Natural Fibre Composites;
Recent Developments

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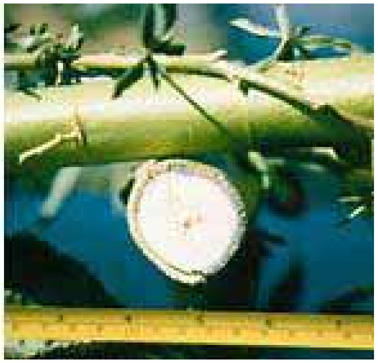
Flax


Hemp


Kenaf


Sisal

Introduction

What? Focus on natural FIBRES

* with Thermoplastic and Thermoset polymer matrices

* with Biodegradable and non-Biodegradable matrices

* with natural, bio-based (“renewable”) and petroleum based (“synthetic”) matrices

What is a “Green” Composite?

Term “Bio-composites” usually reserved for bio-compatible, medical composites

Introduction

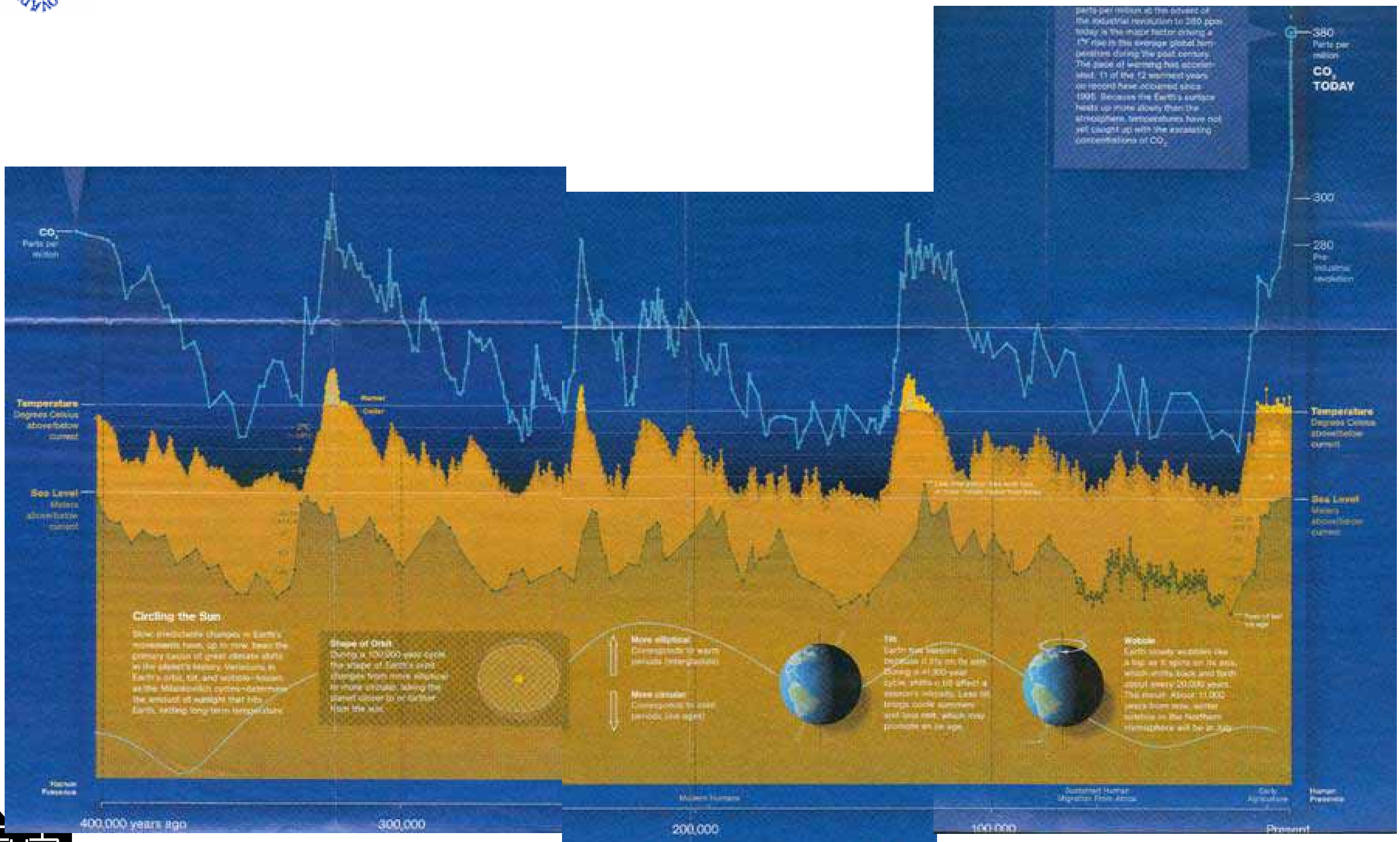
Why?

1) Environmental reasons:
   - Renewable resources
   - Thermally recyclable, biodegradable, **CO_2 neutral**
   - Low energy consumption (low CO_2)

   So: low “Carbon footprint”

2) Cost: often (potentially) low cost (not silk)
3) Health & safety: less abrasive, more pleasant to handle
4) Good specific mechanical properties
5) Natural image, design aspects
6) Others, like good acoustic damping, low CTE

Introduction; Carbon footprint



Introduction

Some data on energy utilisation for fibre production:

Lignocellulosic fibres:	4-15 MJ/kg
Natural Fibre Mat:	9.7 MJ/kg
Glass Fibre:	30-50 MJ/kg
Glass Fibre Mat:	55 MJ/kg
Carbon Fibre:	130 MJ/kg

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)

Introduction

How?

* First focus on fibres (starting with traditional matrices)

* Replacement of synthetic fibres, particularly glass; opening opportunities for composites in developmental countries

When?

• Last 10 – 15 years!

Who?

• Europe: automotive: flax and hemp and “exotic fibres” (jute, sisal, ananas, coir)

• USA: Wood Polymer Composites (WPC): recycled wood dust and plastic waste: deckings

• Developmental world: cheap local fibres instead of glass fibre

Introduction, Applications

Where?

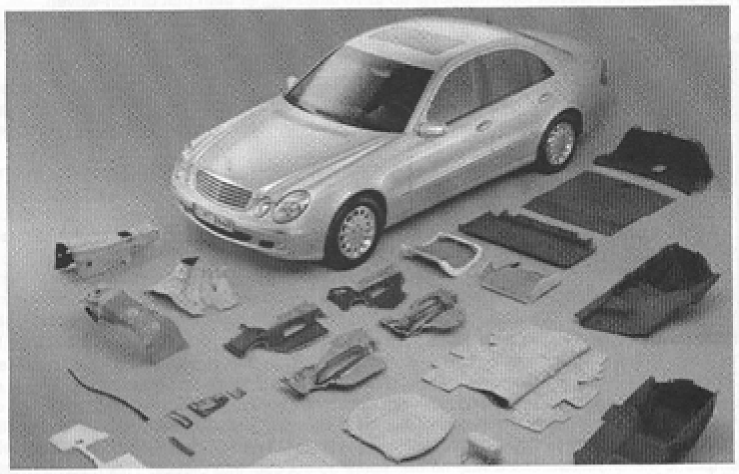


Figure 2.4 Flax, hemp, sisal, wool and other natural fibers are used to make interior Mercedes-Benz E-Class components. (www.daimlerchrysler.com)

Mixed natural fibres with PP and UP matrices

Flaxcat (NPSP)
Flax fibre
catamaran

Jute-coir hybrid composite panels

Renault Ellypse concept car: natural fibres for acoustic damping

Applications

Flax-Carbon hybrid bike (JEC 2007)
(prepreg technology)

Jute-PP suitcase (latex impregnation)

Mixed NF - PP (Injection Moulding)

Mixed NF – PP? inner door panel(s)

Issues (of Research!)

