LEUVEN mrc Materials Research Centre

Composite Materials group

KATHOLIEKE UNIVERSITEIT LEUVEN

A new natural reinforcement for polymer composite materials: Long Bamboo fibres

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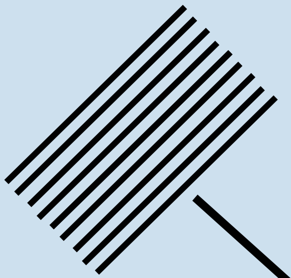
Katholieke Universiteit Leuven

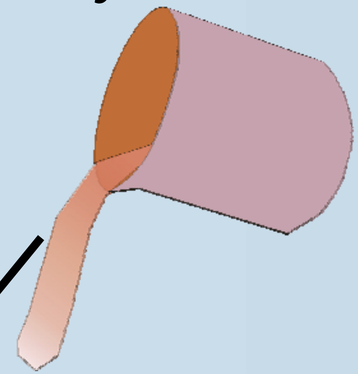
First; what do we call polymer composite materials?

Fibre: reinforcement

Light but stiff & strong!



Polymer: matrix



Light but weak

Impregnate

Consolidate

COMPOSITE

Light, stiff & strong

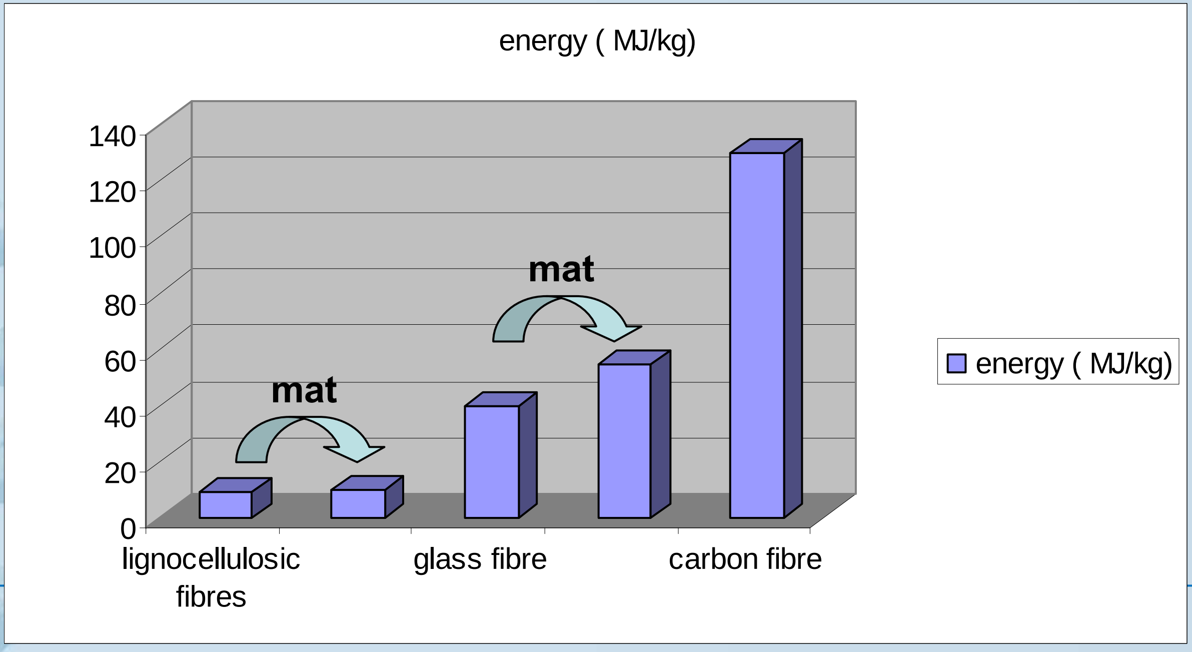
- *Long* fibres give better mechanical properties
- Fibres typically *Glass and Carbon*

Natural Fibres (and Bio-polymers): why?

Environmental reasons:

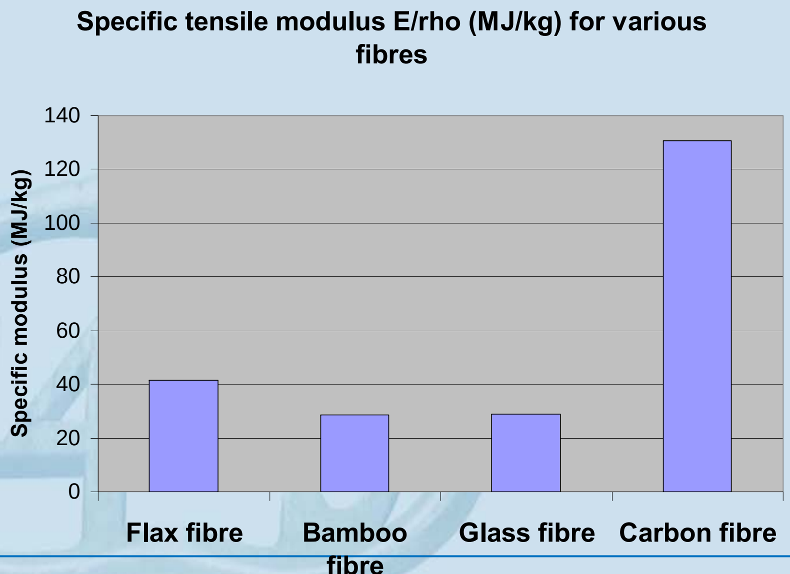
- Renewable resources
- Thermally recyclable, optionally biodegradable, **CO_2 neutral**
- Natural fibres: Low energy consumption (low CO_2)

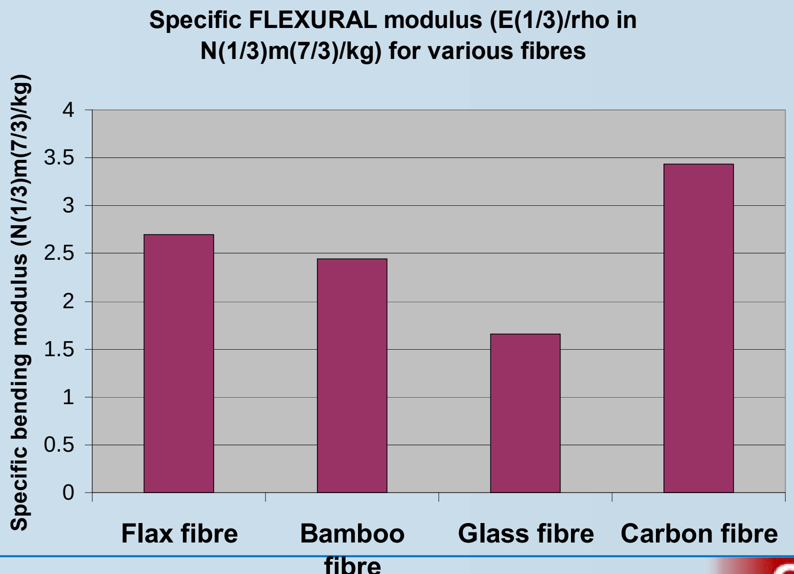
So: low "Carbon footprint"



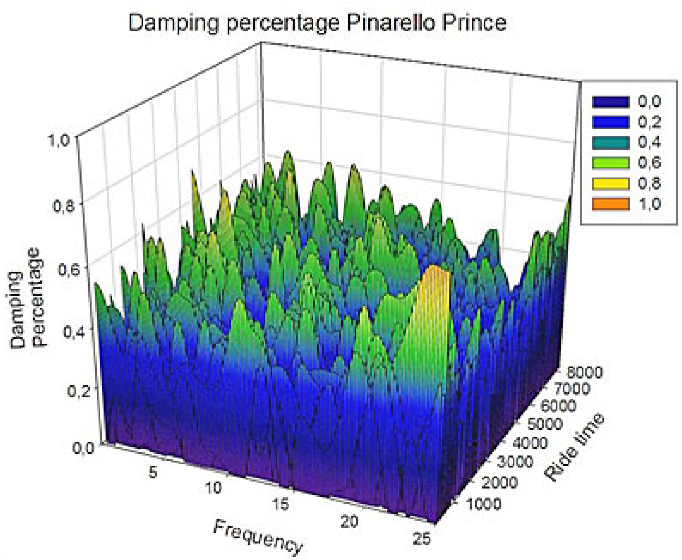
Natural Fibres and Bio-polymers: why?

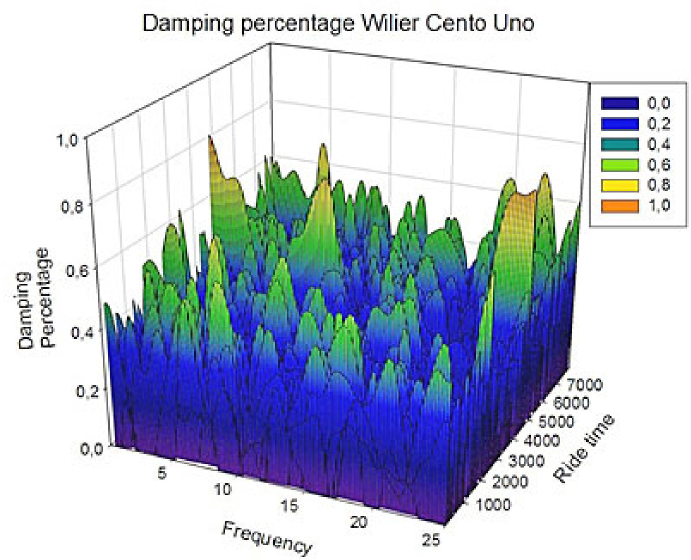
- Cost: often (potentially) low cost (not silk)
- Less abrasive
- Good specific mechanical properties (low density)
- Potential bio-compatibility for e.g. bio-medical applications
- Natural image, design aspects
- Others, like good acoustic & vibration damping, radar transparency, low CTE



