KATHOLIEKE UNIVERSITEIT
LEUVEN

Composite Materials Group

Bamboo (*Guadua angustifolia*) ***fibres for STRONG-light composite materials***

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Content

Bamboo fibres →
- **Extraction**
- **Properties**

Bamboo fibre composites →
- **Discontinuity of the fibre**
- **Properties**

The future →
- **Applications**
- **Pros and cons**

Conclusions

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Resource

Why bamboo?

- **Fast growing** → 21 cm/day; Final height in 6 months; Maturity in 4-6 years

- **Natural growing plant** → Enormous capacity of renovation without reseed

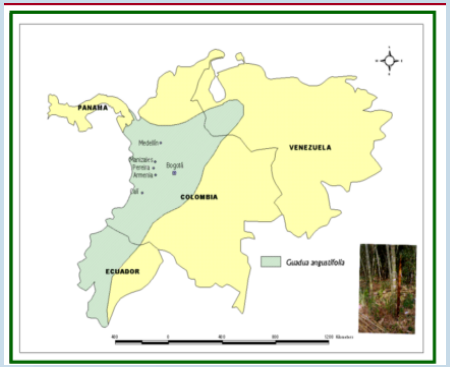
- **Environmental benefits** → Prevention of the erosion; Increases the organic material in the soil; Capture CO_2

  1 hectare of bamboo sequesters 62 tons of CO_2/year

  1 hectar of young forest sequesters 15 tons CO_2/year

  J.Jansen, Technical Univ. Eindhoven, 2000

- **Specie *Guadua angustifolia*** → One of the largest bamboo species on the world; Large size – Good properties

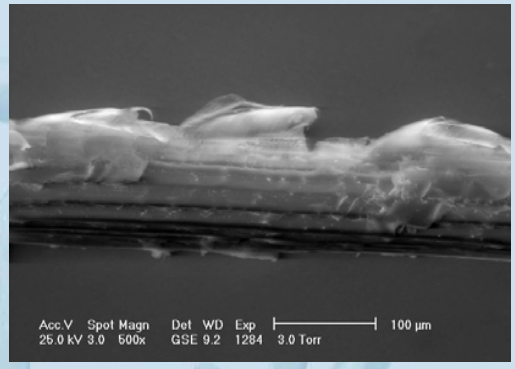


Bamboo fibre extraction process

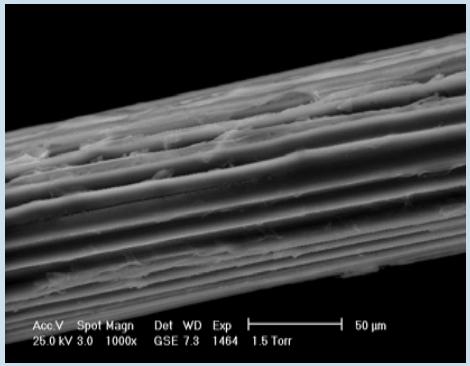
Extraction methods for bamboo fibres

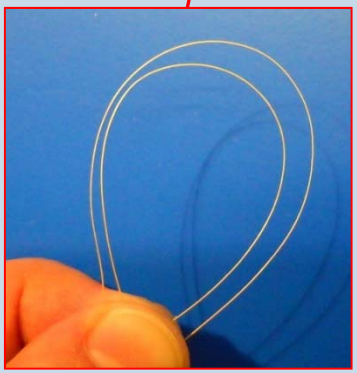
- Steam explosion → High pressure and T° (several times)
- Chemical extraction → NaOH (high concentrations)
- Combination of chemical and mechanical
- Mechanical extraction