1) Fibre properties:

* Understanding mechanical properties: e.g. why is silk so tough?

* Natural variability: H2 control cultivation and minimise weather impact?

* Moisture sensitivity: Make fibres more hydrophobic?

* Temperature resistance

2) Environmentally friendly ***matrices:***

* Biodegradable?

* from renewable resources

3) ***Interface:***

* New materials, so research needed to compatibilise (wetting and adhesion)

* Optimising physical-chemical characteristics (surface tensions)

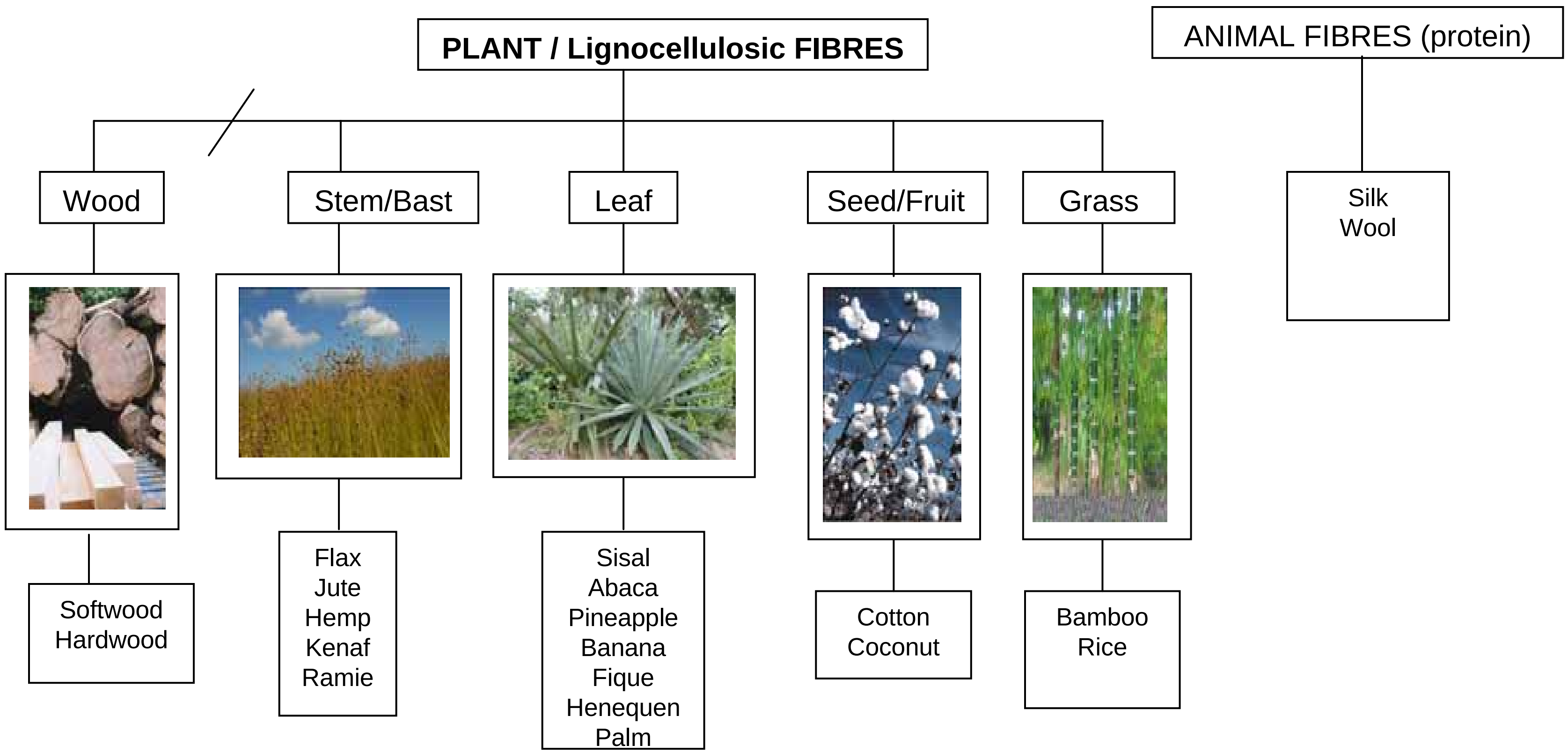
* complex fibre surfaces

Issues (of Research!)

4) ***Processing***

- Extraction and separation: How not to damage the technical fibres?
- Control of fibre length and orientation
- Managing moisture: prevent steam & foam formation!
- Composite processing: usually same processes as for Glass and Carbon

Natural Fibres



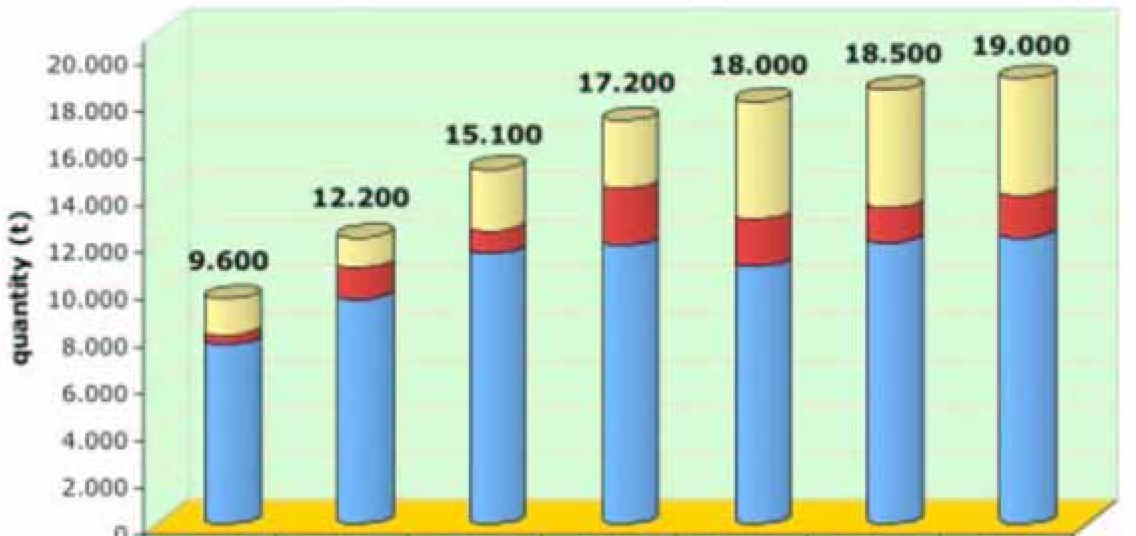
Natural Fibres, Quantities

Estimated annual production, in millions of tons:

Wood	1750	
Steel	800	
Cement	(800)	(before China boom)
Plastics/polymers	120	
Composites (polymer)	1.5	mainly glass fibre composites
Glass fibre (composites)	0.6	at 42 wt% in composites
Carbon fibre	0.035	(= 35,000 tons)
Synthetic fibres	30	
Natural fibres	27	
WPC	(0.5)	extrapolated from 0.1 in Europe
Plant fibre in composites	0.040	in automotive applications Europe