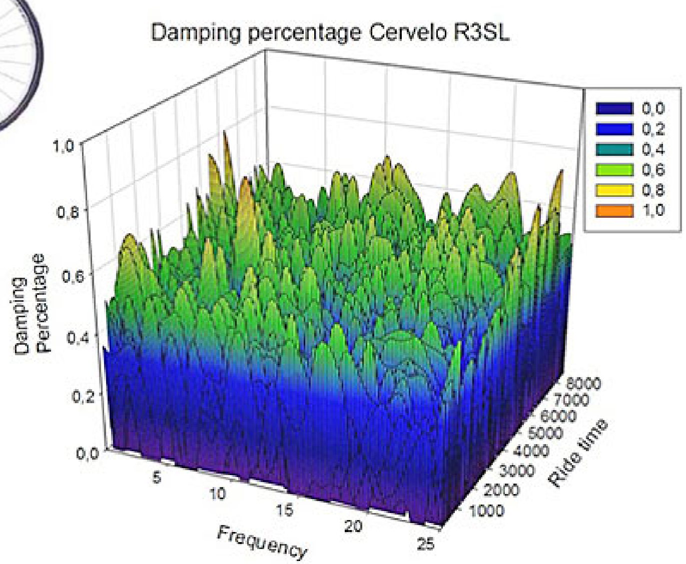


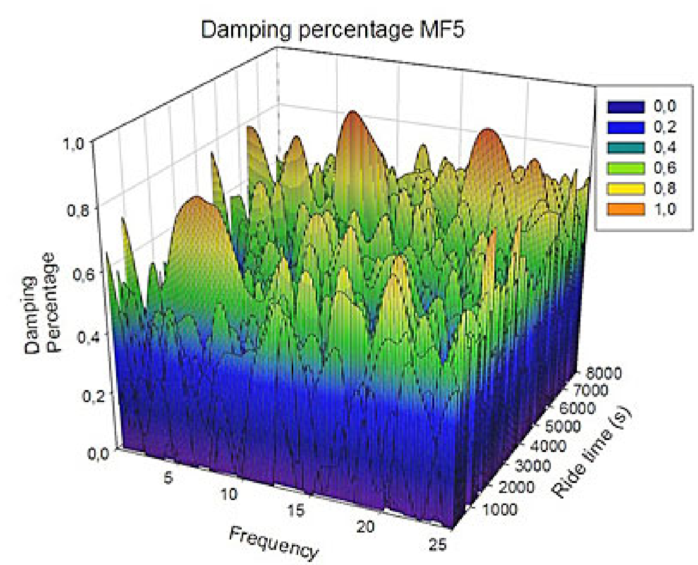
Good vibrational damping: Flax/Carbon hybrid bicycle frame





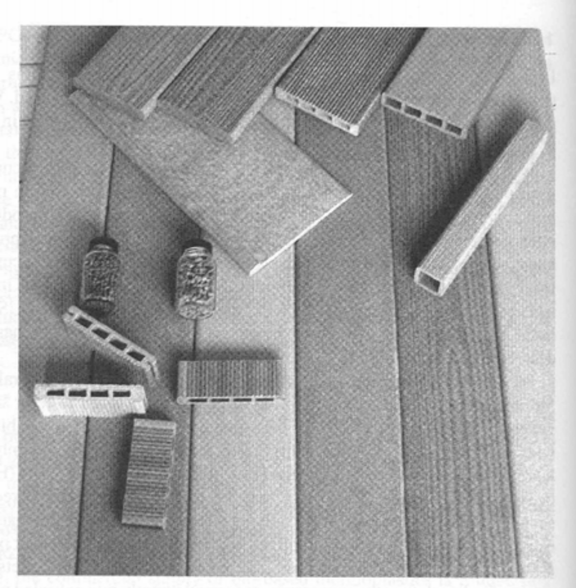
ISO2631: Whole Body Vibration





Applications of bio-based composites; on the market

Wood
Polymer
Composites
(WPC's)
e.g. deckings



Museeuw/Lineo
Flax-Carbon
hybrid bike(JEC
2007);
Prepreg
technology

Mixed NF – PP
Car interiors

Decathlon Artengo
820
Flax/Carbon Fibre
racket
(prepreg Lineo)

Applications of bio-based composites; prototypes

Toyota 1/X concept car (420 kg!):
- Carbon Fibre frame
- Roof of kenaf/ramie fibre composite
    - heat and sound insulation
    - lightweight

Motive Kestrel electric vehicle

•Launch 2012 in Canada?

•Bio-based composite body

Prototype flax/PP
(TU Delft)

NPSP front-end train
- flax-UP composite
- vacuum injection
- ~500 kg lighter than steel construction!

Natural Fibres, Quantities

Estimated annual production, in millions of tons:

Wood	1750	
Steel	1000	
Plastics/polymers	200	
Composites (polymer)	5-10	mainly glass fibre composites
Glass fibre	2-4	(at 42% in composites)
Carbon fibre	0.050	(= 50,000 tons)
Synthetic fibres	30	
Natural fibres	27	(large part cotton)
Flax fibres	~ 1.0	
WPC	1.2	
Plant fibre in composites	0.040	in automotive applications Europe

Natural Fibres

PLANT / Lignocellulosic FIBRES

- **Wood**

  Softwood
  Hardwood

- Stem/Bast

  Flax
  Jute
  Hemp
  Kenaf
  Ramie

- Leaf

  Sisal
  Abaca
  Pineapple
  Banana
  Fique
  Henequen
  Palm

- Seed/Fruit

  Cotton
  Coconut

- Grass

  Bamboo
  Rice

ANIMAL FIBRES (protein)

- **Silk**
  Wool

Main challenges for Bio-based Composites

1) Fibre properties:

* Understanding structure (morphology) – mechanical property relationships

* Fibre off-axis properties: low transverse and shear properties

** Improve internal interface between elementary fibres

* Moisture sensitivity: Make fibres more hydrophobic? / seal them off (interface)

2) (Fibre) Processing

- Extraction, yarn processing, preforming and prepregging

3) Fibre-matrix Interface:

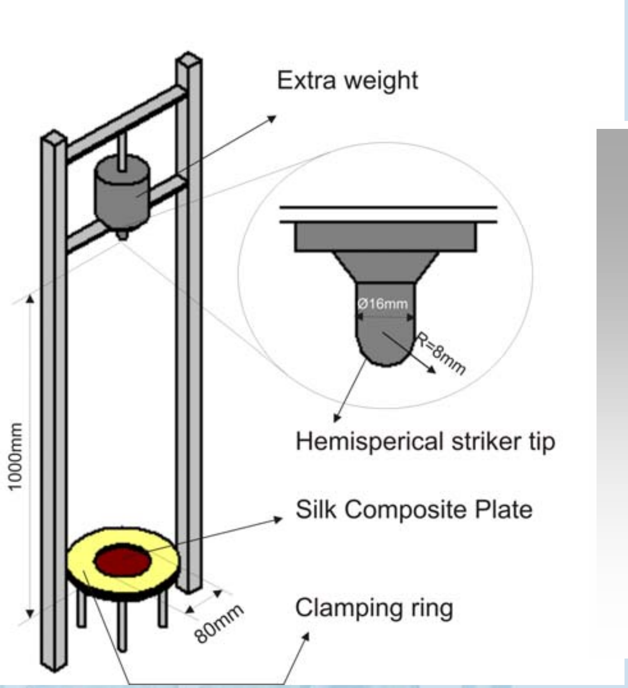
- Improving wetting and adhesion (surface energy matching)

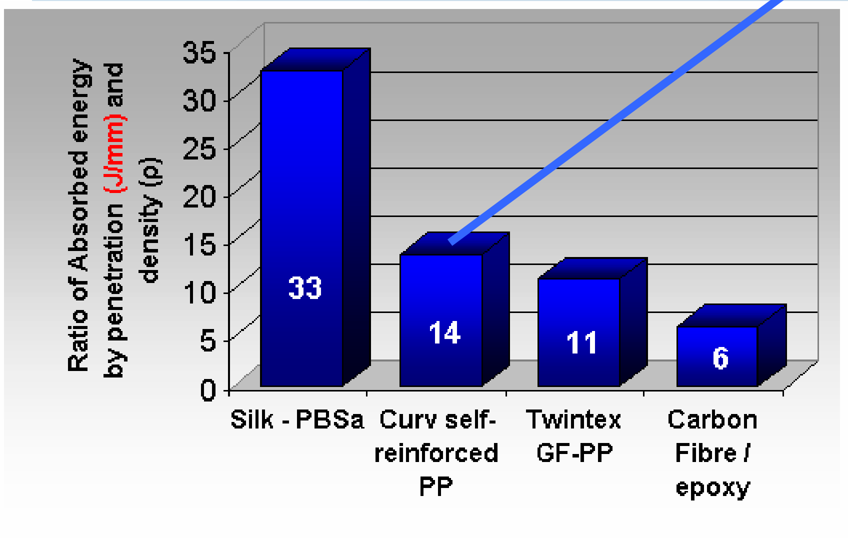
4) Environmentally friendly matrices:

* Biodegradable or Bio-based

Bio-based Composites;
Natural fibre properties; examples

Silk Composites have excellent falling weight impact performance!





Patent: WO 2007-110758 (with Hermès)

Matrices

Classification of matrices:

* Thermoplastic (TP) and thermoset resins (TS)

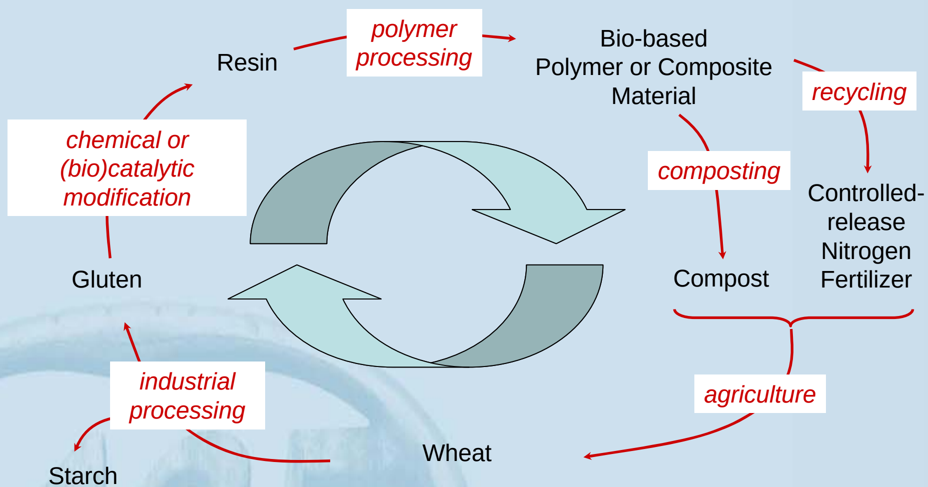
Examples of polymers	Natural polymers: (renewable)	**BIO-BASED** polymers (***renewable*** feedstock, synthesized!):	"Synthetic" petroleum based polymers
Biodegradable	Lignin	PLA PHA, PHB Starch	PBS PCL PVA
Non-biodegradable	Cashew nut shell resin (CSNL)	Furan resin Vegetable oil -PUR (polyol) AESO Ethanol based PE Some nylons (PA-11)	Most well-known polymers: * PP, PE, nylons, etc. * Epoxy, UP

• Research on renewable matrices is relatively recent, especially for bio-thermosets

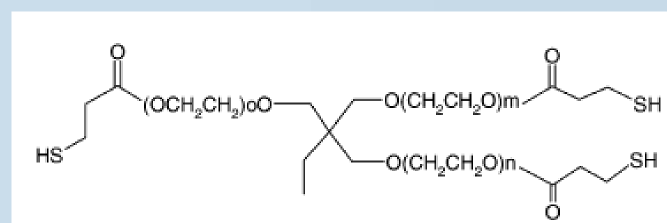
Bio-based Composites; Developing environmentally friendly matrices

Development of renewable *gluten* based bio-polymers:

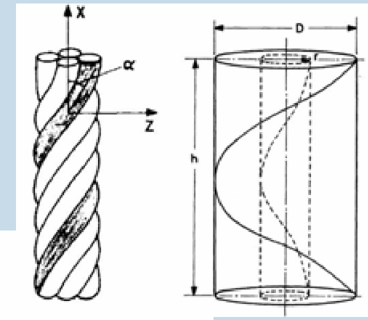
- Improvement of toughness & rheology
- Patent on thiol-based modifiers (WO 2004/029135)
- So far 50% improvement in strength and strain to failure (approaching epoxy)

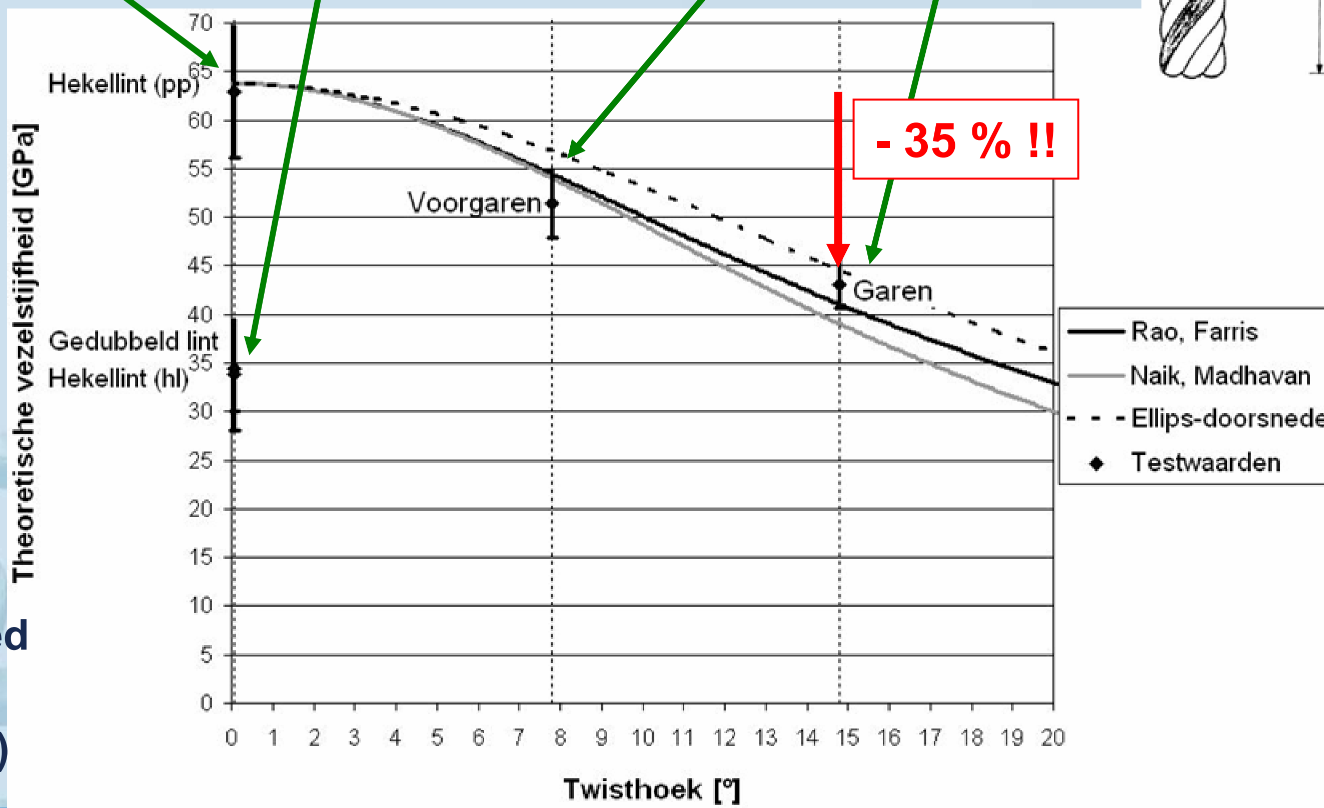


Thiol-terminated star-branched modifiers:
Crosslinking + phase separation?



Fibre processing research;
Effect of twist on FLAX UD-composite stiffness (CELC)

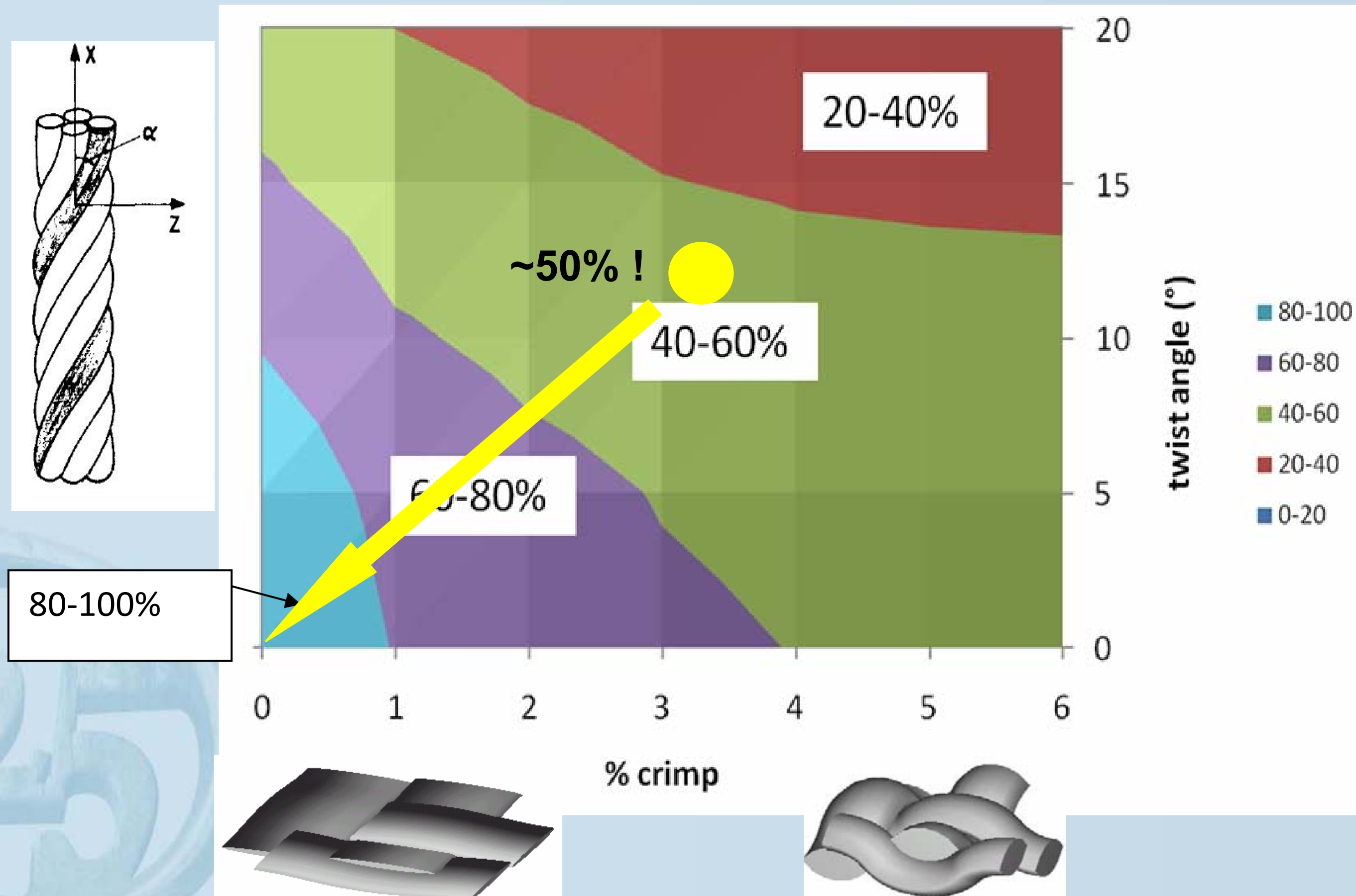




Back-calculated fibre stiffness (matrix=epoxy)

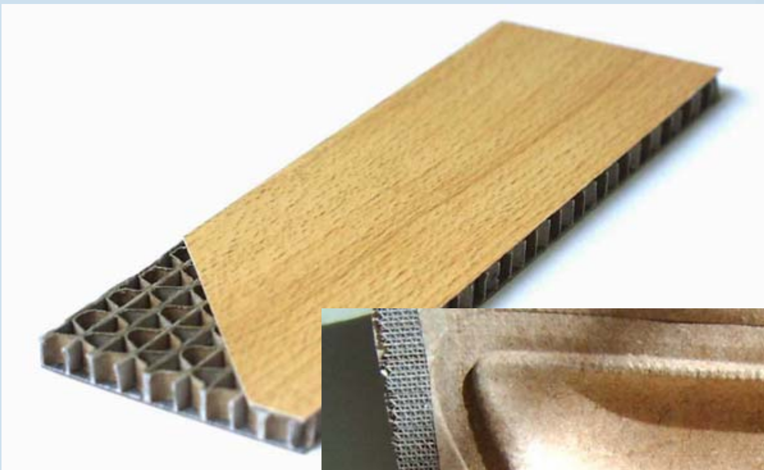
Research in cooperation with CELC

Combined effect of twist and crimp on composite modulus



Bio-based Composites; Paper honeycomb panels

Applications of ‘Torhex’ cardboard honeycombs; sandwich panels with NF composite skins



www.econcore.com

Large Projects at SLC - BioComposites

•Cornet Nature Wins (with Centexbel and ITA Aachen)

Thermoplastic bio-composites, flax/hemp + PLA

- Mixed yarns & textiles / non-wovens
- Consolidation and thermoforming

•TIS Change2Bio (with VKC and Centexbel)

"Renewable polymers – important element to develop the bio-economy"