K.U.Leuven



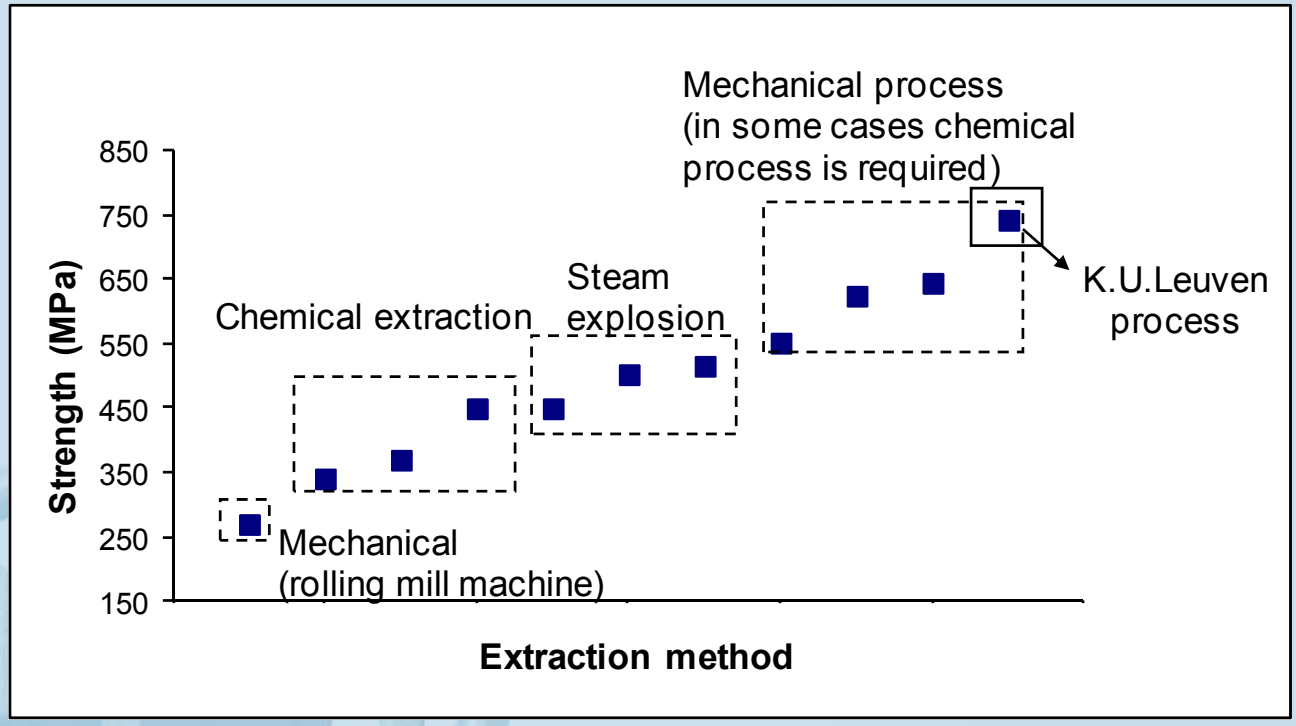
Bamboo fibre without extraction process

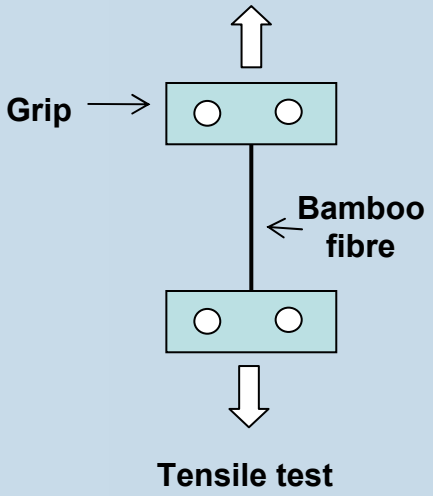




Bamboo fibre extraction process

Strength comparison between different bamboo fibre extraction techniques



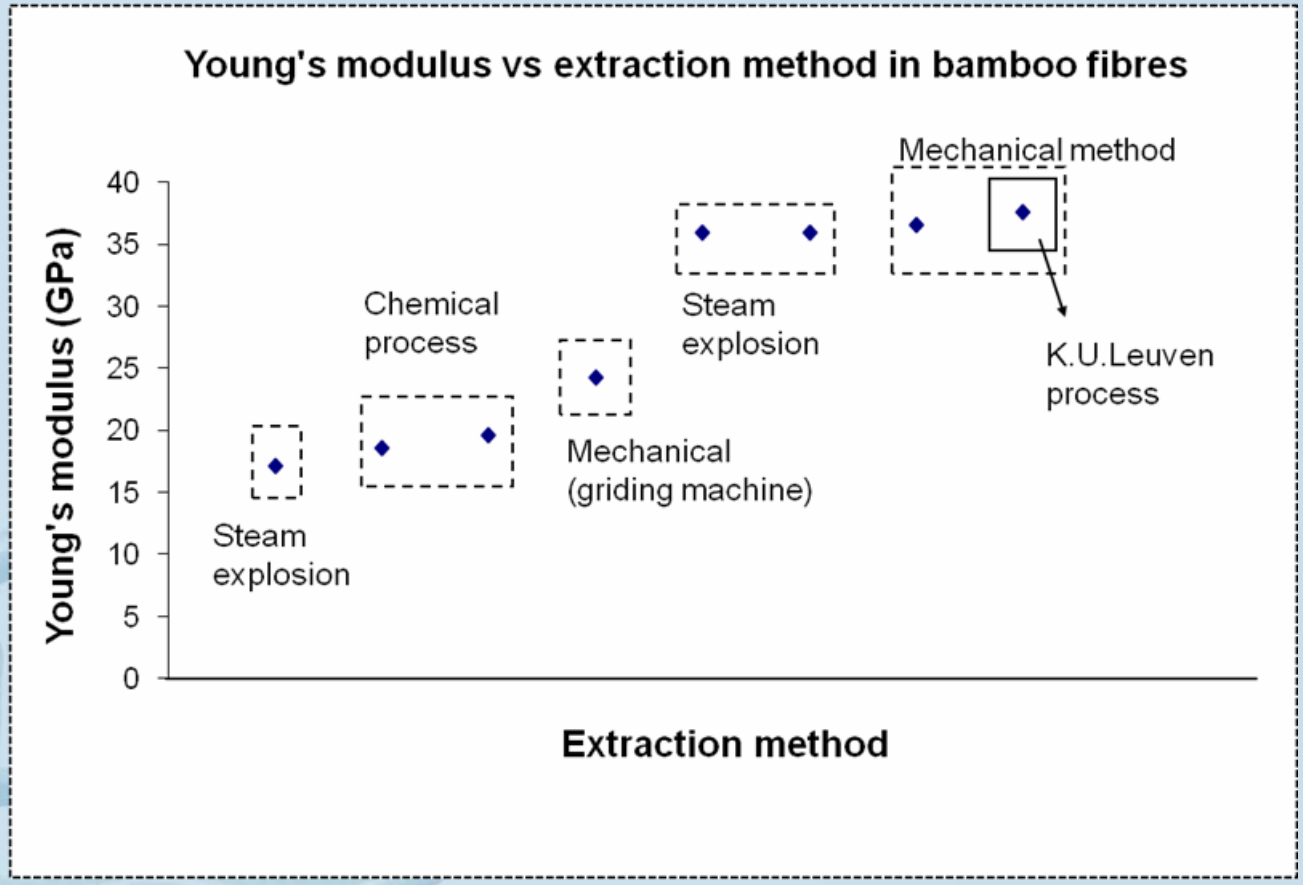


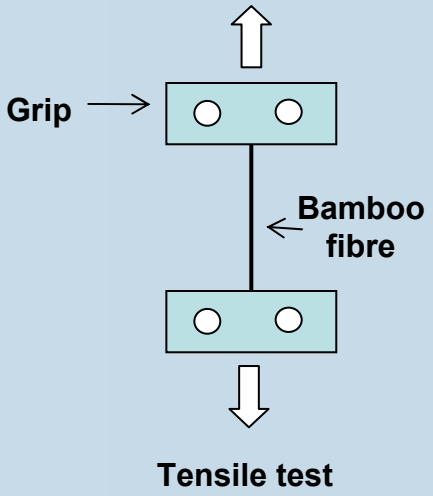
New extraction process:

- No chemicals are used
- Room temperature
- Not previous preparation of the raw material (e.g. retting)
- Continuous process

Bamboo fibre extraction process

Stiffness comparison between different bamboo fibre extraction techniques





Bamboo fibre extraction process

KU Leuven fibres

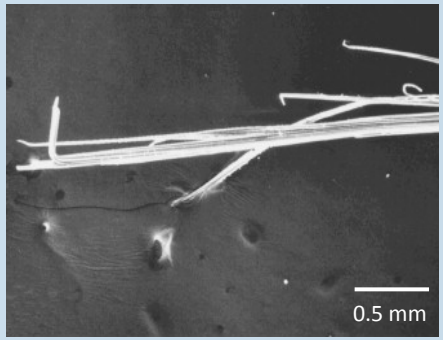
Bamboo fibres from different sources

Industry

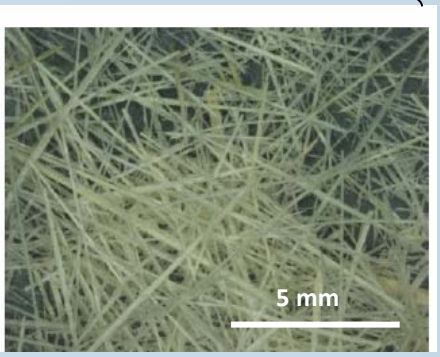
Bamboo Industry Development Co., (2011)

Scientific papers

Hiroyuki Kinoshita et al, 2009



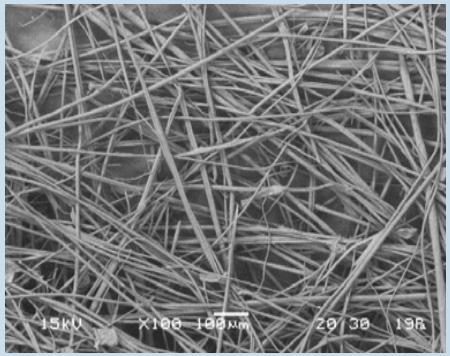
S. Shibata et al, 2008



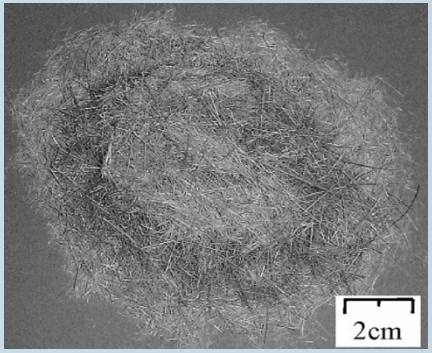
Keiji Ogawa et al, 2008

Bamboo fibre technology group (2011)

R. Rowell 2008



O. Yamashita et al, 2007



Kazuya Okubo et al, 2004

Bamboo fibre extraction process

Fibre yield after extraction

Fibre	Growing cycle (days)	Biomass waste (Ton) to produce 1 Ton of fibre	Fibre yield (kg/hectare)
Flax	85-120	-	1100*
Sisal	Continuous	25*	3360* 600-1200**
Ramie	45-60	-	550*
Jute	120-150	20*	2200* 1600-2000**
Kenaf	150-180	-	1700* 2300**
Hemp	130-180	-	1225*
Cotton	180-200	-	790*
Abaca	Continuous	48*	3000* 500-1000**
Henequen		-	1500*
Bamboo *(G. angust.)*	**Continuous**	**~11 - 14**	**~1045 - 3120**

Source:

* *R. M Rowell,* (2008)
** Wallenberger, F. And Weston, N., (2004)

Fibre properties

Why bamboo fibres?

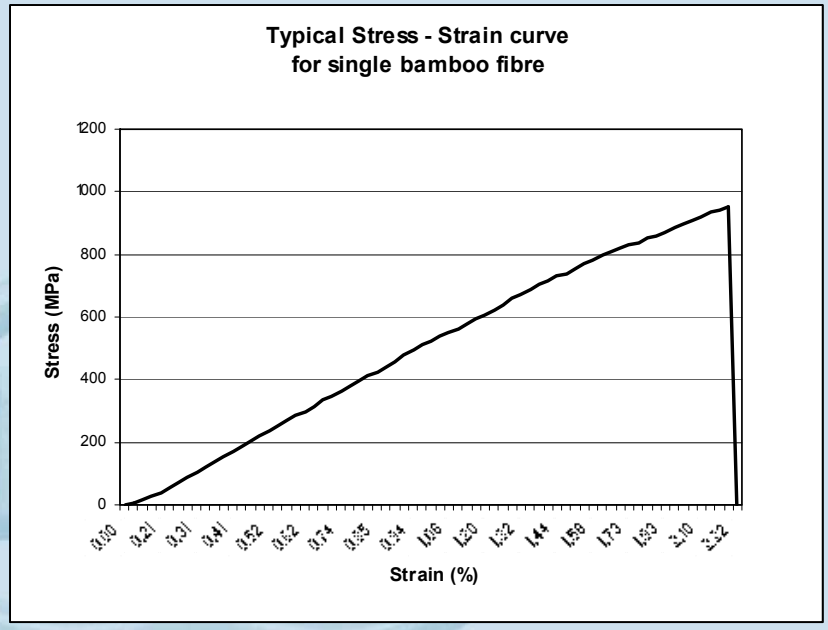
Bamboo fibres show some similarities with glass fibres