Natural fibres; Quantities

Use of Natural Fibres* for Composites in the German Automotive Industry 1999-2005



	1999	2000	2001	2002	2003	2004	2005
Total	9.600	12.200	15.100	17.200	18.000	18.500	19.000
Exotic Fibres	1.548	1.279	2.618	2.895	4.995	5.000	5.000
Hemp	372	1.350	913	2.416	2.012	1.500	1.800
Flax	7.680	9.571	11.569	11.890	10.993	12.000	12.200

year

* without wood and cotton

2000 all Europe automotive: 28,000 tons of NF

Natural Fibres; properties

material	density (g/cm²)	tensile strength (MPa)	Young's modulus (GPa)	elongation at failure (%)
B. mori silk	1.3-1.38	650-750	~16	18-20
Spider silk	1.3	1300-2000	~30	28-30
flax	1.45	500-900	50-70	1.5-4.0
hemp	1.48	350-800	30-60	1.6-4.0
kenaf	1.3	400-700	25-50	1.7-2.1
jute	1.3	300-700	20-50	1.2-3.0
bamboo	1.4	500-740	30-50	~2
sisal	1.5	300-500	10-30	2-5
coconut/coir	1.2	150-180	4-6	20-40
E-glass	2.5	1200-1800	72	~2.5
Carbon	1.4	~4000	235	~2
Kevlar 49	1.44	3600-4100	130	~2.8

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	Gluten resin? Starch based emulsion?	Corn based TP polyester PLA, PLA-L PHA, PHB Starch based polymers Soy protein resin	PBS PCL PVA
Non-biodegradable	Cashew nut shell resin?	Furan resin Vegetable oil -PUR (polyol) Wood based epoxy resin Epoxidised soy oil? Ethanol based PE	Most well-known polymers: PP, PE, nylons, etc. Epoxy, UP

- Research on renewable matrices is relatively recent
- Existing systems often have relatively poor mechanical properties

Matrices; commercial bio-based polymers

Table 7.1 Summary of commercially available polylactides, polyhydroxyalkanoates and starches or starch blends

Polymer type	Manufacturer	Product name
Polylactides	Biomer	
	Birmingham Polymers, Inc.	Lactel, Absorbable
	Boehringer Ingelheim	Resomer®
	Cargill-Dow LLC	NatureWorks™
	Galactic SA	Galactic
	Hycail	
	Mitsubishi Plastics, Inc.	Ecoloju
	PURAC	Purasorb®
	Shimadzu Corporation	Lacty
Polyhydroxyalkanoates	Biomatera Inc.	
	Biomer	
	Metabolix, Inc.	PHA, Biopol®
	Procter & Gamble	Nodax™
	PHB Industrial S/A	
Starch	Avebe	Paragon
	BioPlastic (Michigan)	Envar
	BIOTEC GmbH	Bioplast®, Bioflex®, Biopur®
	Earth Shell	Starch-based composite
	Groen Granulaat	Ecoplast
	Hayashibara Biochemical Labs	Pullulan
	Midwest Grain Products	Polytriticum® 2000
	National Starch	Eco-Foam®
	Novamont	Mater-Bi
	Rodenburg Biopolymers	Solanyl®
	Starch Tech	RenEW,ST1,ST2,ST3
	Supol	Supol
	Vegemat	Vegemat®

Sources include: Mohanty *et al.* (2000b), Johnson *et al.* (2003a), www.biopolymer.net.

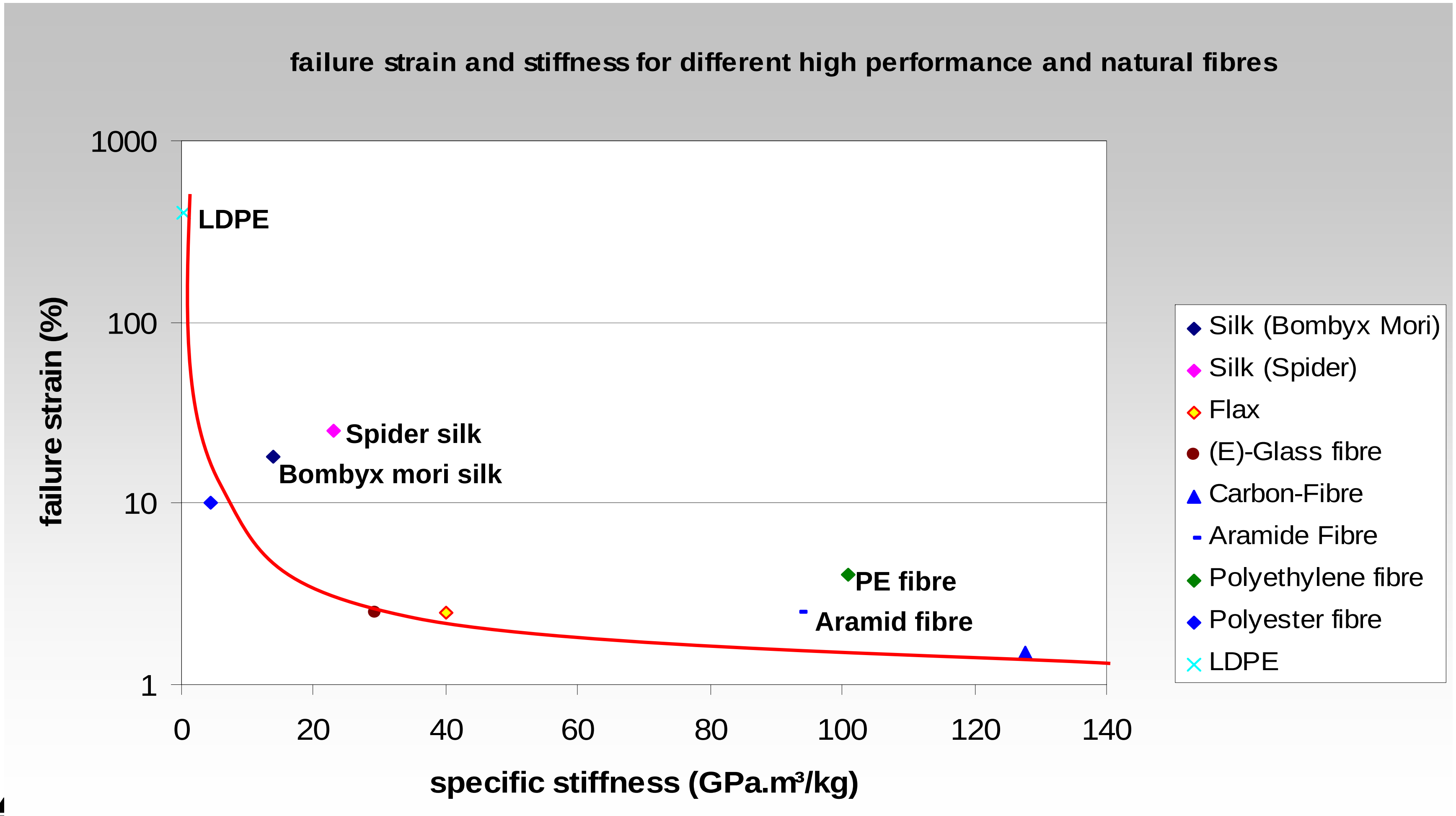
Case studies; Research at KU Leuven

1) Silk composites: tough
2) Flax&hemp composites: high performance
3) Bamboo composites: Glass replacement
4) Coir composites: cheap and abundant
5) Wood – PVC compounds and extruded profiles
6) Paper honeycomb panels