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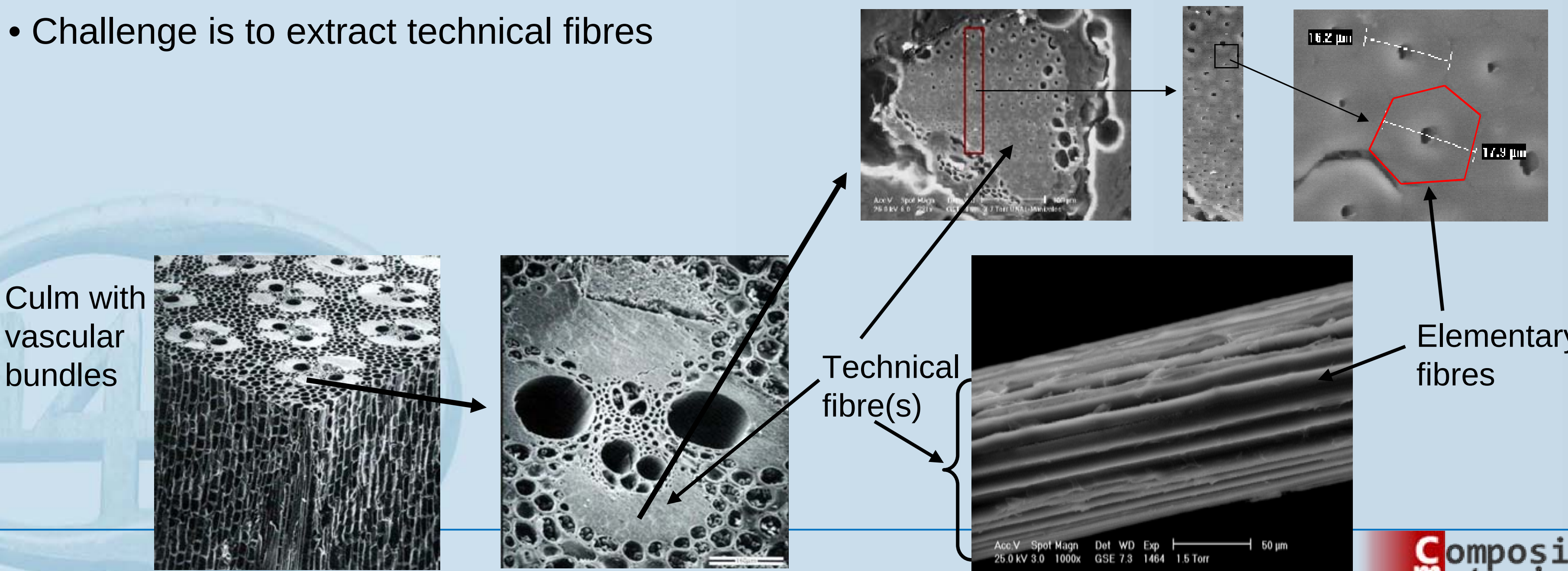
Bamboo Fibre Composites

- ***Bamboo fibres*** have excellent mechanical properties
- Specific properties comparable to glass fibre
- Bamboo can grow to 20 m in 6 months
- Can fix 50-60 tons of C/ha.year
- Challenge is to extract technical fibres



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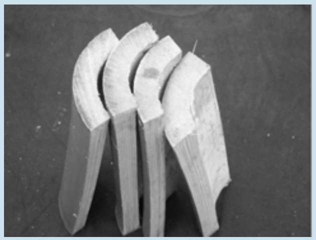
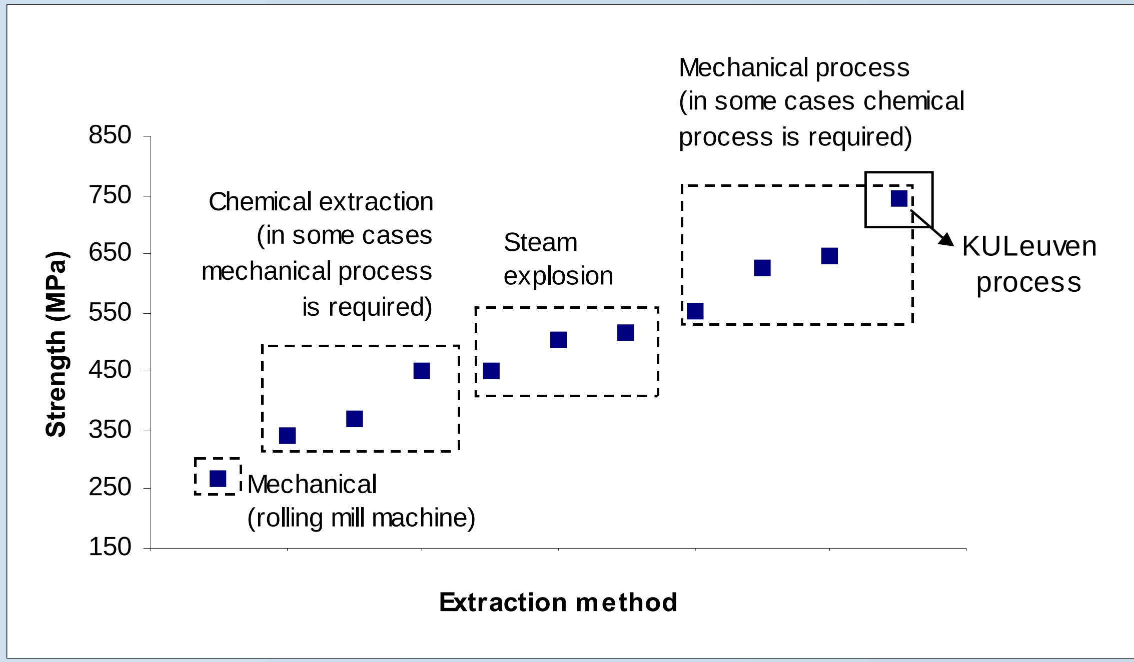
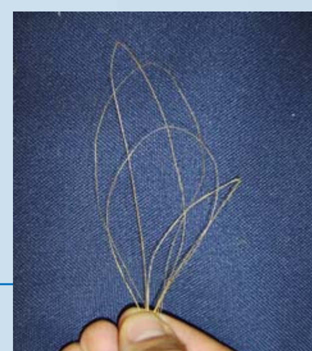
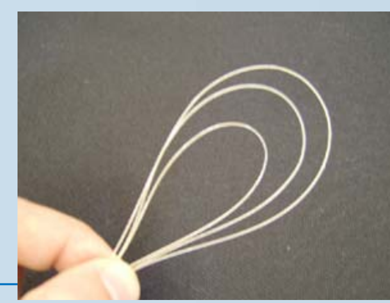
Bamboo Fibre processing

Bamboo Fibre Extraction









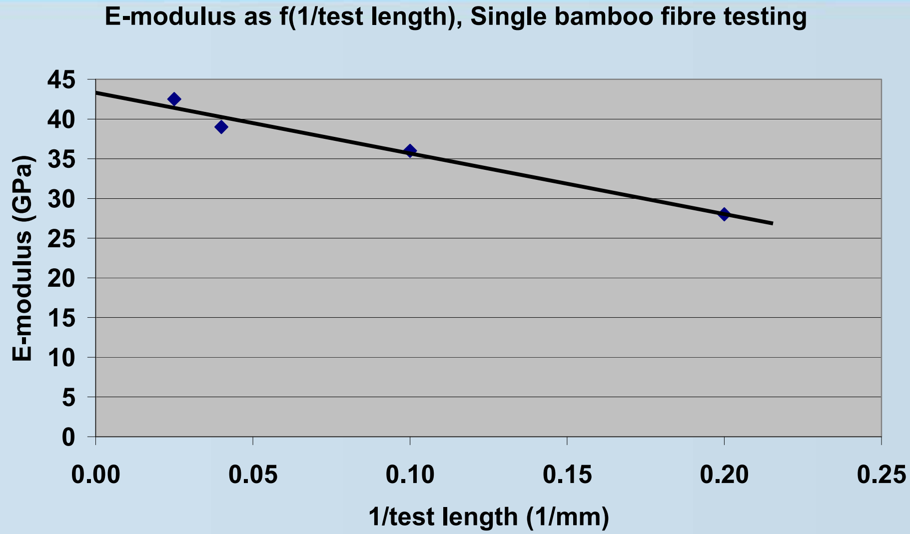
Loop test

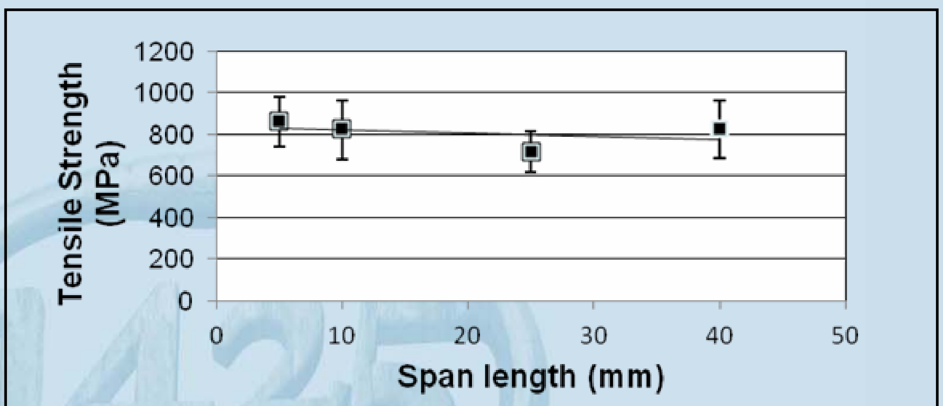
Bamboo Fibre properties

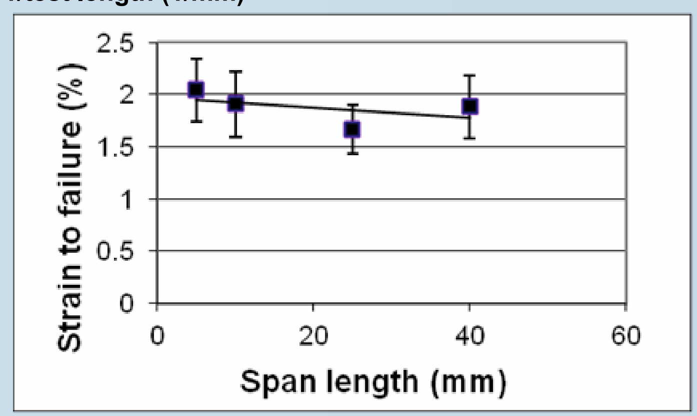
Single fibre tensile tests;

Corrected for system compliance

* E(extrapolated) ~ 44 GPa







New developments: * use of Digital Image Correlation (camera extensometer)

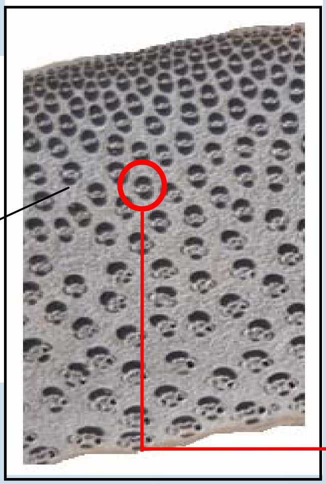
* Fibre bundle tests (dry + impregnated)

* Study of off-axis properties

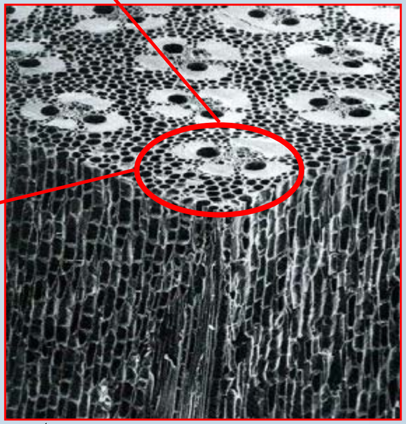
Bamboo Fibre morphology
(Lina Osorio)

