Utilisation of Composites: An Introduction to NFCs and WPCs in Composite Applications

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What are composites?

- Composites is quite a broad term:
- Fibre or reinforcing element
- Matrix
- Different structures:
- Cross-ply lamination of fibre reinforcement
- Particulate, short fibres or platelets
- Single direction fibre or filaments
- Sandwich panels

Nature is full of examples

- Bone

- Nacre

- Wood

	E (GPa)	σ_f (MPa)
Hydroxyapetite	112	115
Collagen	2.4-9	50-100
Bone	6-20	30-150
Aragonite	72	
Chitin	40-49	
Matrix proteins	2.8	
Nacre	30-120	170-230
Cellulose	150	18
Hemicellulose	5-8	
Lignin	2.5-4	25-75
Wood, spruce	16	80

Introduction to Natural Fibre Composites

Composites comprise at least two components, often a strong stiff component embedded in a matrix

Biocomposites or Natural Fibre Composites (NFCs) can be defined as composite materials where one (or more) of the components is of biological origin

Introduction to Natural Fibre Composites

Why the interest in NFCs?

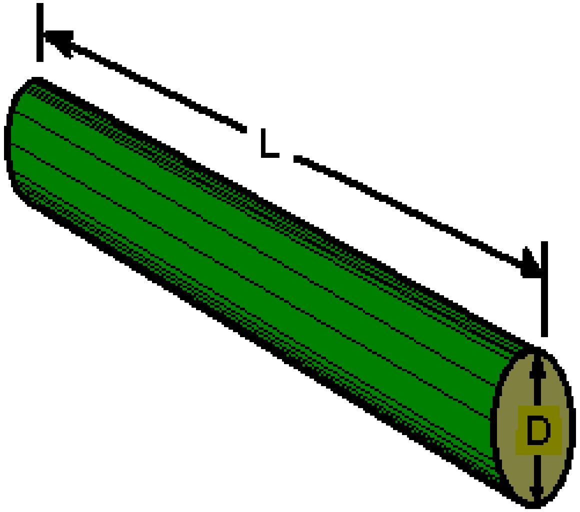
- “Green”
- Sustainable - natural fibres
- Reduced Global Warming Potential
- CO_2 sequestration / carbon storage
- Renewable
- Reduced reliance on fossil fuels
- Low embodied energy
- Enhance the properties of plastics
- Cost

Fibre Composites

- Reinforcement:
  - Usually strong and stiff
- Matrix:
  - Usually weaker and more compliant
- Interface:
  - Transfer of load from matrix to reinforcement
  - For thermoplastic matrices this is often assisted by using a compatibiliser
- Properties:
  - Can rival glass fibre on specific strength and specific modulus

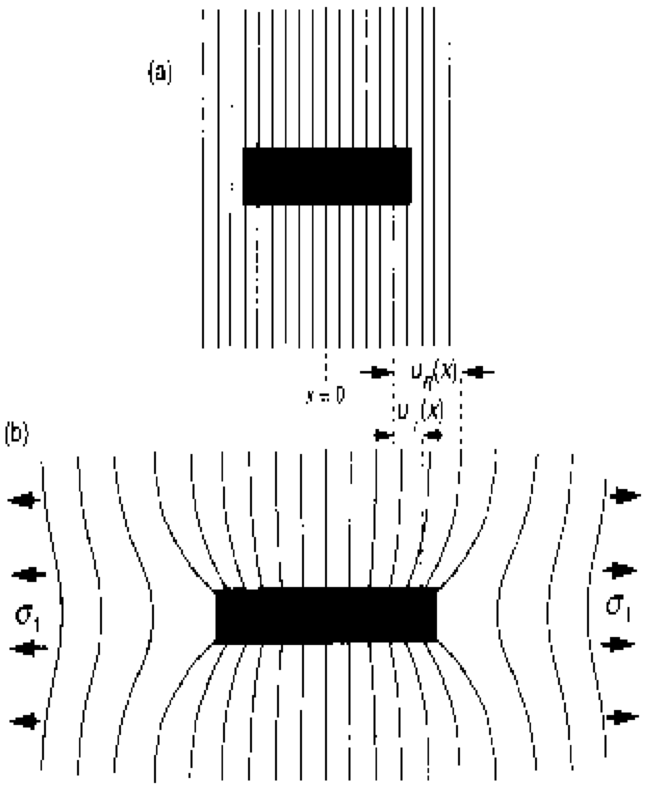
Fibre Reinforcement

- Efficacy of reinforcement, and performance of the composite, depend in part on:
  - Fibre geometry, in particular the aspect ratio (L/D)
  - Lay-up architecture
  - Intrinsic properties of the fibre
  - Interaction with matrix
    - Good interfacial bonding required for adequate transfer of load to the reinforcement