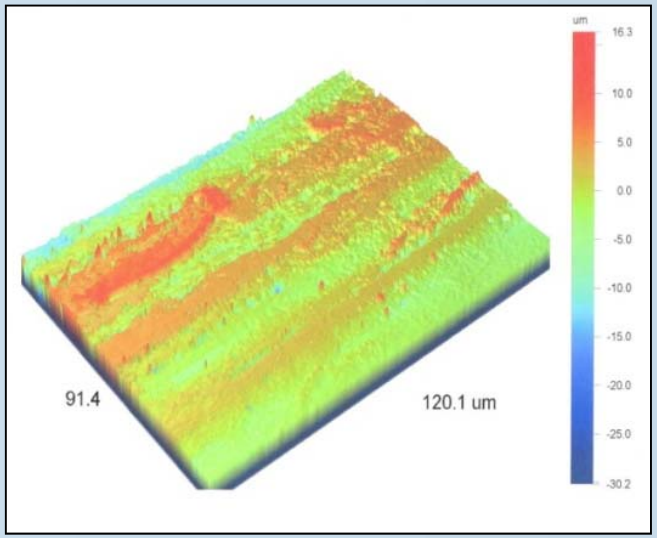
- The same linear elastic behaviour under tensile load
- Brittle fibres (strain ~ 2%)
- Specific properties are comparable with glass fibre

Density Glass fibre: 2.5 (g/cm3)

Density bamboo fibre: 1.4 (g/cm3)

$$\left(\frac{\sigma}{\rho}, \frac{E}{\rho}\right)$$

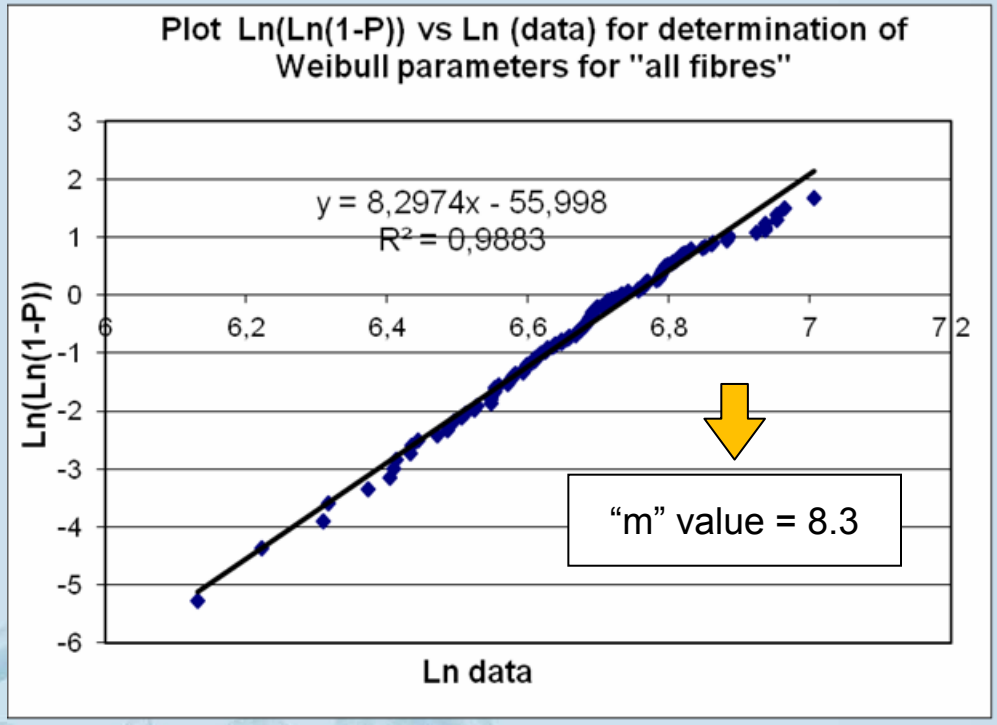




Roughness of the bamboo fibre (Veeco profilometer)

Fibre properties

Weibull distribution



$$P = 1 - exp\left[-\frac{L}{L_o}\left(\frac{\sigma}{\sigma_o}\right)^m\right]$$

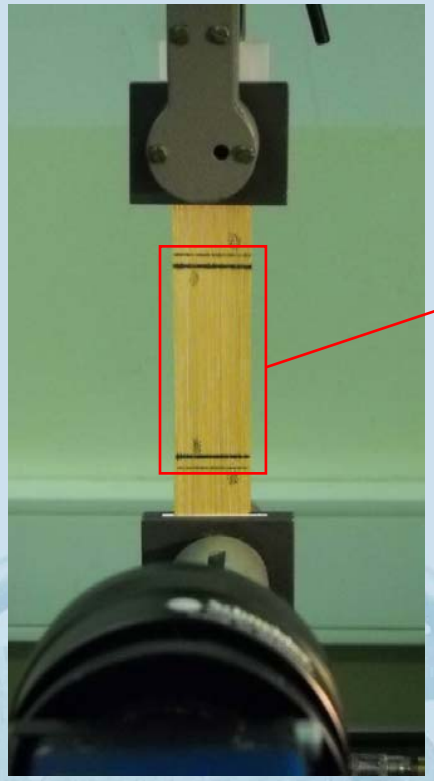
Fibre	"*m*"	*Reference*
Jute	6	***Shaha, et al 2011***
Jute **Coir**	3-4 9-3	***Defroid,et al 2010*** Span length: 15mm - 35mm
Flax	3 - 4	***Baillie, et al 2007***
Jute	2-1	***Xia, et al, 2009*** Span length: 5mm- 20mm

Shape factor (*m*) → indicator of the variation in the data: the bigger the value the smaller the variation in the data.

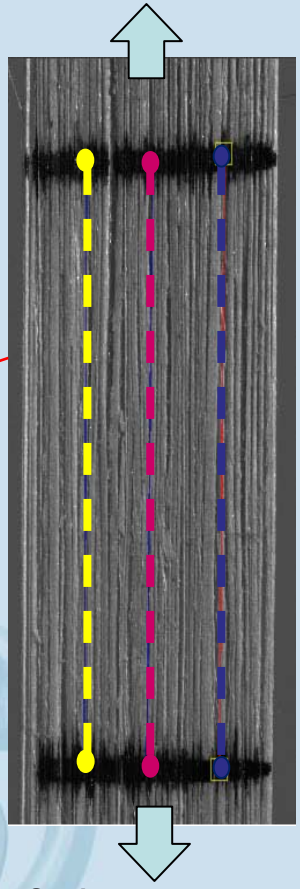
Manmade fibres usually 5 and 15,
Natural fibres (larger variation in their properties) between 1 and 6 (*Baillie, 2007*).

Fibre properties

Fibre bundle test

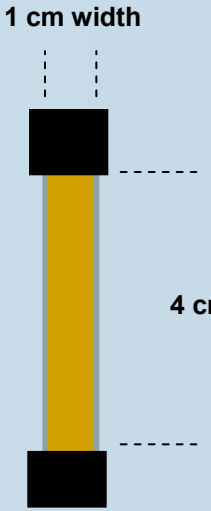


Fibre bundle test



Strain measurement

Failure of the bundle



Failure bundle tensile results

Shape parameter (*m*)	σ_f (MPa)	E (GPa)
5.7	640±45	49±11

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Bamboo fibre composites →
- **Discontinuity of the fibre**
- **Properties**

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Conclusions

Bamboo fibre composites

Unidirectional disposition of the fibres (UD)