1) (Renewable gluten based resin)
2) (Tree bark fibre composites (Art Nature Design))
3) (Jute composites (VLIR project Bangladesh))
4) (Natural Fibre panels for landmine protection)

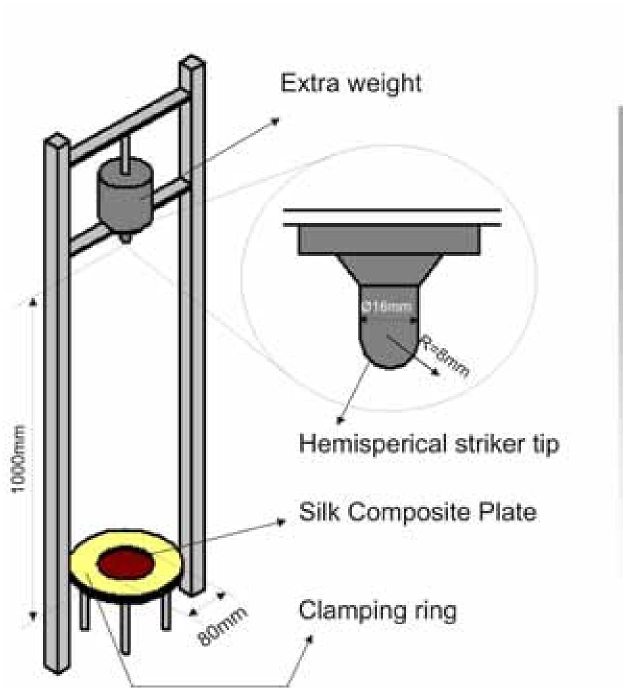
1) Silk composites

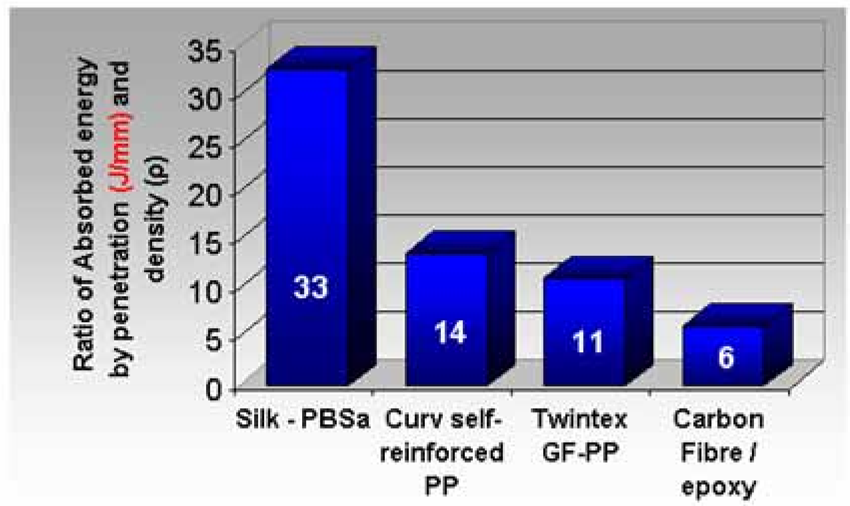
What makes silk fibres special?



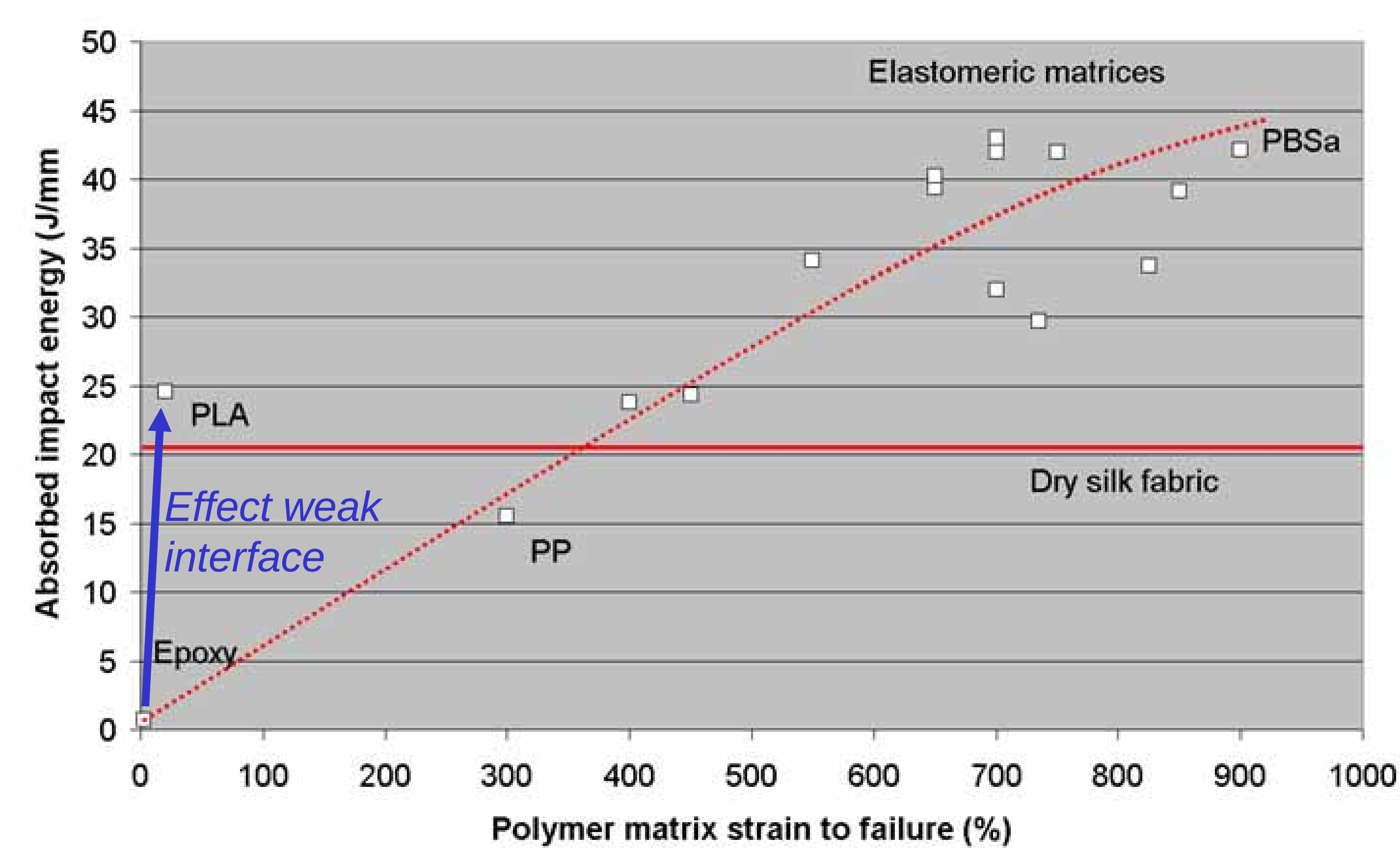
1) Silk composites

Excellent falling weight impact performance!