Bamboo culm

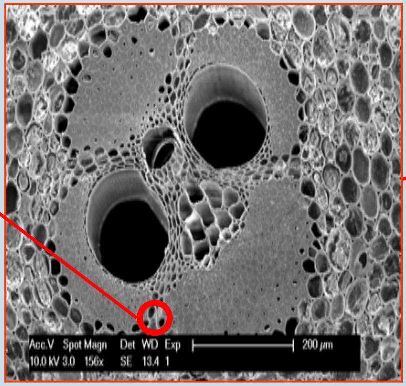
Cross section



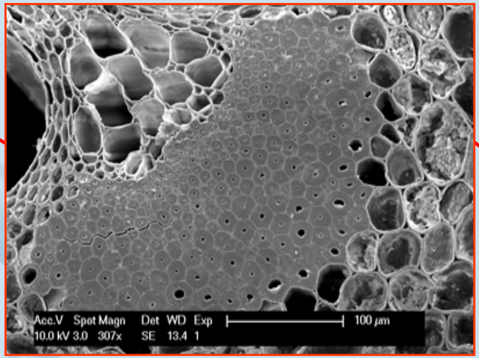
Vascular bundles have higher concentration towards the outside of the culm



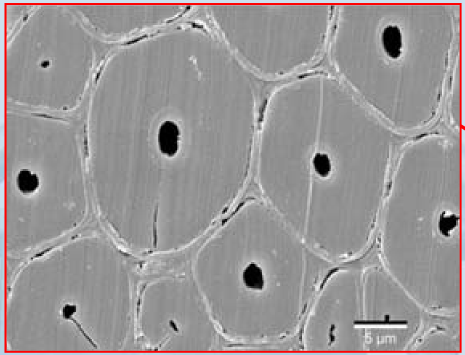
Bamboo wall
Liese, W., 1998



Vascular bundle



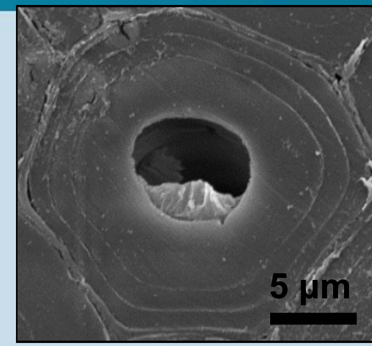
Fibre bundle



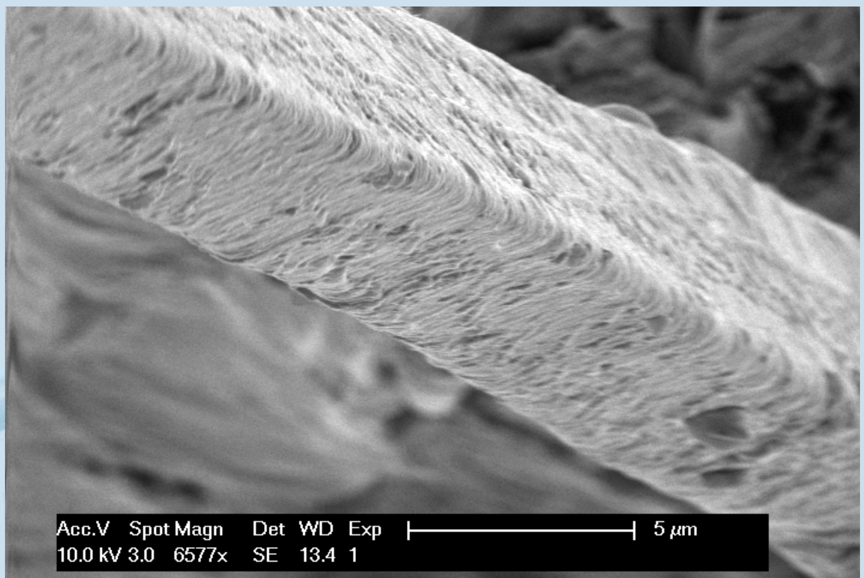
Elementary fibres

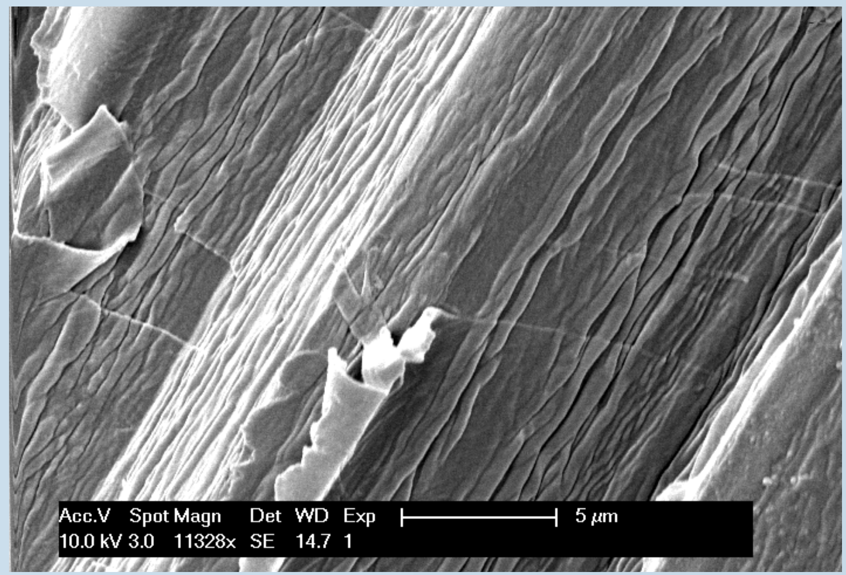
Bamboo Fibre morphology

Most elementary fibres seem to have a simple 2 layer structure



Primary layer with 90° orientation;
from fracture surface





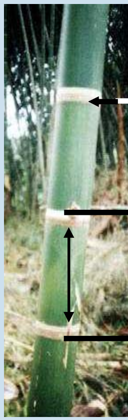
Secondary layer with 0° orientation;
After etching away primary layer

Next: Measurement of off-axis properties (tests on composites)

Bamboo fibre process development

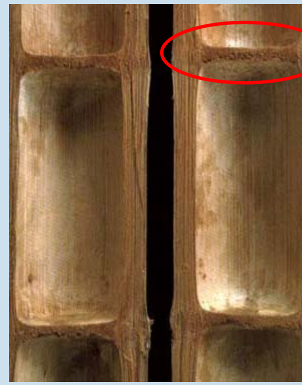
(Eduardo Trujillo)

Problem statement

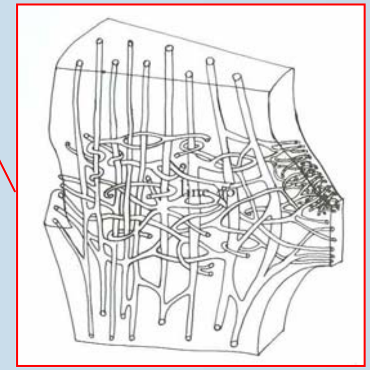


Node

Internode



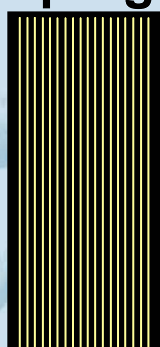
Discontinuity of the fibre



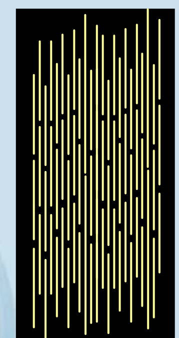
Length of internodes

(± 25 cm)

UD prepreg with discontinuous fibres; continuous process?



Continuous UD prepreg



Discontinuous UD prepreg

UD bamboo fibre-polypropylene tape

Understanding and improving the fibre-matrix interface; a combined physical-chemical-mechanical approach (Carlos Fuentes)

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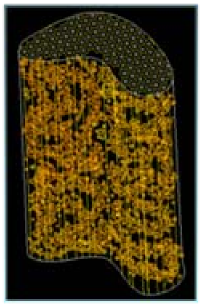
Microstructure → **Surface** → **Wetting** → **SEC theories** → **Adhesion Improvement**

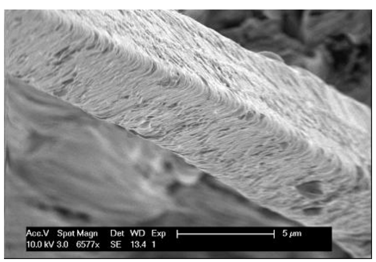
Microstructure

Technical fibre ~100 – 200 µm

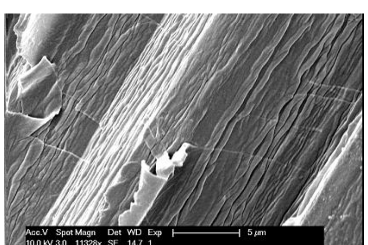


Elementary fibre ~10 µm

With micro/nano fibrils:



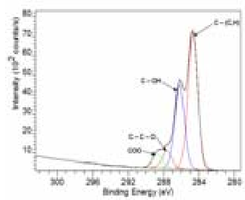
Primary wall: 90° orientation



Secondary wall: 0° orientation

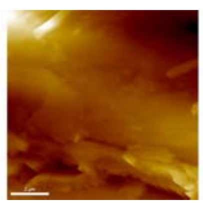
Surface

Chemical composition

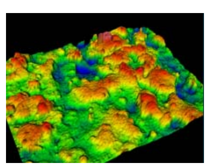


X-ray photoelectron spectroscopy (XPS)

Topography



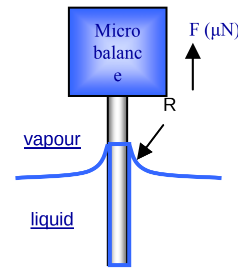
AFM



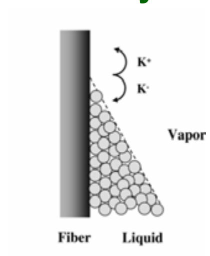
Profilometer

Wetting

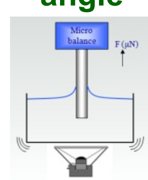
Fibre and matrix



Molecular kinetic theory

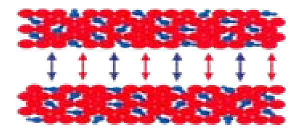


Equilibrium contact angle



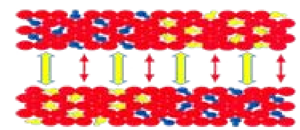
SEC theories

Owens/Wendt



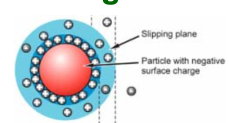
$$\gamma_{sv} = \gamma_{sv}^{P} + \gamma_{sv}^{D}$$

Acid/base



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

Streaming Potential



Adhesion Improvement

Approaches:

1. Make a good match with untreated fibre:

   Polyvinylidene fluoride (PVDF)