Bamboo fibres

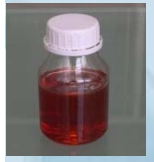
Reinforcement

+

Curing time

=

Bamboo fibre / epoxy **composite**



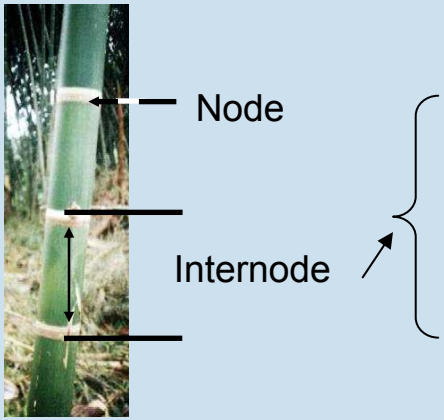
Resin Hardener

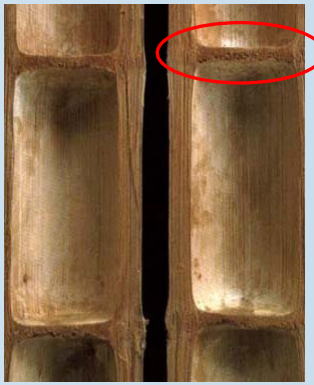
Matrix

Force

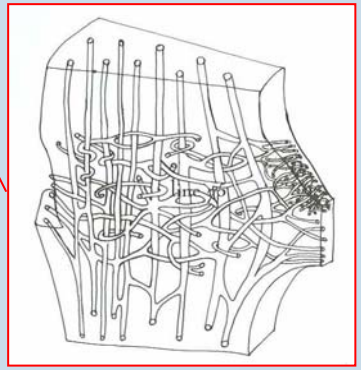
Bamboo fibre composites

Discontinuity of the fibre





Discontinuity of the fibre

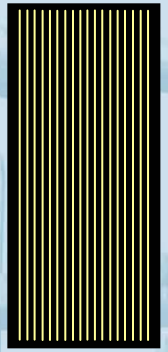


Walter Liese 1998

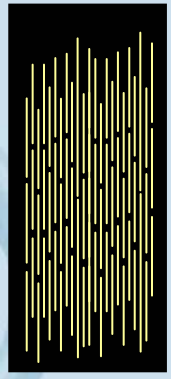
Length of internodes

(± 25 cm)

Continuous and discontinuos UD prepreg



Continuous UD prepreg

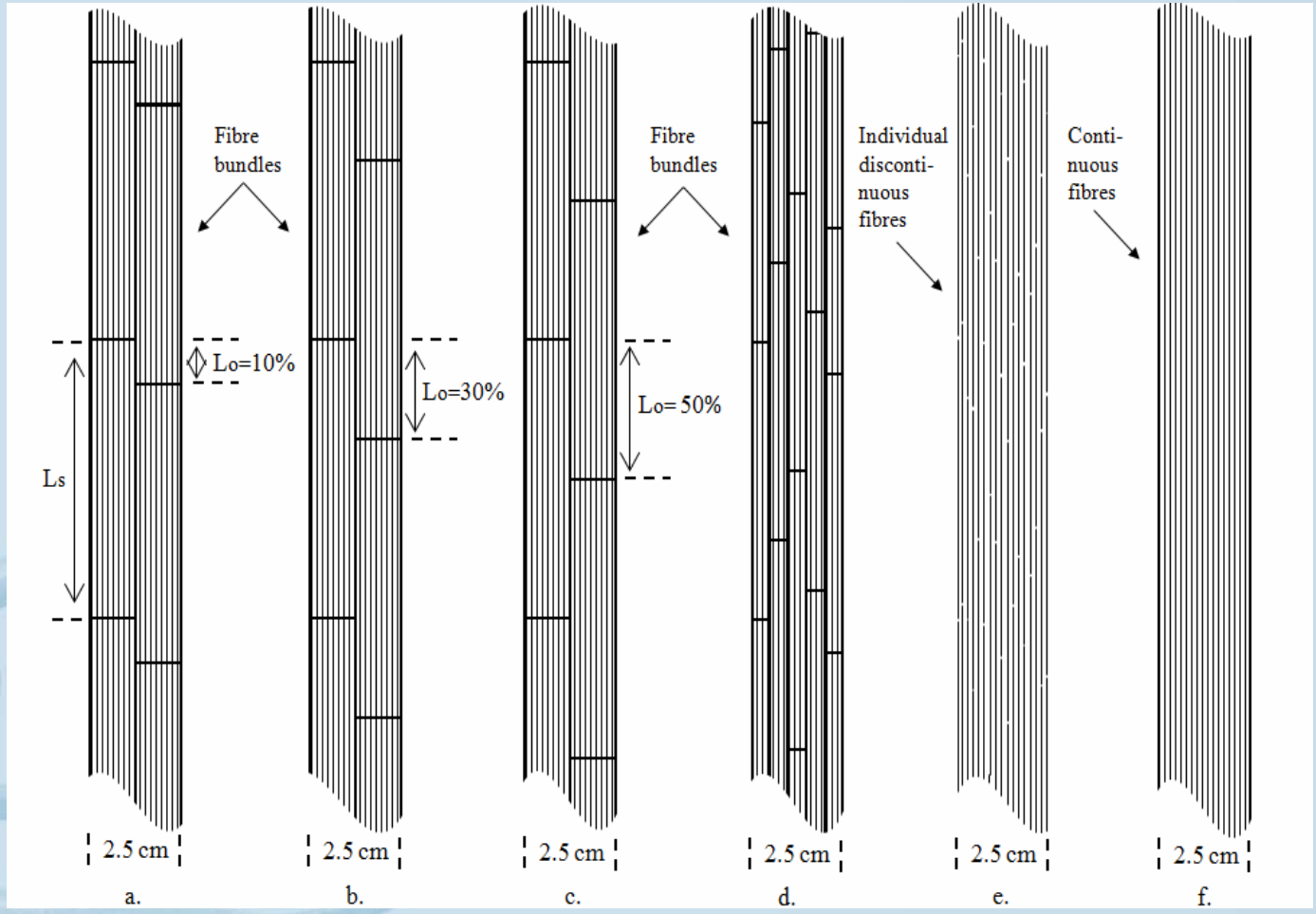


Discontinuous UD prepreg

UD bamboo fibre - TP tape

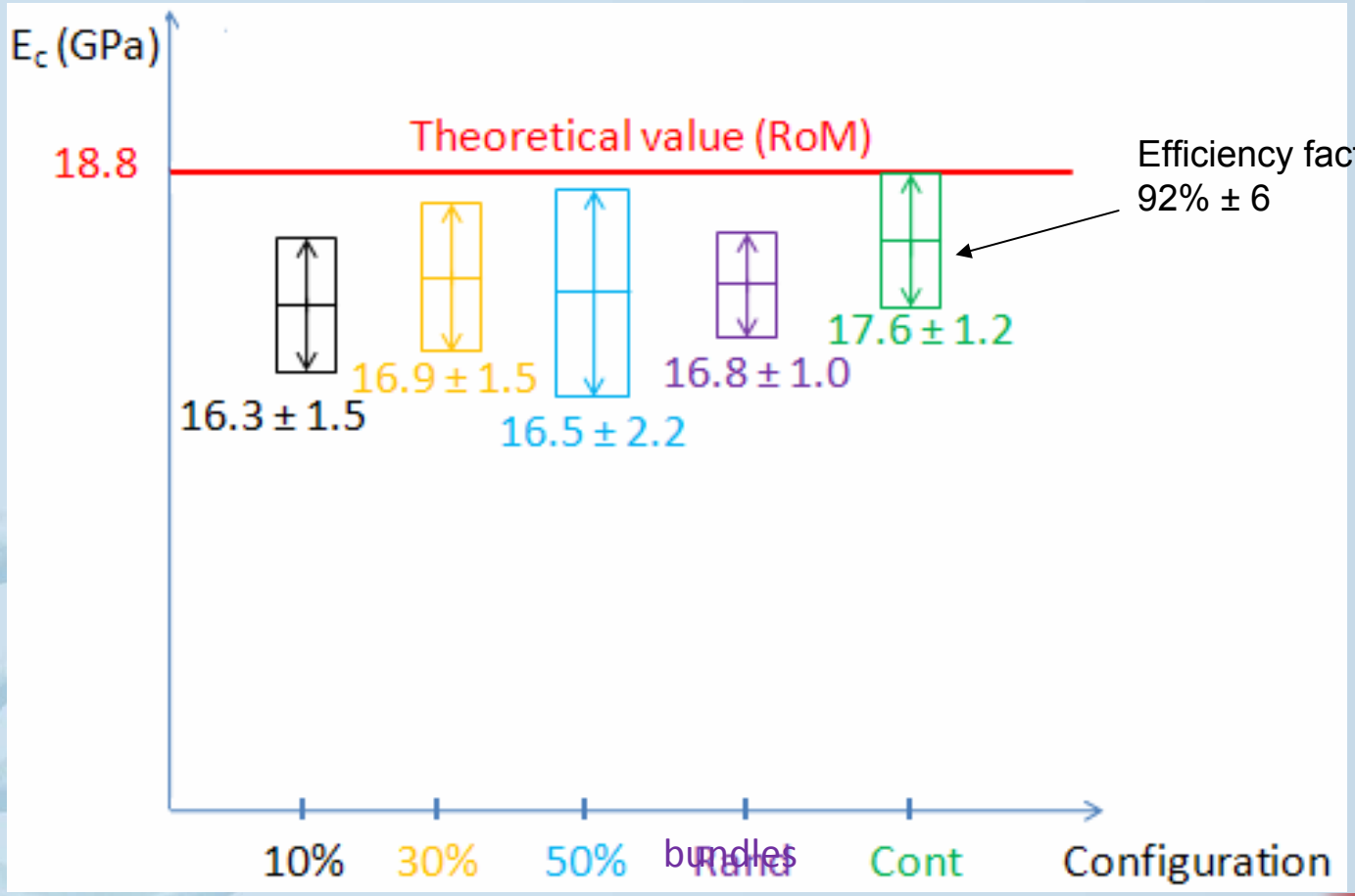
Unidirectional discontinuous BF/epoxy composites