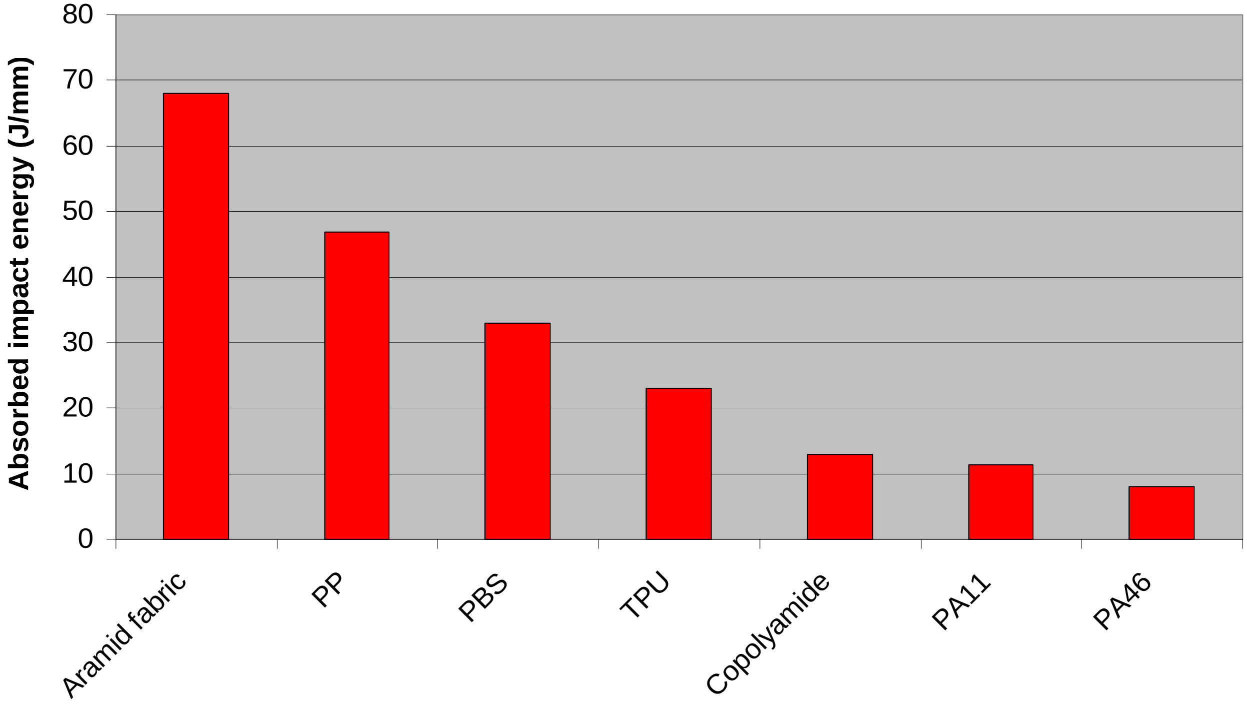
1) Silk Composites



* No clear indication of effect interface strength for tough matrices

1) Silk Composites

Effect of polymer matrix, aramid fabric composites

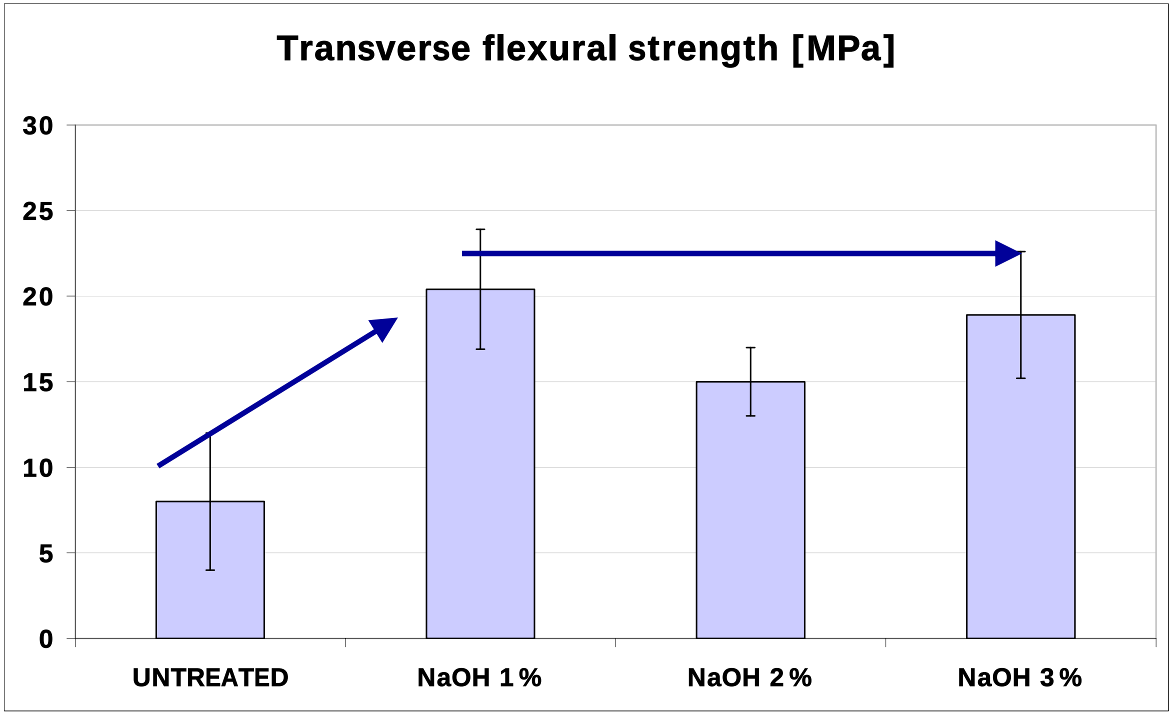


• Hypothesis is that interface properties (impregnation and adhesion) play a crucial role here (weakest is best..)

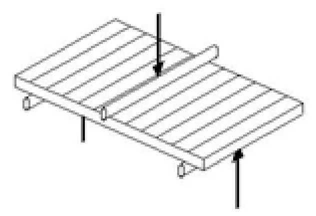
(all matrices have relatively high strain to failure here)

