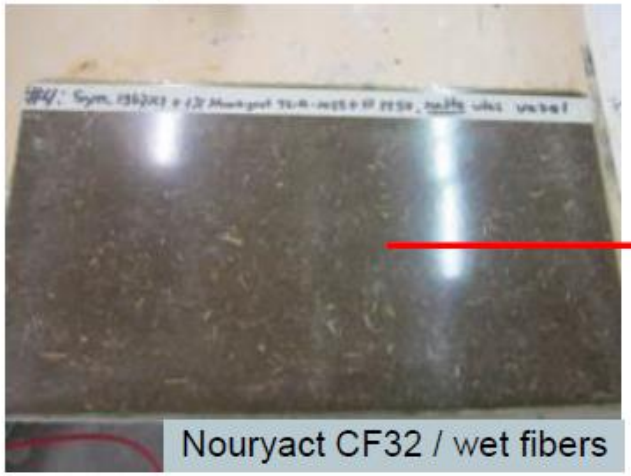


Cobalt / wet fibers

Hardly any cure



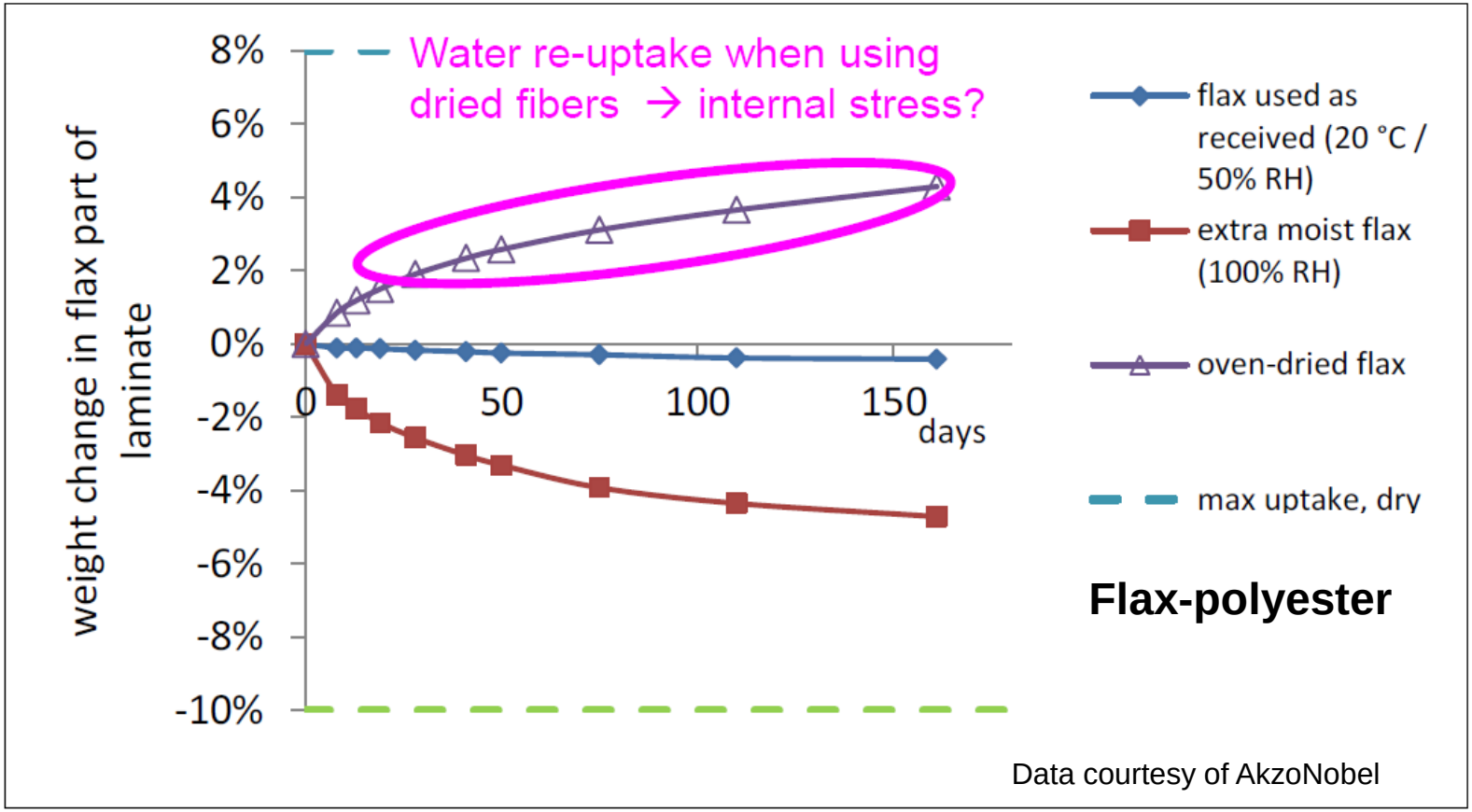
Nouryact CF32 / dry fibers



Nouryact CF32 / wet fibers

Excellent cure

New Perspective on Water Uptake

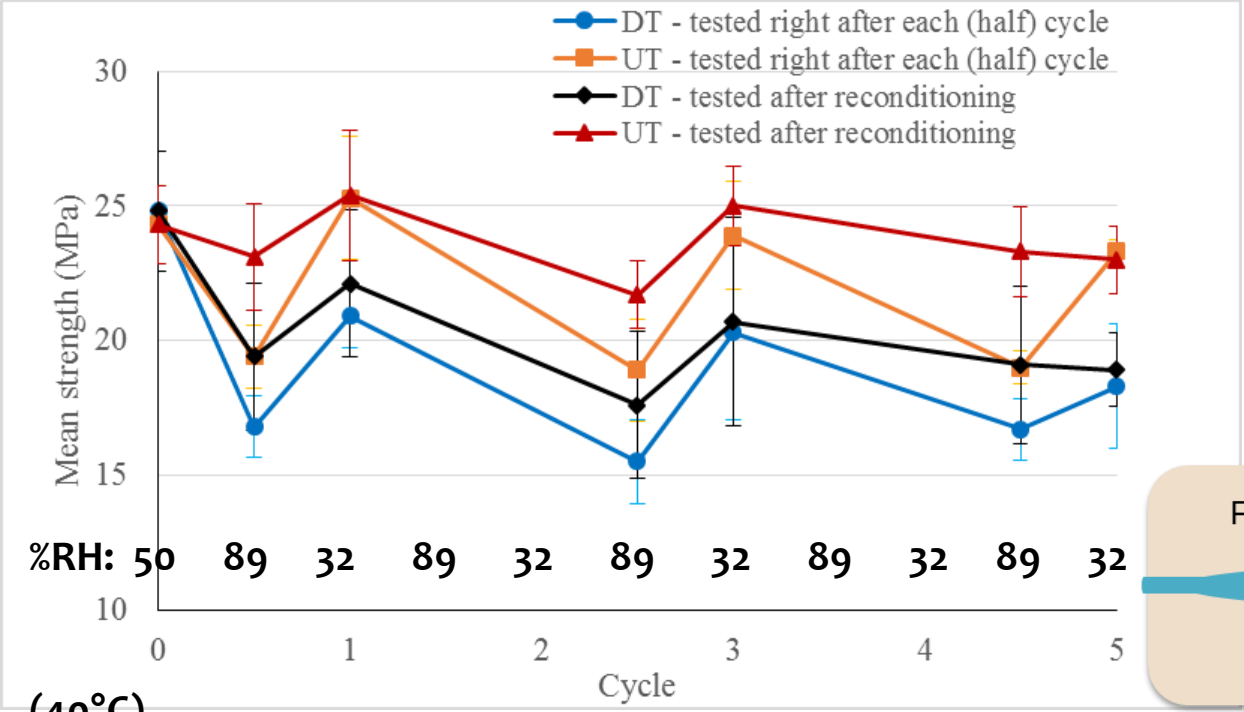


Long term average indoor conditions 20°C and 50%RH

Hypothesis: Durability better for damp natural fibres equilibrated at Equilibrium Moisture Content of average environment: pre-swelling

* Less swelling, shrinkage, cracking

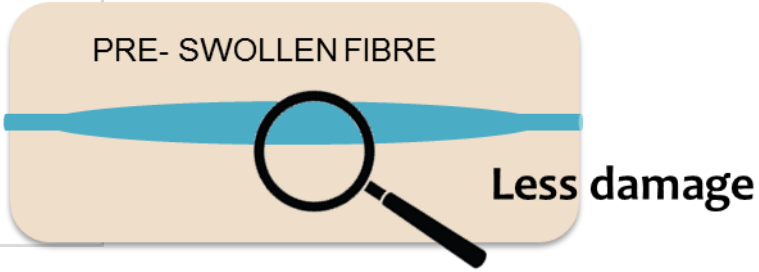
Do un-dried fibres have higher durability?