Fibre patterns



Unidirectional discontinuous BF/epoxy composites

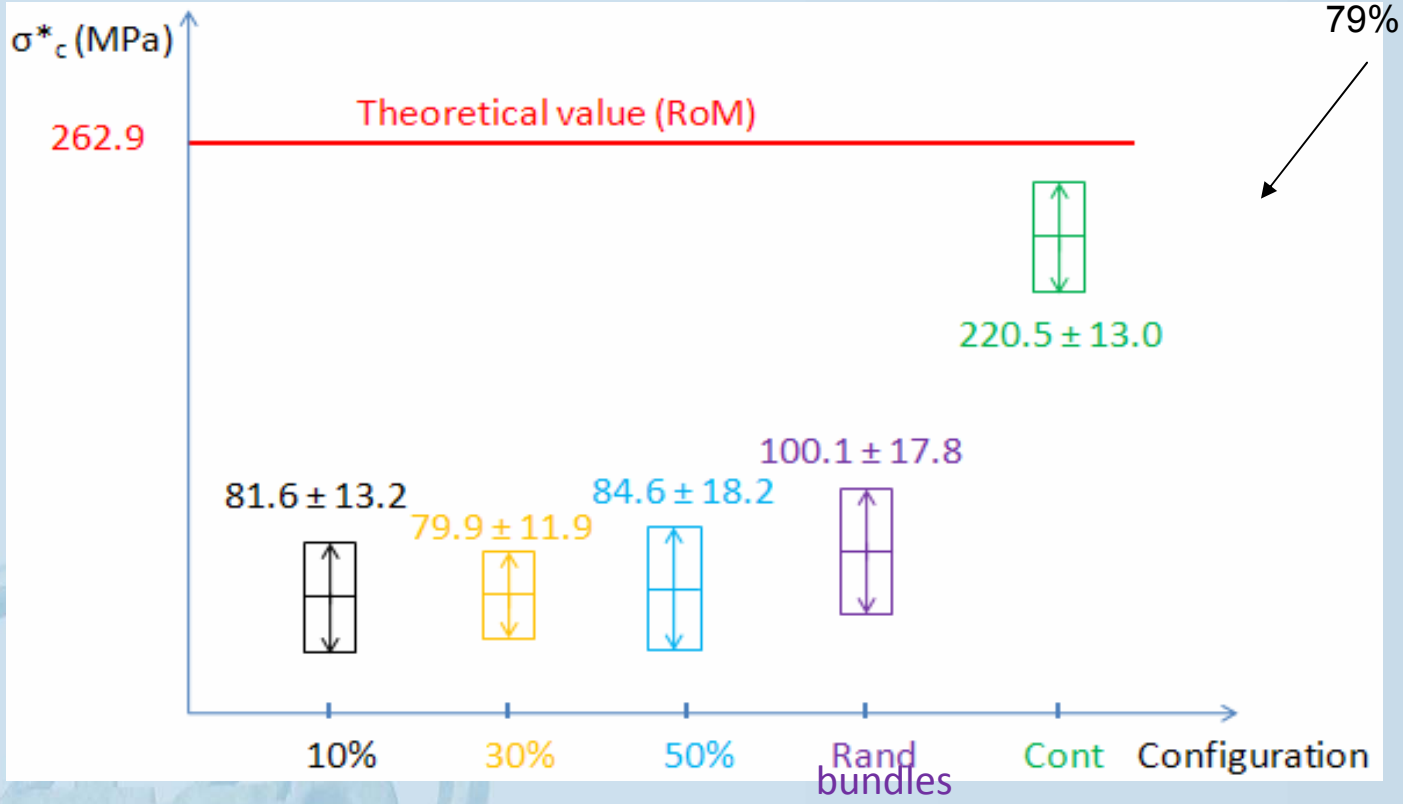
Experimental results: Tensile stifness



Unidirectional discontinuous BF/epoxy composites

Experimental results: Tensile strength

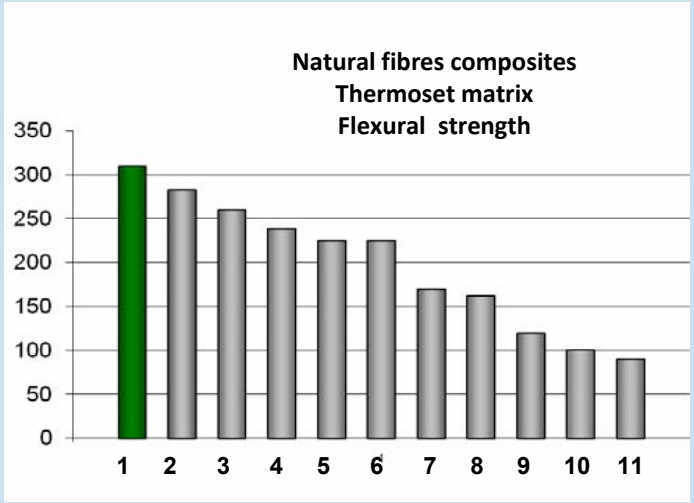
Efficiency factor:
79% ± 4



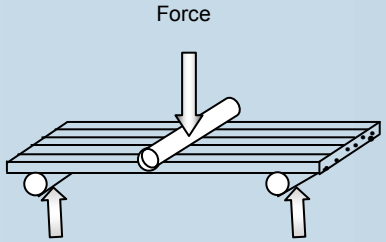
Good agreement with "The local load sharing (LLS) model"

Unidirectional discontinuous BF/epoxy composites

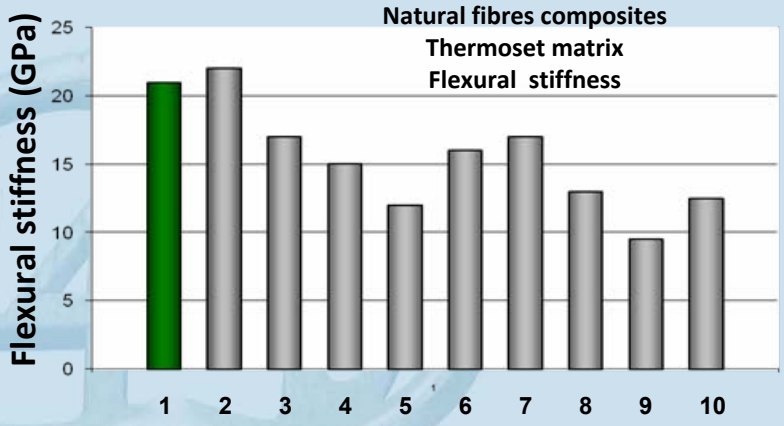
Experimental results: Flexural strength



1. Bamboo (G. ang.) + Epoxy (Vf: 40%)
2. Flax + Epoxy (Vf: 40%)
3. Jute + Epoxy (Vf: 40%)
4. Jute + Vinylester (Vf: 35%)
5. Hemp + Epoxy (Vf: 35%)
6. Sisal + Epoxy (Vf: 37%)
7. Kenaf + Cashew nut Shell (Vf: 64%)
8. Bamboo + Polyester (Vf: 15%)
9. Kenaf + Polyester (Vf: 60%)
10. Hemp + Polyester (Vf: 60%)
11. Hemp + Cashew nut Shell (Vf: 65%)