2. Treat the surface to get a good match:

   Chitosan layer, Silanes

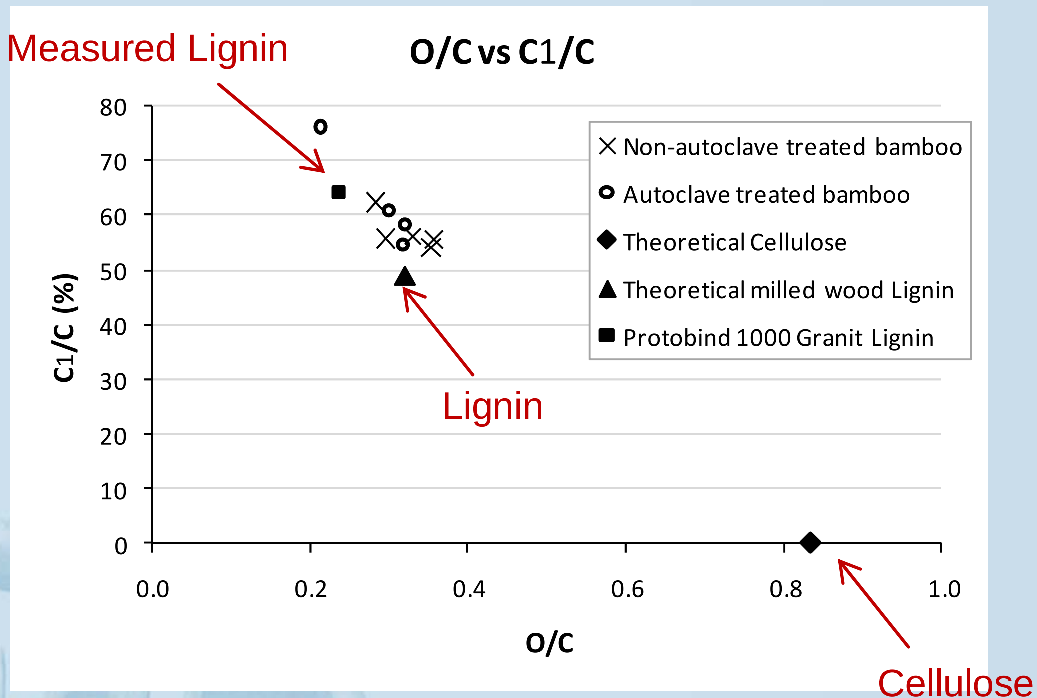
Interface Characterization

Micromechanical test: Pull-out tests

Flexural test: Transverse 3 point bending test

Bamboo fibre surface analysis

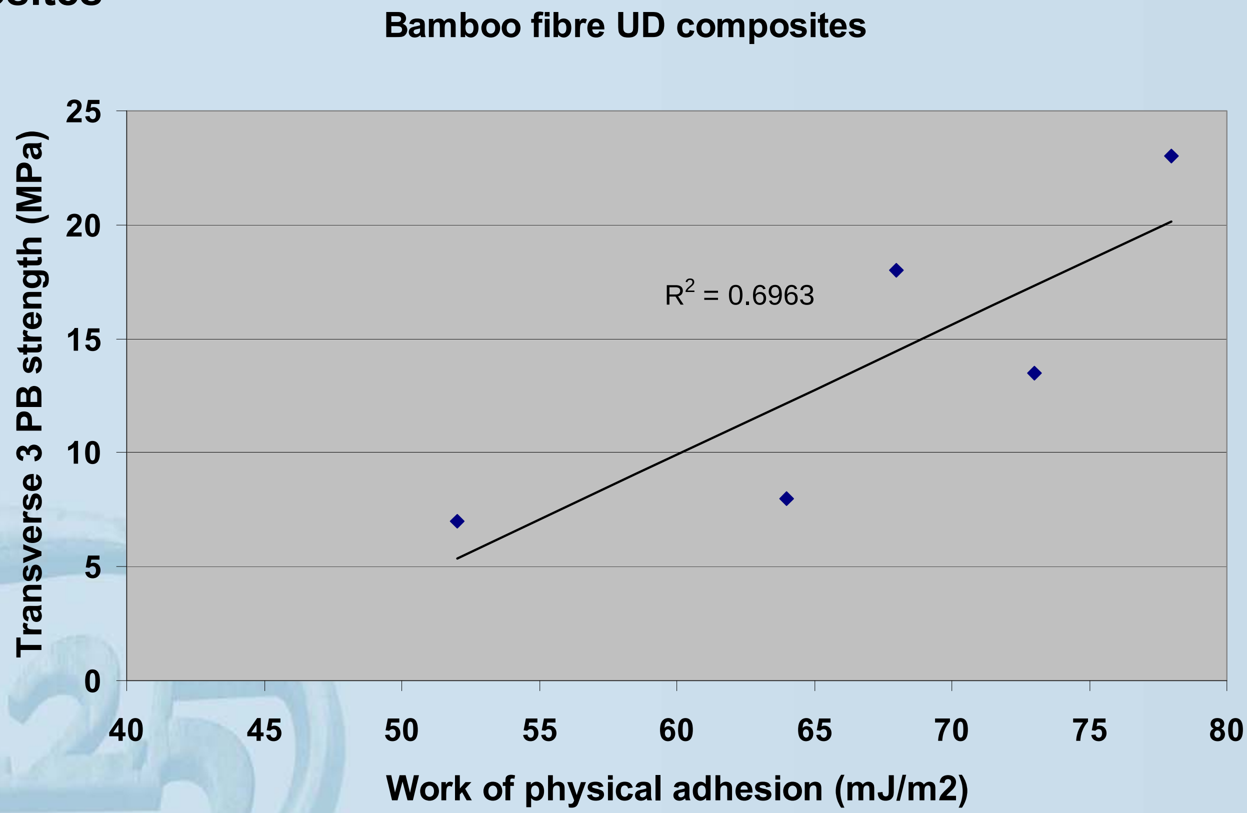
XPS results; courtesy C. DuPont, UCL

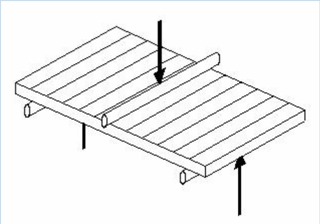


Extracted bamboo fibre surface seems to be covered with lignin

Interface studies; Bamboo fibre composites

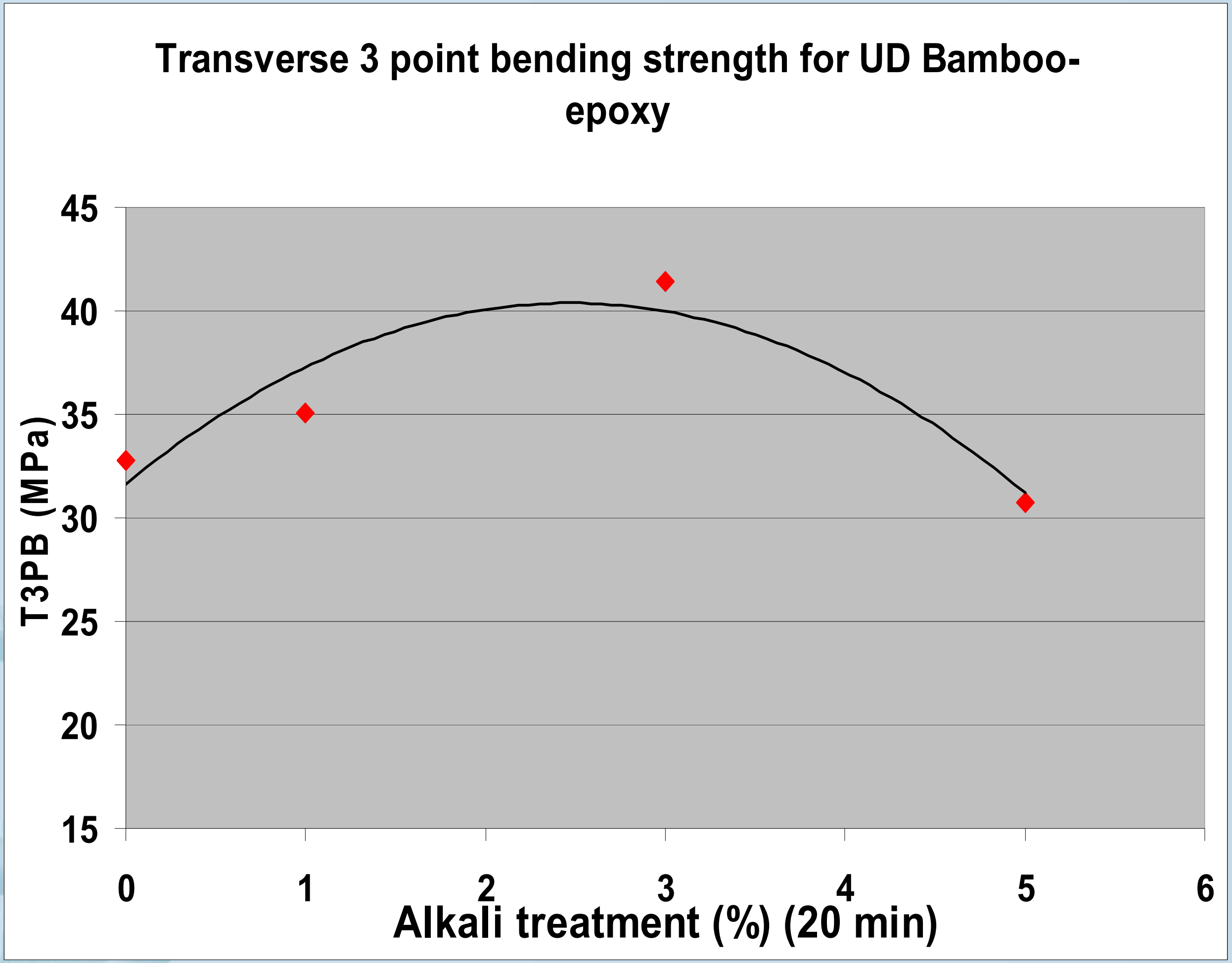
Results of Surface Energy Component matching; Effect of Physical Adhesion in thermoplastic composites