2) Flax fibre composites

Flax-epoxy



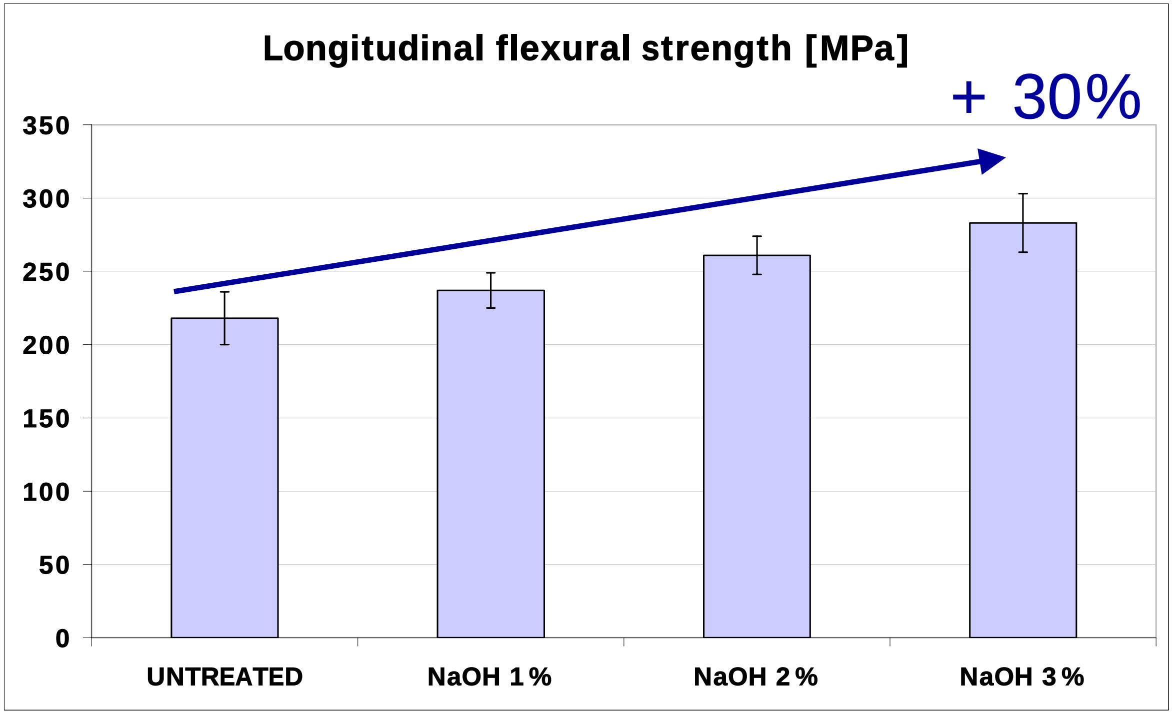
V_f: 40 vol%
Time: 20 min



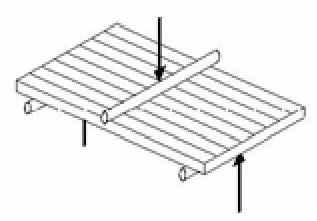
Alkali treatment leads to stronger interface

2) Flax fibre composites

Flax-epoxy



V_f: 40 vol%
Time: 20 min



Fibre treatment with alkali leads to better interface strength

3) Bamboo fibre composites

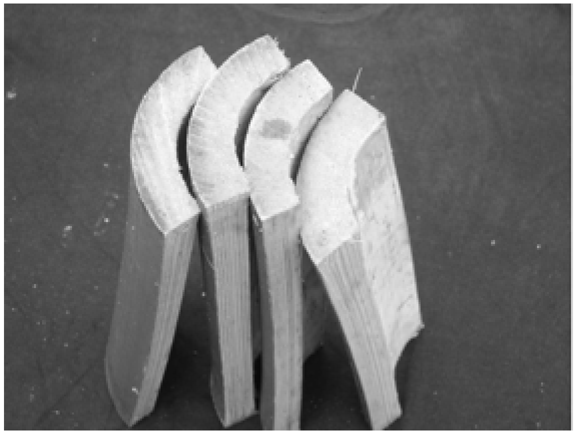
Projects with Columbia and Vietnam (BelSPO)

Extraction of technical bamboo fibres (length ~ 30 cm !):

• Existing processes such as steam explosion and mechanical crushing lead to extensive fibre damage

• New process developed in Columbia and at KU Leuven:

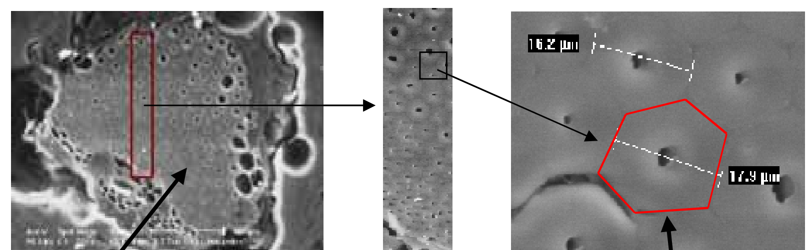
* Strongly reduced fibre damage

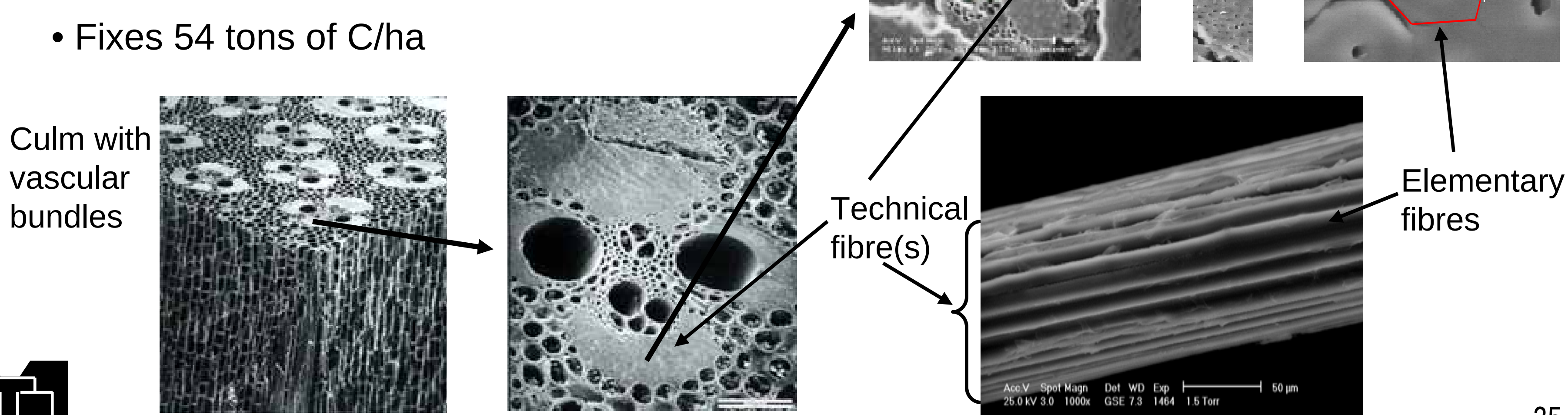


3) Bamboo fibre composites

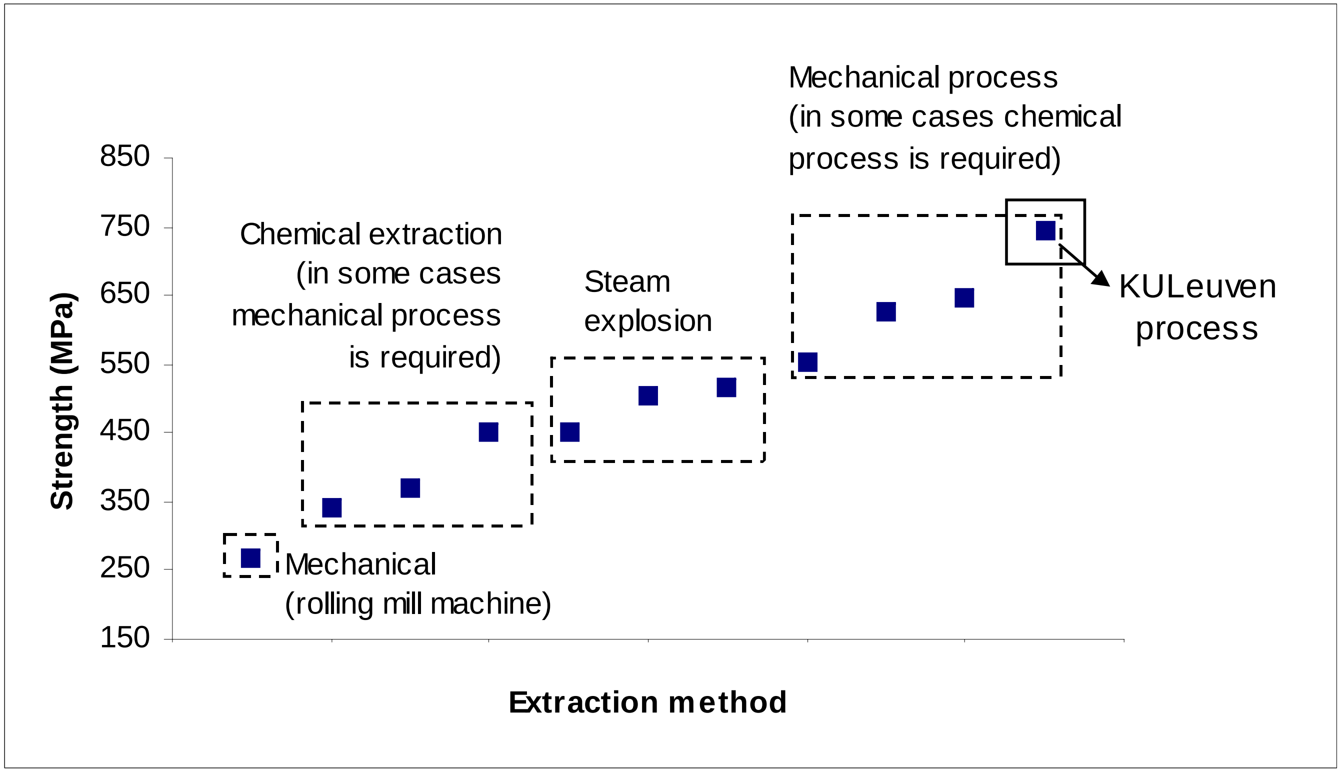
Guadua Angustifolia

- Growth up to 20 cm/day
- Grows to 20 m in 6 months
- Matures in 4 years; can be used after 1 year
- Fixes 54 tons of C/ha

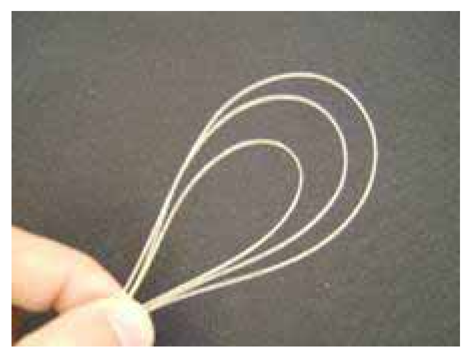




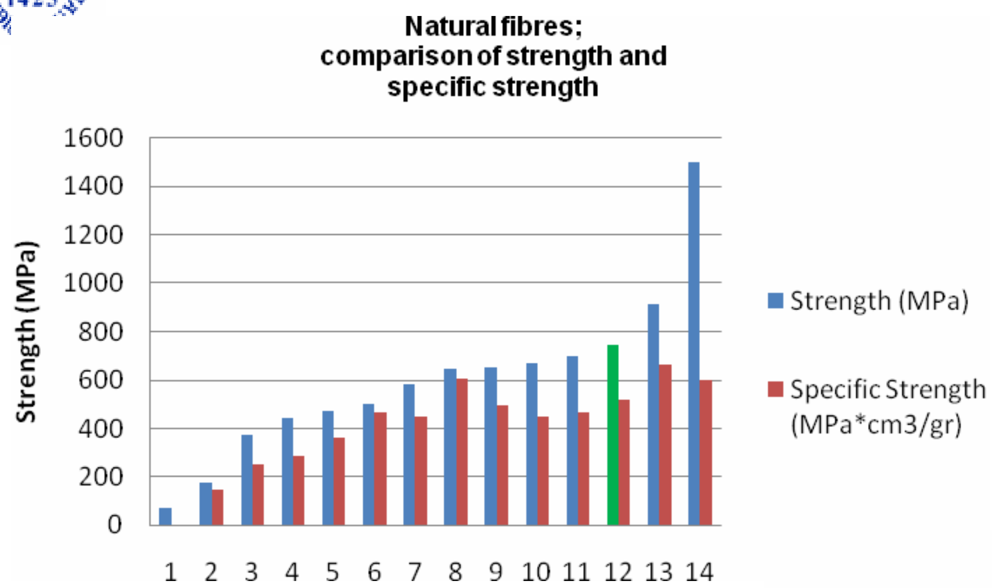
3) Bamboo fibre composites



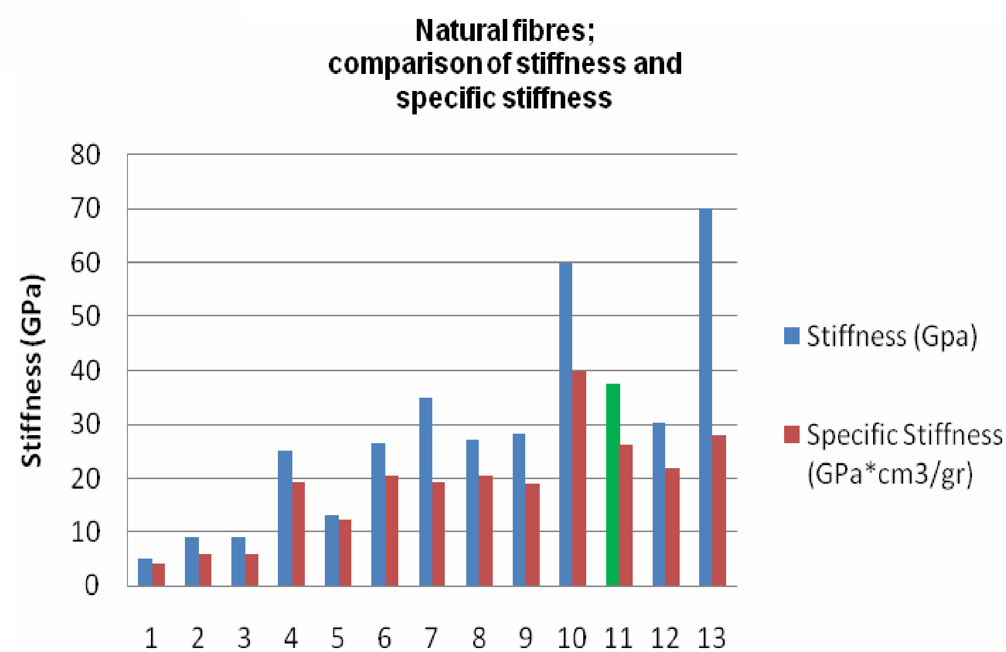
Loop test



3) Bamboo fibre composites



1. Bagasse
2. Coir
3. Sisal
4. Cotton
5. Kenaf
6. Henequen
7. Jute
8. Hemp
9. Pineapple
10. Ramie
11. Flax
12. Bamboo
13. Curauà
14. E-Glass