3 point bending test



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7. Kenaf + Cashew nut Shell (Vf: 64%)
8. Kenaf + Polyester² (Vf: 60%)
9. Hemp + Polyester (Vf: 60%)
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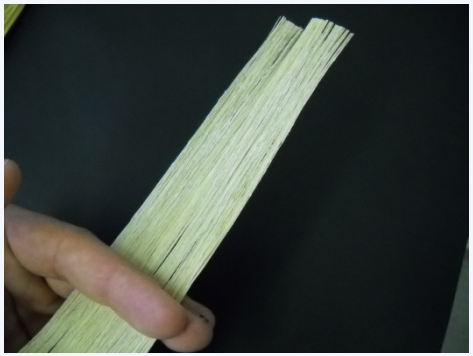
Bamboo fibre composites →
- Discontinuity of the fibre
- Properties

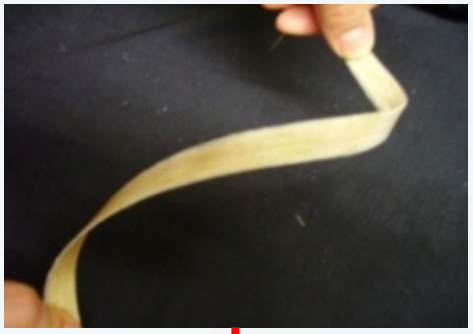
The future →
- **Applications**
- **Pros and cons**

Conclusions

Applications



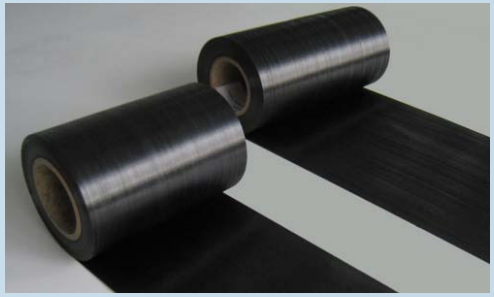
Continuous tape



Continuous "tape" of aligned bamboo fibres to make composite materials

Glass fibre

This "tape" is currently used in composites industry



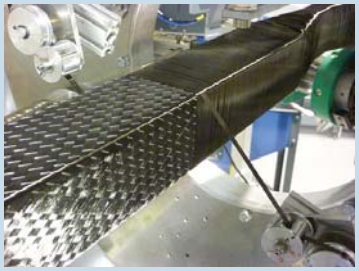
Carbon fibre

Applications

Continuous "Tape"

Further Hi- Tech applications

Semi-esructural composites market



Picture: http://www.ircomas.org

Fotobron: http://www.lineo.eu/

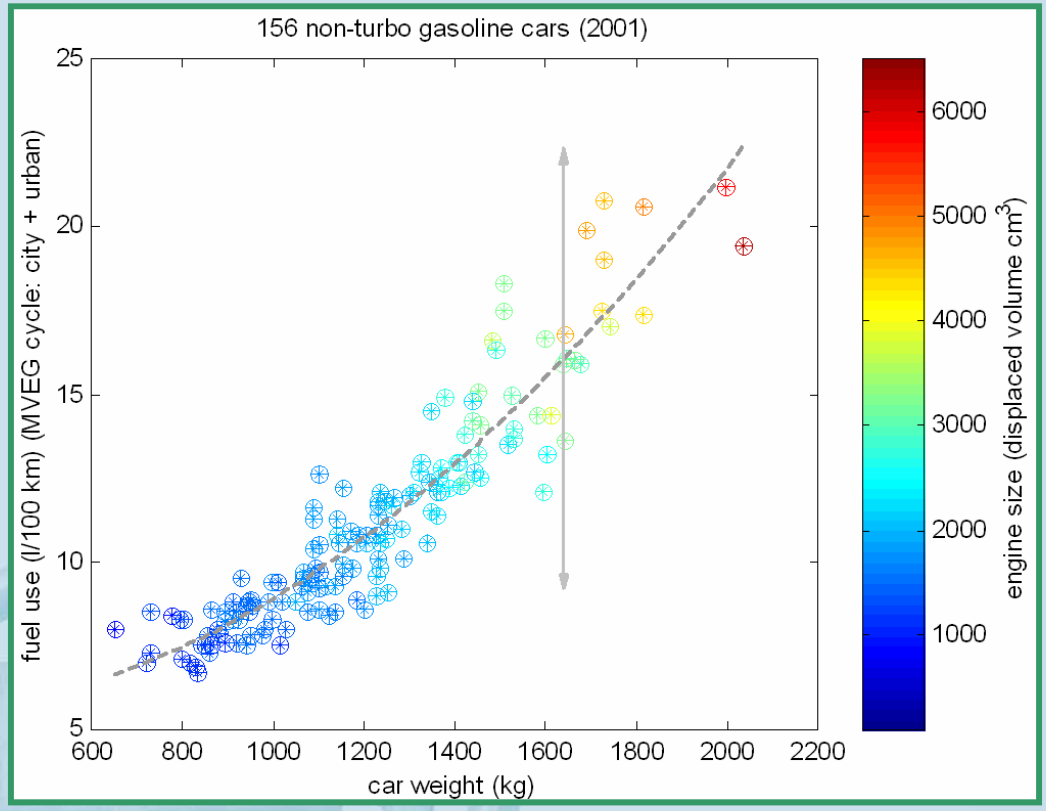
Picture: JEC - 2011

Picture: http://www.ircomas.org

- Broader range of applications
- High adaptability to existing composites technologies
- Green choice

Applications

Lighter cars … reduce energy consumption!



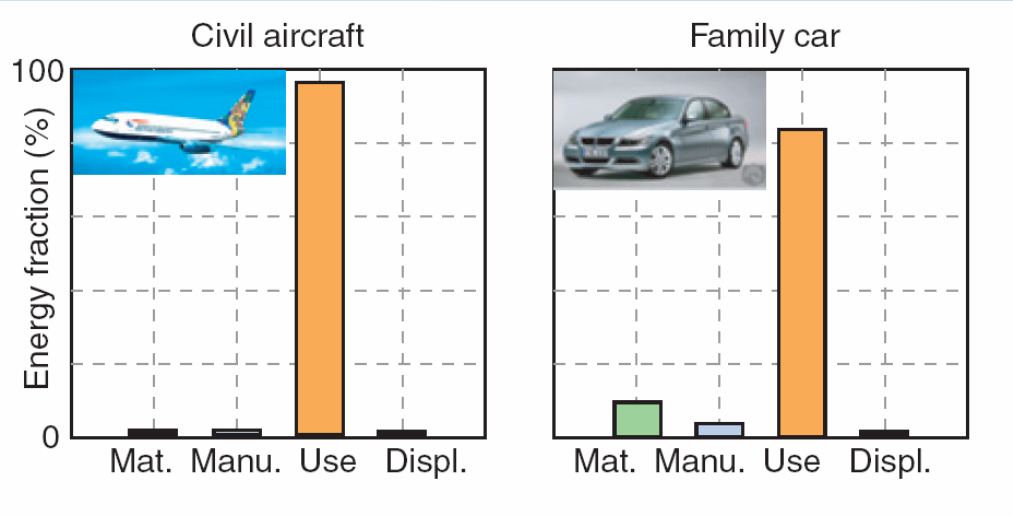
Sorce: KULeuven: De Moor Jozef, 2008

In all moving applications, the energy consumption is ± proportional to the **mass**…

… hence **mass** reduction is needed !!!