DT = dried transversal

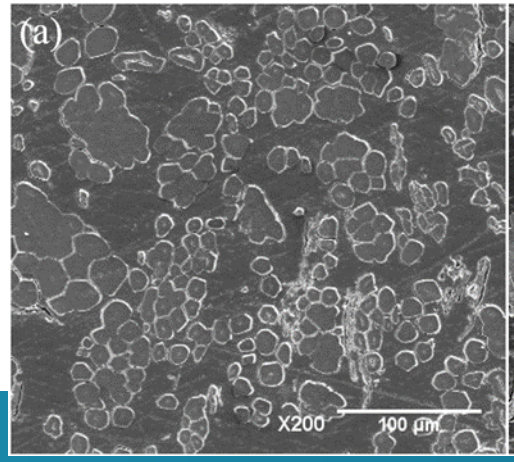
UT = undried transversal

PhD Morissa Lu

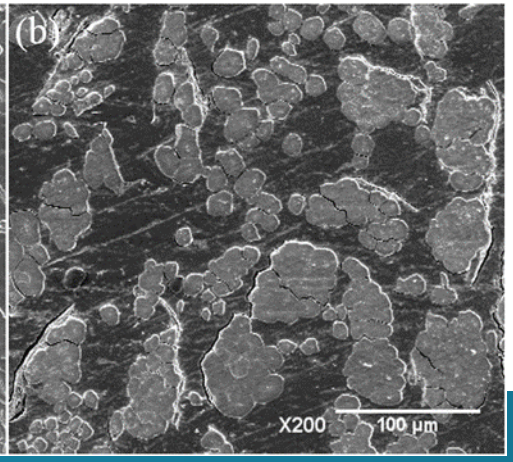


Images after half cycle at high humidity

UT



DT



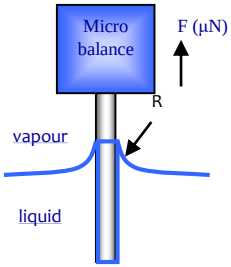
Already cracks for dried fibres, also inside bundles!

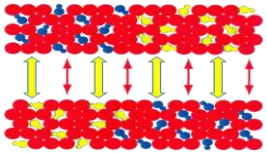
CMG expertise: Studying and improving the Fibre Matrix Interface; Durability enhancement (Dr. Carlos Fuentes)

FibreNet

- An integrated physical-chemical-micromechanical approach

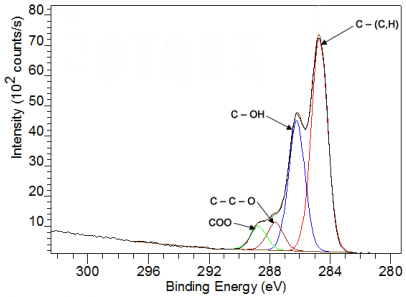
1) Physical characterization: surface energy components from contact angle measurements





$$\gamma_{L,i}(1+\cos\theta_i) = 2\left(\sqrt{\gamma_{L,i}^{LW}\gamma_S^{LW}} + \sqrt{\gamma_{L,i}^{+}\gamma_S^{-}} + \sqrt{\gamma_{L,i}^{-}\gamma_S^{+}}\right)$$

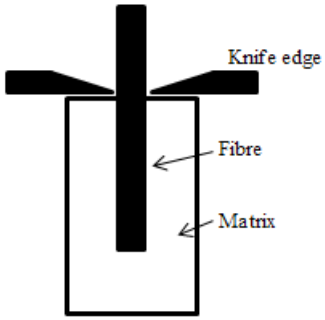
2) Surface chemistry: XPS, ToF-SIMS



X-ray photoelectron spectroscopy (XPS)

3) (Micro)-mechanical testing of adhesion

(single fibre pull-out & transverse UD 3-point bending)



Tools for selecting fibre treatment or matrix modification

For improvement of wetting and adhesion

Conclusions

1) Scutched-only flax fibres can be a low cost alternative with equivalent properties to hackled flax
2) Enzymatic treatments can replace retting
3) Extraction by hand shows hidden potential of flax fibre (E = 85 GPa)
4) Bamboo fibres loose much less stiffness in wet condition than flax fibres
5) Di-aldehyde treatments show significantly lower EMC for flax fibres, but embrittle the fibres

   * Next other treatments

6) Making composites with undried, pre-swollen fibres, gives significant improvements in durability for flax fibre composites

   - Plus save energy and time for not having to dry

Acknowledgements:

Dr. Carlos Fuentes

(Current) PhD students:

Delphine Depuydt

Kevin Hendrickx

Jana De Prez

Gilles Koolen

Lina Osorio

Dieter Perremans

Morissa Lu

Alexandros Prapavesis

Embodied energy of building materials

Material	*Embodied Energy*	*Embodied Carbon*	*Embodied Energy*
	MJ/kg	$kgCO_2/kg$	MJ
Bricks, Facing	8	1	1968
Aluminium Virgin	218	11	1177
Steel Sheet Galvanised	39	3	612
Timber Plywood	15	1	594
FRP (Glass/Polyester)	100	8	540
Steel Sheet Virgin	32	3	495
Timber MDF	11	1	462
Hemp/Polyester composite	69		249

Figure 1 - Embodied energy in a 1m x 1m typical panel for various materials[7,8,9]

- Difference in embodied energy/kg between GFRP and NFRP is smaller than expected because of large contribution of polymer (~80 - 130 MJ/kg);
- Glass ~55MJ/kg, flax ~5-10 MJ/kg