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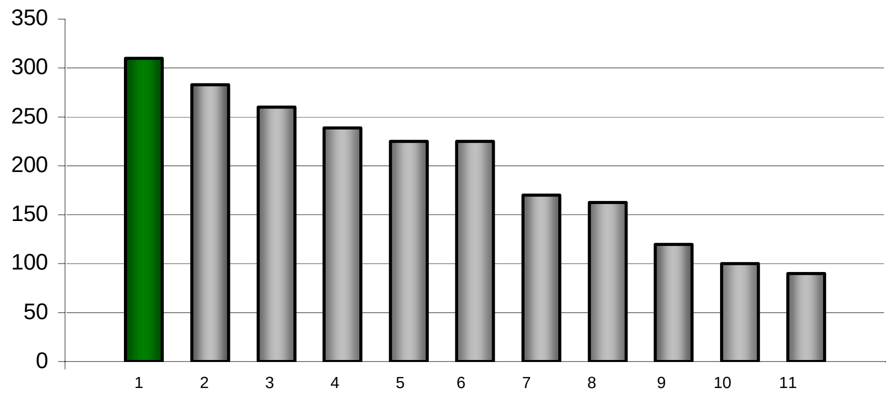
3) Bamboo fibre composites

Natural Fiber composites
Thermoset matrix
Flexural strength



1. Bamboo (G. ang.) + Epoxy
2. Flax + Epoxy
3. Jute + Epoxy
4. Jute + Vinylester
5. Hemp + Epoxy
6. Sisal + Epoxy
7. Kenaf + Cashew nut Shell
8. Bamboo + Polyester
9. Kenaf + Polyester
10. Hemp + Polyester
11. Hemp + Cashew nut Shell

Figure 67. Flexural strength comparison between UD bamboo+epoxy (V_f 48%) and UD natural fibres+thermoset matrix composites; V_f 35% - 60%

Good performance for *untreated* bamboo in epoxy

- Only limited effect of alkali treatment

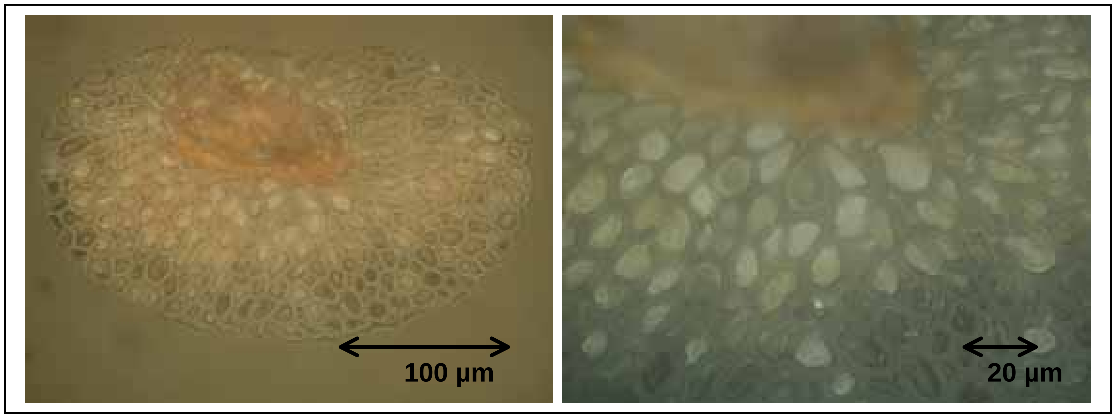
Good adhesion for untreated bamboo in epoxy:

- Stiffness and strength in longitudinal direction as expected (V_f)
- Transverse flexural strength quite good at around 35 MPa

4) Coir composites

Project with Vietnam (BelSPO)

1) Measuring basic mechanical properties + microscopic examination
2) Understanding the interfacial adhesion: measurement of contact angles (direct measurements and with Wilhelmy set-up)



Light microscope pictures of technical coconut fibre

5) Wood-PVC

Market for WPC's is strongly growing, especially deckings in the USA

• Wordwide market around $ 2 billion

• Europe 2005 about 100,000 tons, growing at 10-20% / year

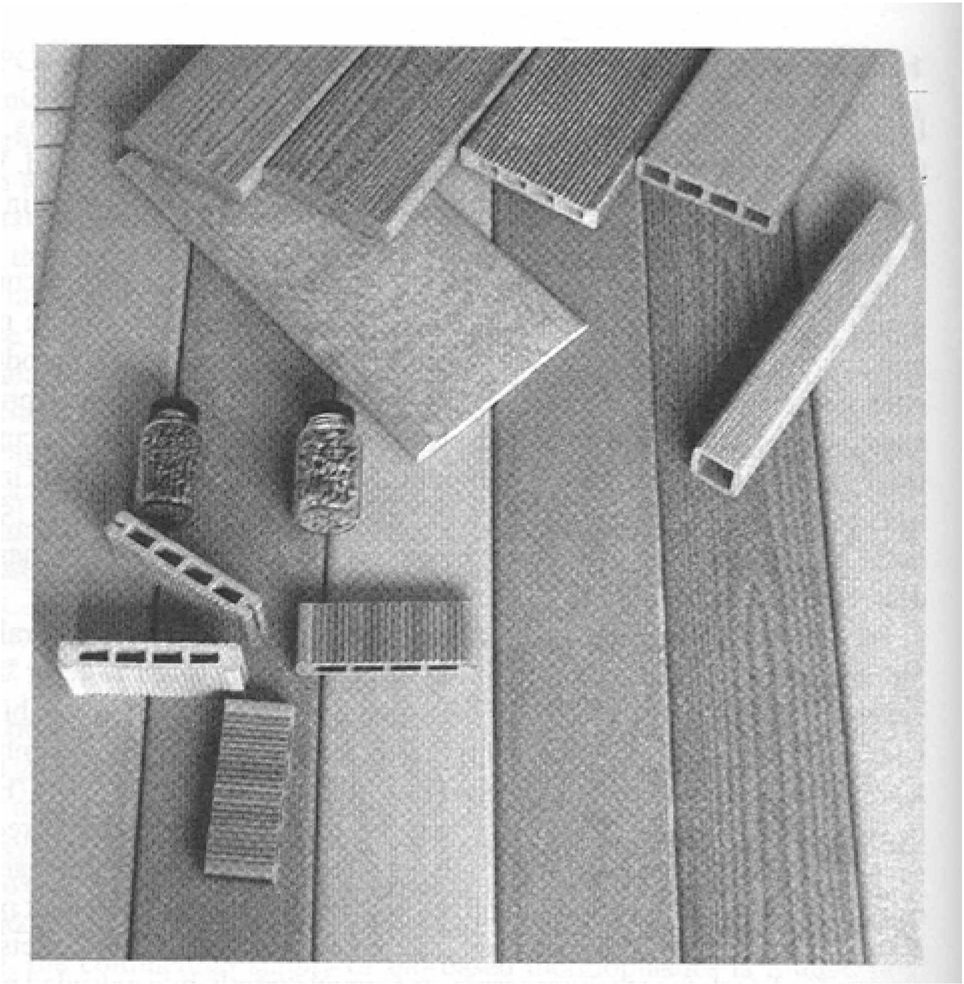
• Started with recycled wood dust and recycled PE and PP (e.g. agricultural waste foil)

• e.g. Deceuninck in Belgium has launched wood-PVC for deckings and other extruded profiles

• environmental benefits e.g.

* replacement for (tropical) hardwood

* replacement for treated soft wood (hazardous chemicals)



6) Paper honeycomb panels

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

www.econcore.com

Bibliography

Main references for this text:

1) Green Composites, Caroline Baillie, CRC Press, 2004

2) Natural Fibers, Plastics and Composites, Frederick T. Wallenberger & Norman Weston, Kluwer, 2004

3) Natural Fibers, Biopolymers and Biocomposites, Amar K. Mohanty et.al., CRC Press, 2005