Applications

The 4 phases in the life of a product and their relative importance



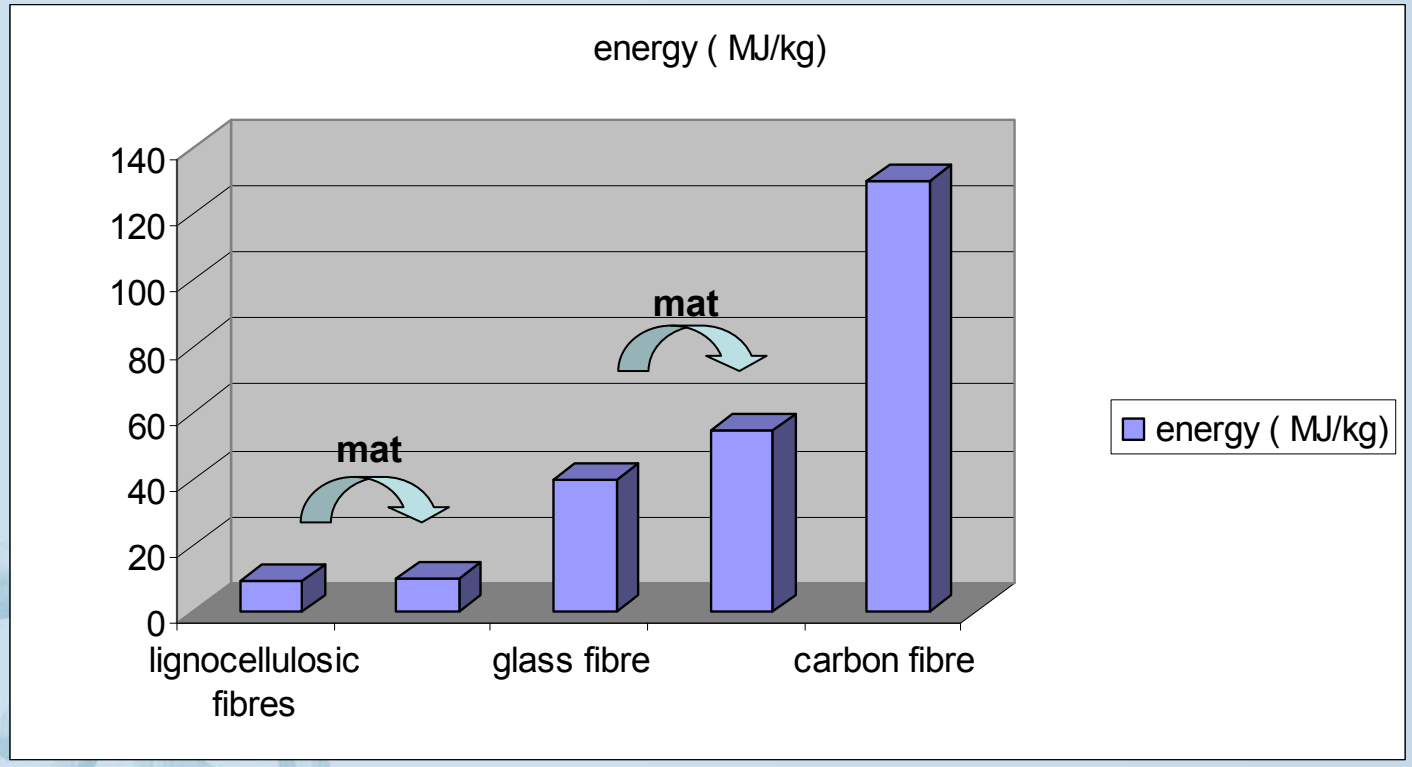
Source: Ashby, M. et al. Materials engineering, science, processing and design (2007)

In the total life cycle, these 4 aspects have a different impact, depending on the application area

In "moving" applications the **use** efficiency is most important

Applications

Energy content of natural fibres

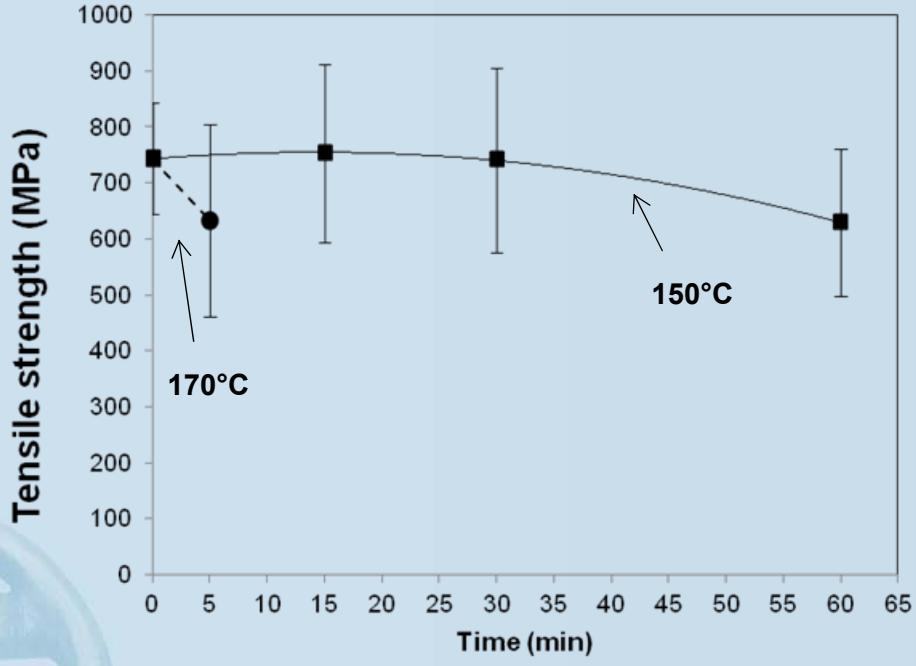


Hemp can store about 0.75 kg of CO_2 per kg of fibres during growth

Hemp releases 10 MJ/kg upon incineration (with energy recovery)

Disadvantages

Thermal degradation (bamboo fibres)



Moisture absorption

Conclusions

Good mechanical properties for bamboo fibres were obtained by using a **novel green mechanical extraction process**

Composites based on extracted long bamboo fibres and epoxy resin were **successfully produced**

Performance in terms of strength and stiffness reach: 78% and 95% of the theoretical value (ROM)

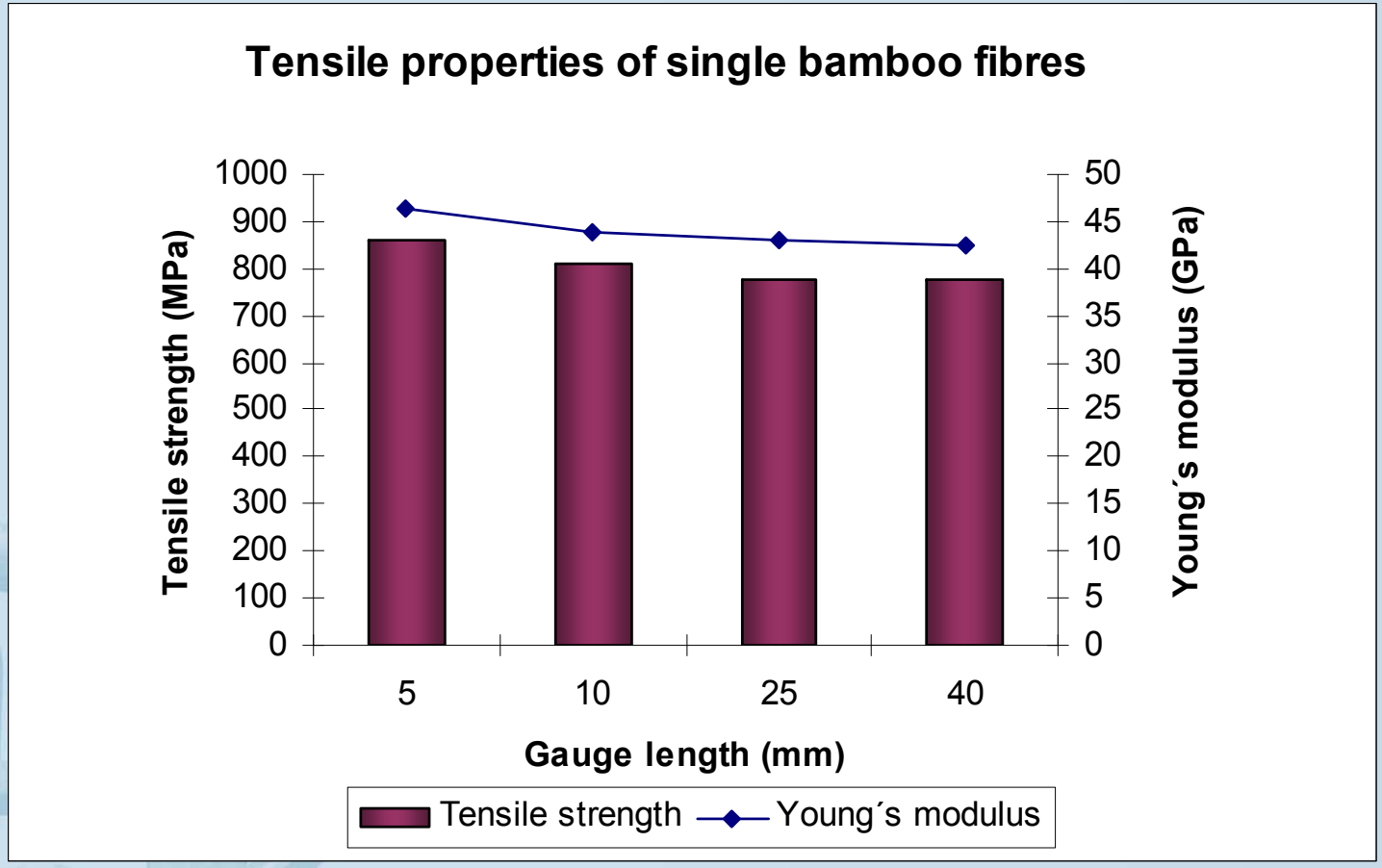
Future work: Research in progress - further **technology development** is required

Thank you!