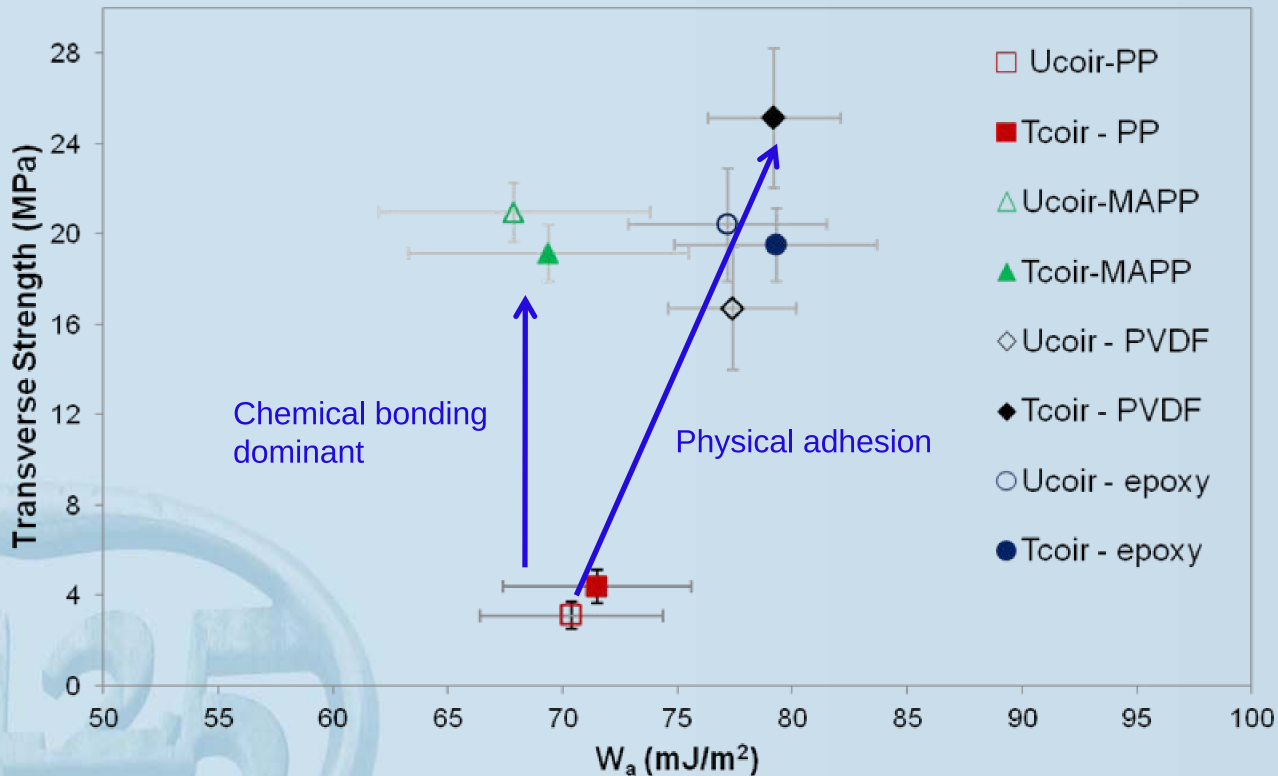


Matrix: PP and PVDF (+ some treatments)

Addition of chemical adhesion



Work of Adhesion versus Interface strength for coir composites



U = Untreated

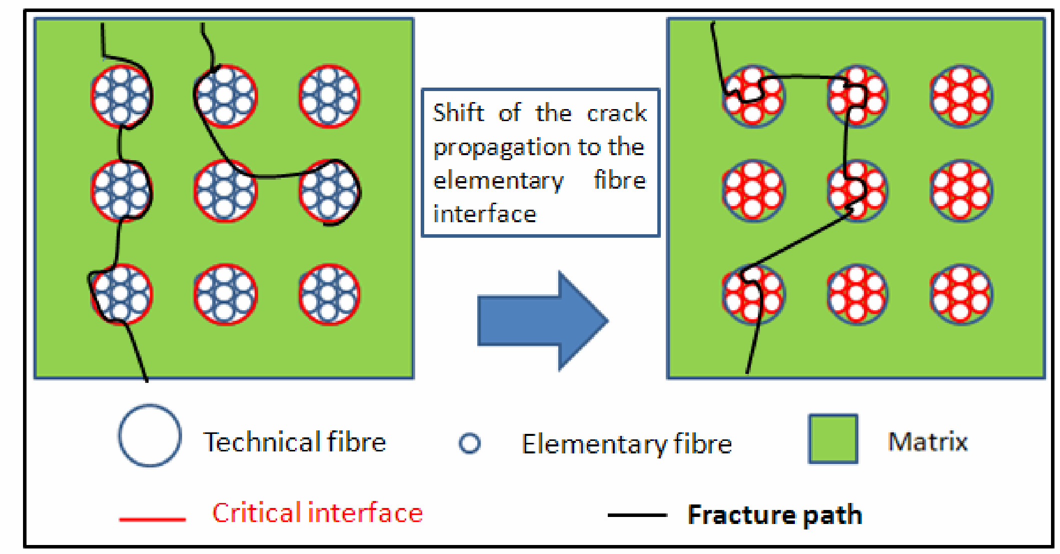
T = Alkali treated

Bio-based Composites; Fibre properties

Flax fibre property improvement

* Fibre Treatment to Reduce Direct and Indirect Moisture Uptake

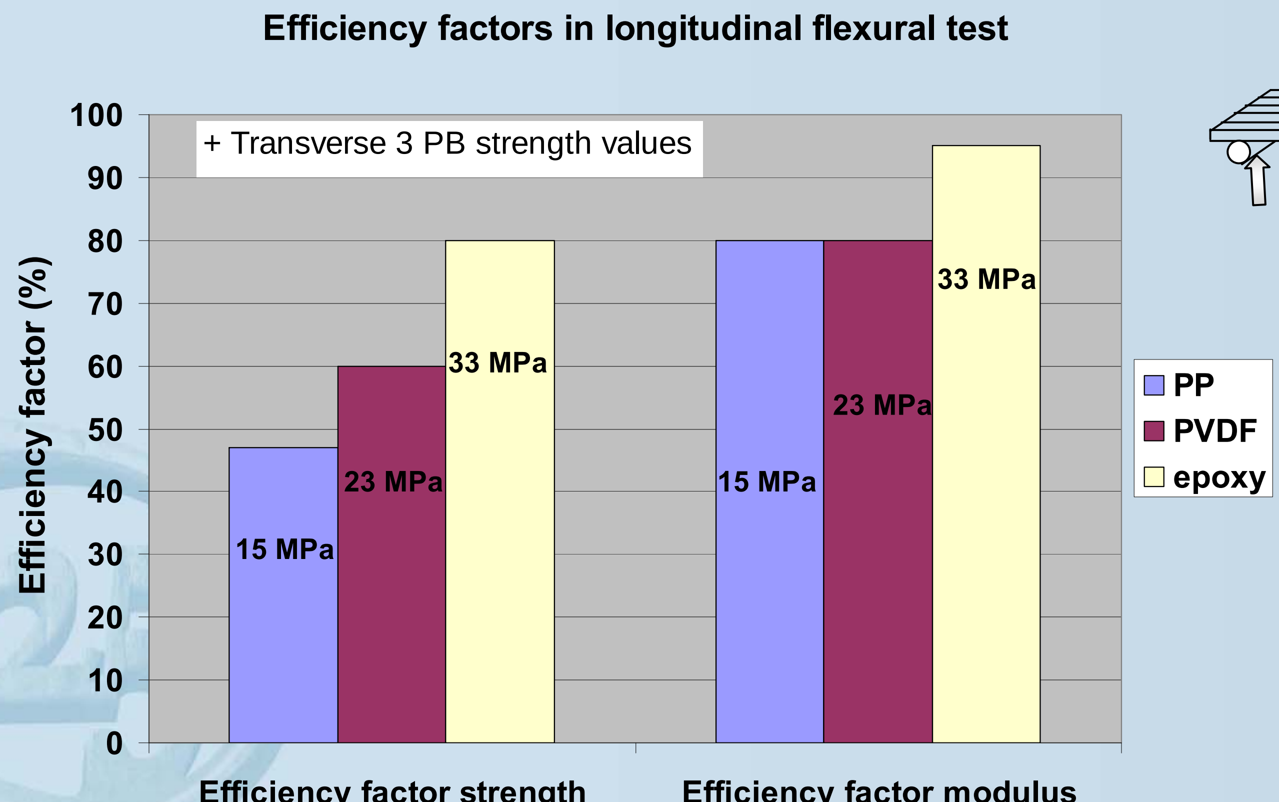
* Fibre Treatment to Improve internal fibre strength

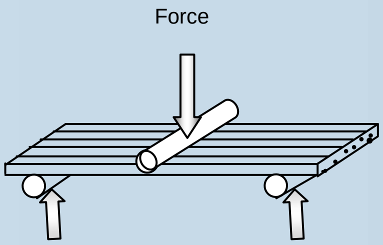


Bamboo Fibre Composite performance

COMPOSITE longitudinal *flexural* tests

Efficiency factor = measured property / theoretical property based on fibre properties





Moisture resistance Bamboo fibres

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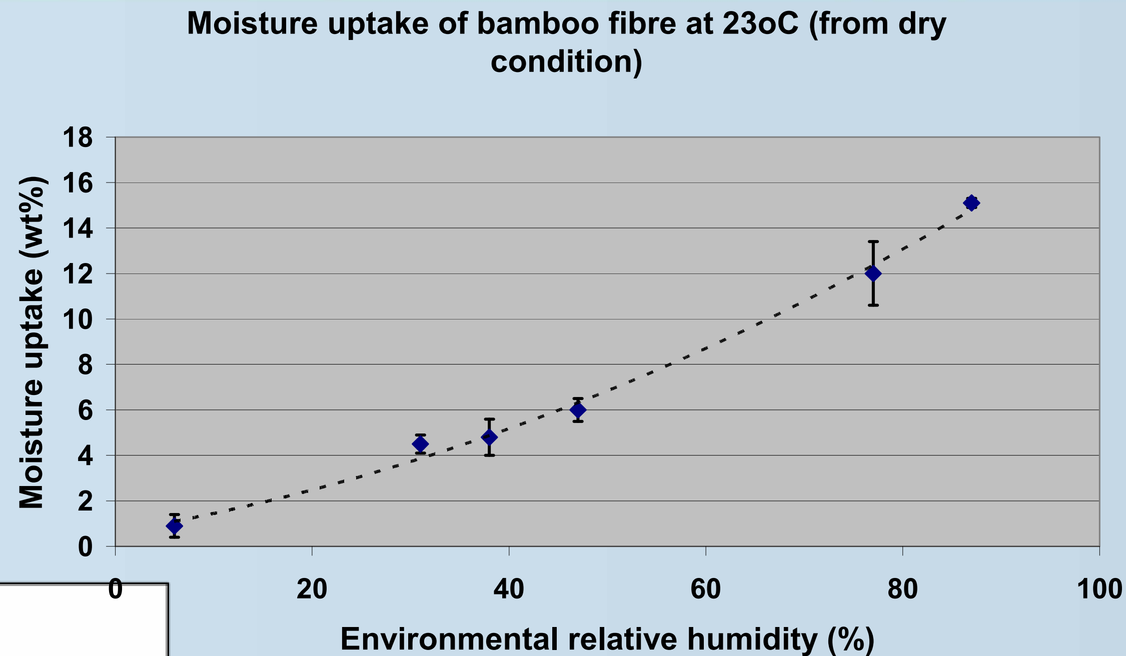
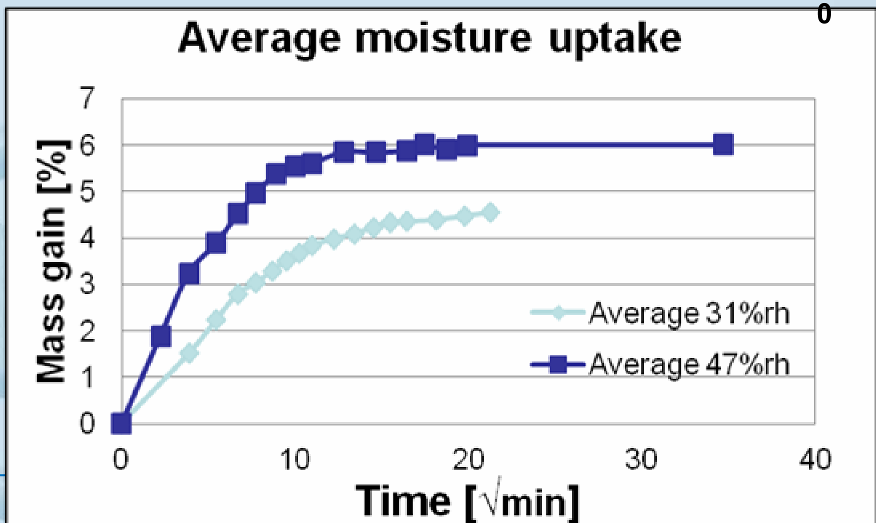
Fibre moisture uptake,