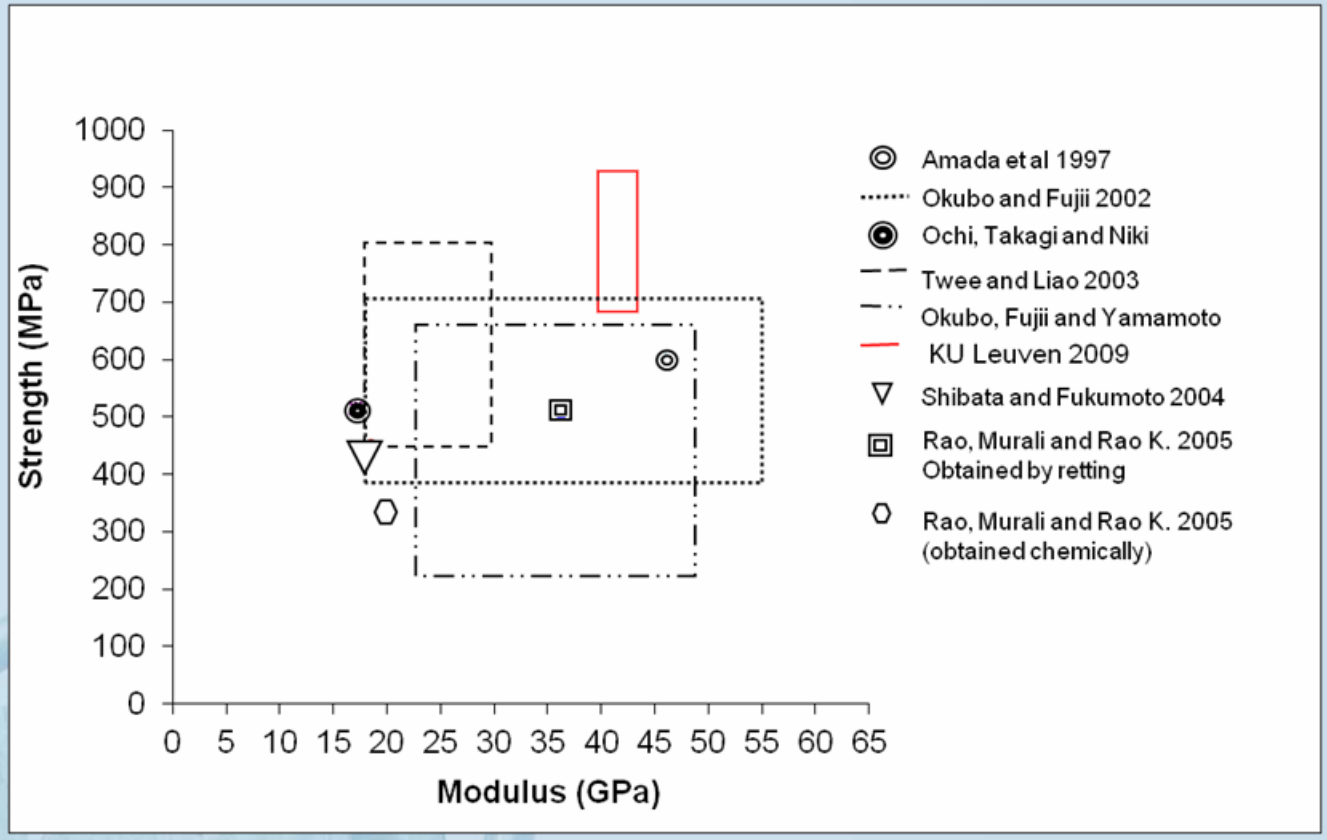
Annexes

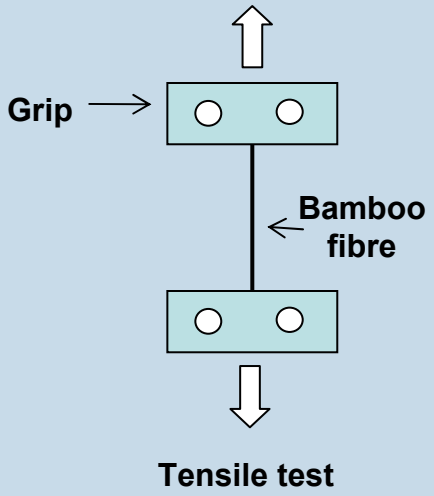
2. Fibre properties

2.2 Results for single bamboo fibre tensile test



Comparison with other studies (bamboo fibres)





Strength vs Modulus from some studies on bamboo technical fibres

Bamboo fibre extraction process

Fibre extraction

- In line process (continuous)
- No seasonal resource (“all year harvesting”)
- High fibre extraction yield

↓ Competitive Price

Target value

Ligth RTM

Advantages:

•Accurate determination of Vf

• Control of the thickness

• Two flat surfaces

•Easy positioning (stacking) of the fibres

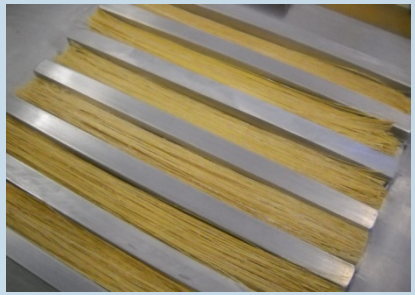
Test and samples:

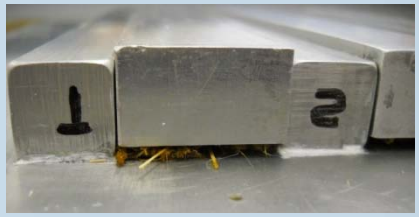
• ASTM 3039 (tensile test)

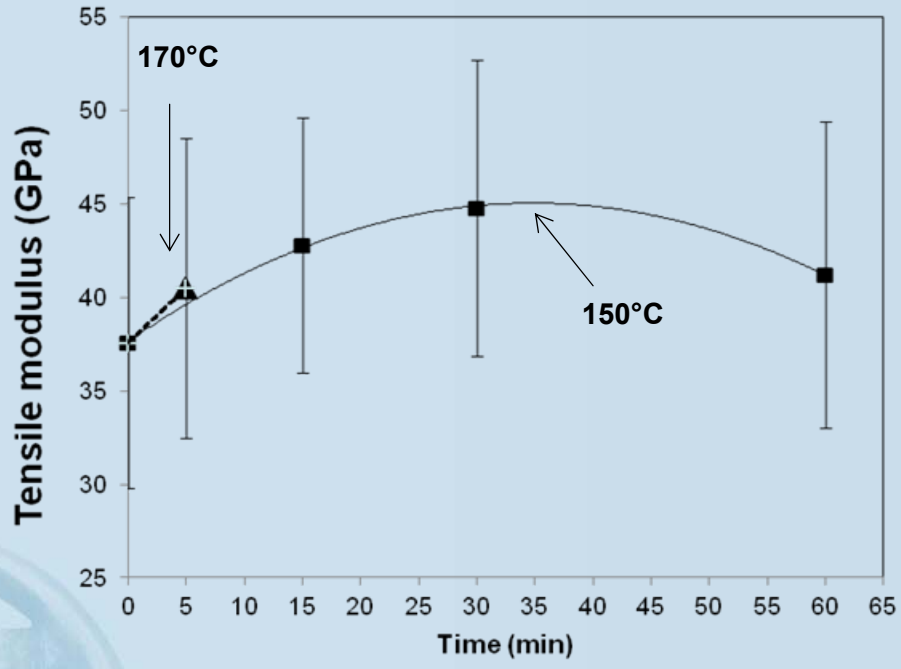
• Dimensions: Length: 26 cm, width: 2.5 cm, thickness: 1.8 mm

• Vf: ~45%

• 6 samples / pattern






170°C
150°C
Tensile modulus (GPa)
Time (min)
55
50
45
40
35
30
25
0
5
10
15
20
25
30
35
40
45
50
55
60
65