Absorption isotherm



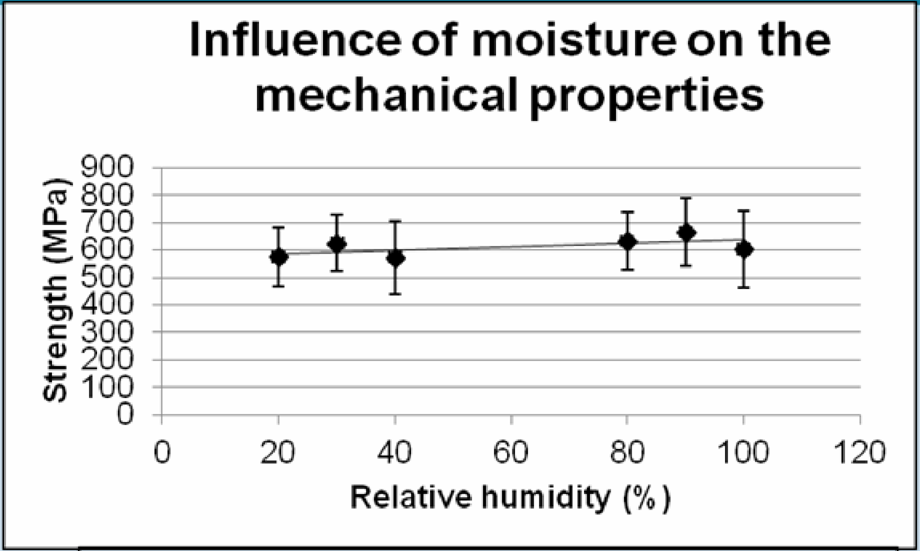


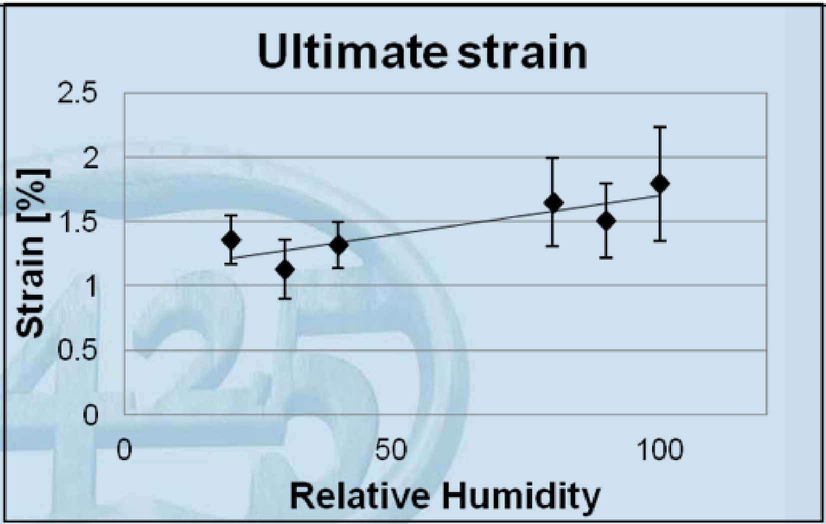
Moisture uptake is intermediate to literature data for (solid) lignin and cellulose

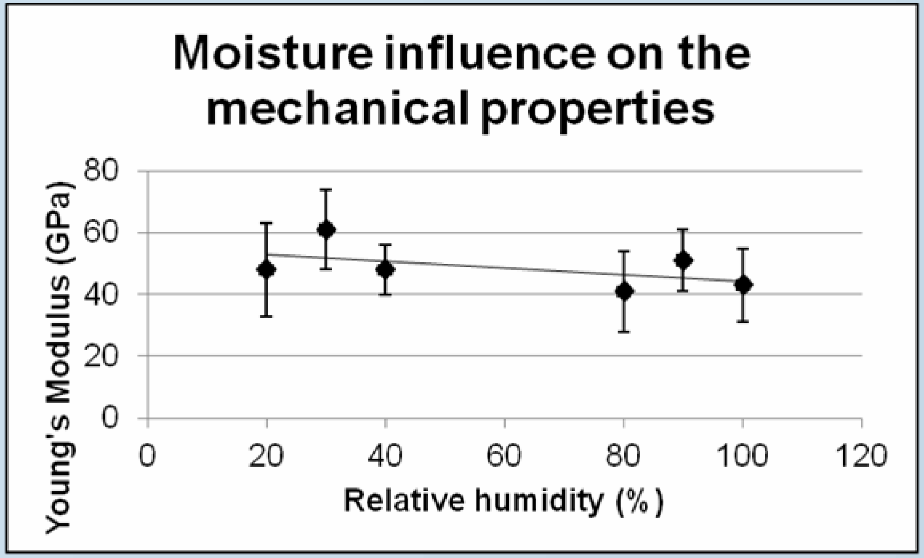
	Diffusion coefficient [m^2/sec]
Bamboo	1.04 x 10^{-10}
Flax	1.25 x 10^{-8}

Composite materials group

Moisture effects on Bamboo fibres

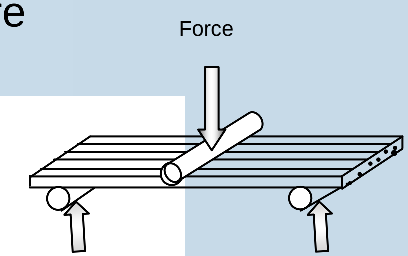


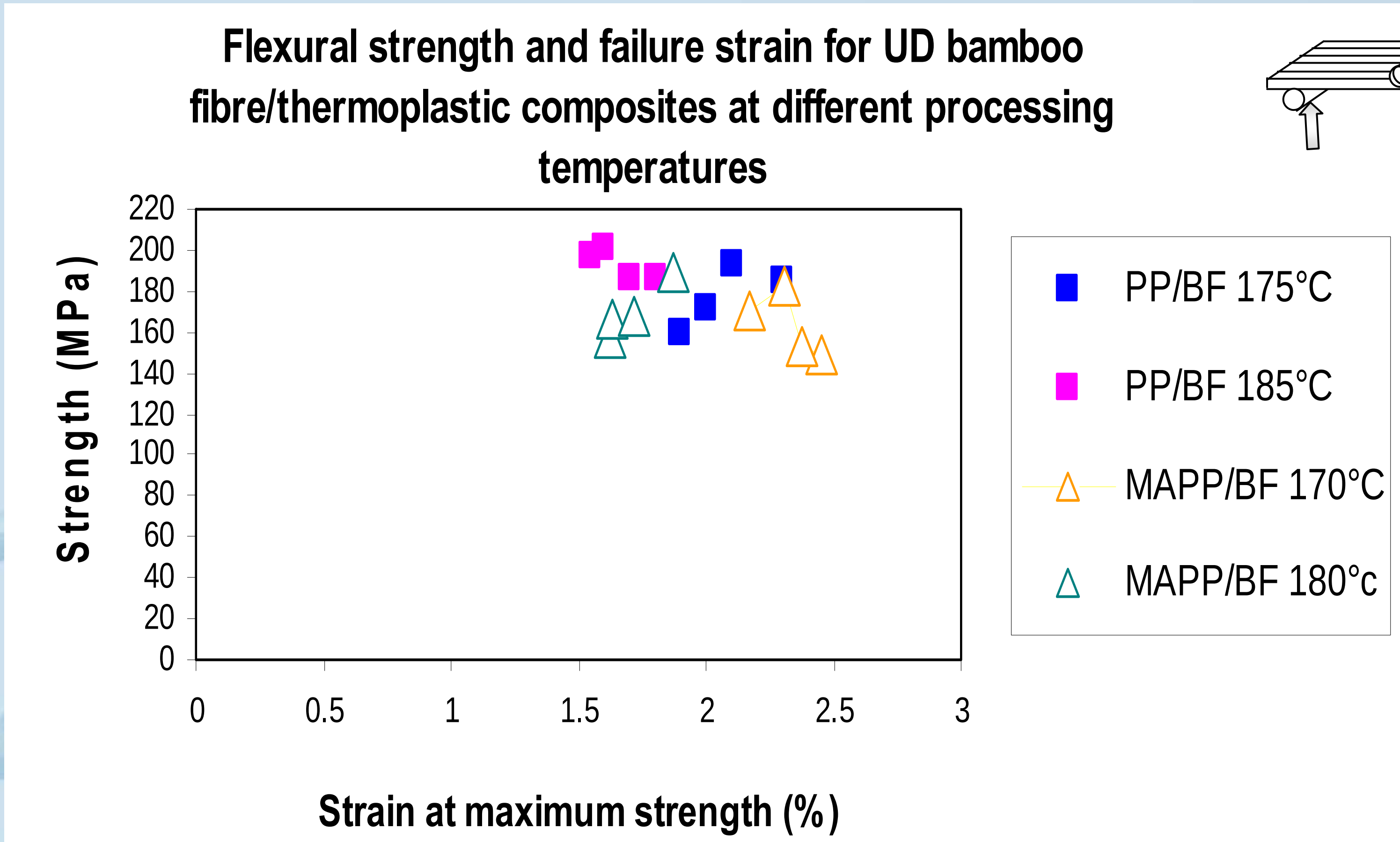




Thermal degradation Bamboo fibre composites

Single fibres: Degradation starts around 170°C in normal atmosphere





Concluding (Bamboo Fibre Composites)

- A promising fibre extraction process was developed for Bamboo Fibres
- Next processing development is cleaning, stretching, aligning and prepregging
- Most elementary fibres have predominantly 0 degree nanofibril orientation, combined with an outer wrap of 90 degrees
- Extracted bamboo fibre seems covered by lignin
- Surface energy component matching allows improving physical adhesion; so far good results with PVDF
- There is a clear correlation between interface strength and UD longitudinal strength
- Efficiency factors for epoxy reach 95% for modulus and 80% for strength
- Moisture uptake is as expected intermediate to solid cellulose and lignin
- Fibre strength and modulus are hardly affected by moisture; strain to failure is affected (plasticisation)

Thanks for your attention!

JEC 2012 Tradeshow in Paris: KU Leuven - SLC booth

www.slc-lab.be

The **Composite Materials Group**
of the Department of Metallurgy and Materials Engineering (**MTM**) of the
Katholieke Universiteit Leuven (Belgium)
cordially invites you to the

CompositesWeek@Leuven

16-20 September 2013

Three one-day symposia on :

- **nano-engineered composites,**
- **designing with composites**
- **bio-based composites**

+

the TEXCOMP 11 conference on textile composites

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