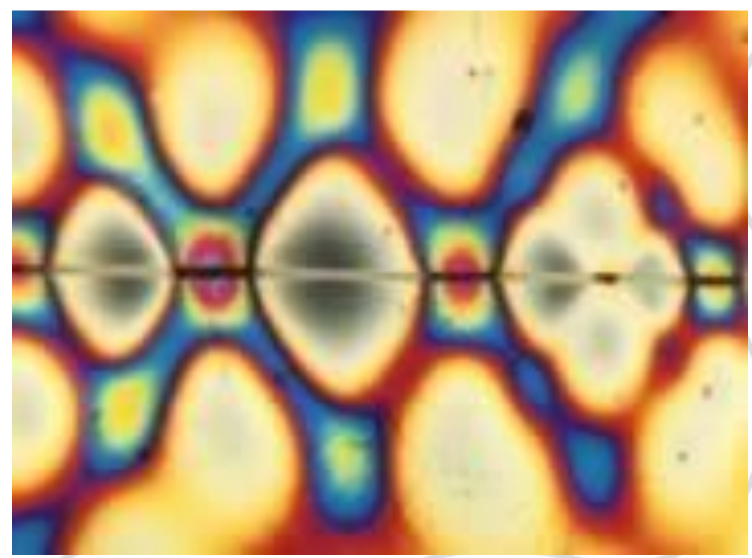
Stress Transfer

Source: Hull & Clyne (1996)



Matrix distortion around reinforcement

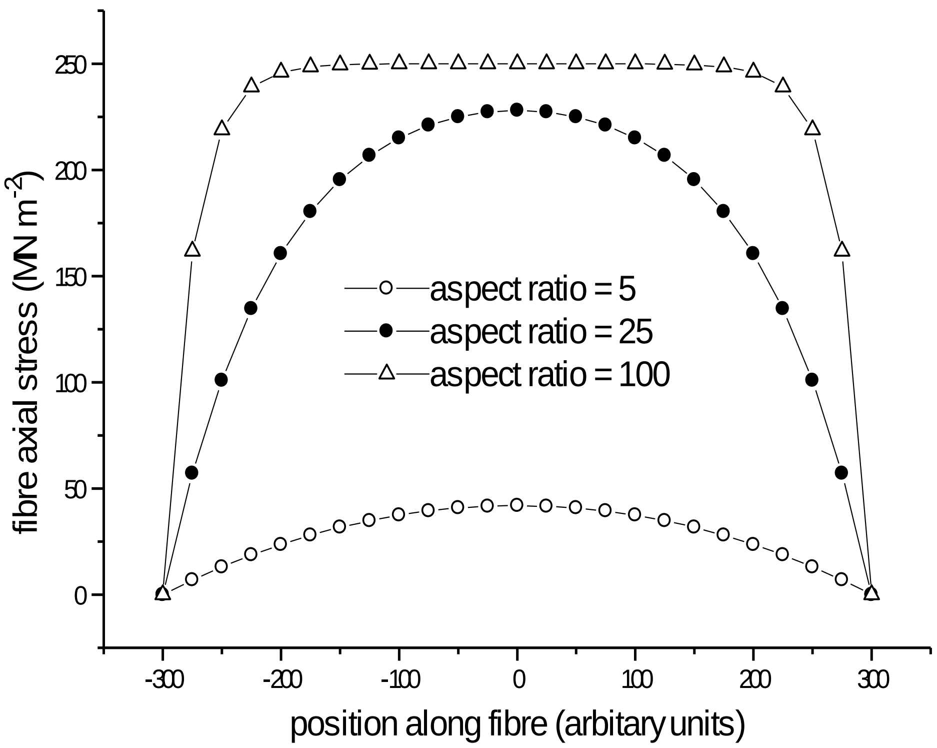
Polarised light photomicrograph of fragmentation test



Source: Hughes (1999)

Effect of Aspect Ratio

- For good mechanical properties it is necessary to:
  - Retain as much fibre length as possible
  - Minimise damage to the fibre in processing



Long Natural Fibre Composites

Natural Fibre Composites (NFCs)

- Could substitute traditional glass fibre – epoxy resin systems
- Components for high-end applications, e.g. car bodywork, boat hulls

Eco One – Warwick Manufacturing Group

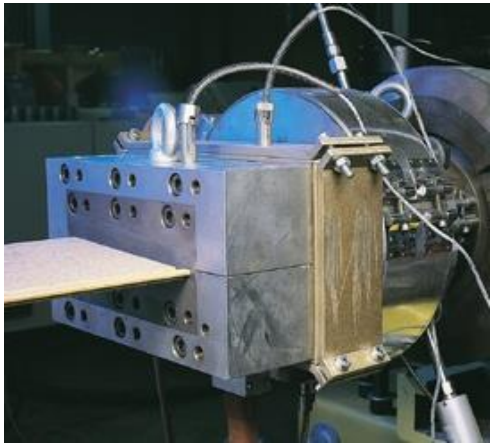
Flaxcat – TU Delft

Particulate Composites

- Reinforcement:
  - Short fibres, or platelets or particles
  - Again strong and stiff
  - May achieve higher volume fractions
- Matrix:
  - Usually weaker and more compliant
- Properties:
  - Below critical fibre length so shear lag model of stress transfer
  - Interfacial properties remain important

Particulate Composites

- e.g. Wood Plastic Composites
- Wood fibre or wood flour can be blended with polyolefins such as PE, PP, PS or PVC
- Fibre loadings of 40 to 60% are typical
- Extrusion is used for blending, and often for forming the product



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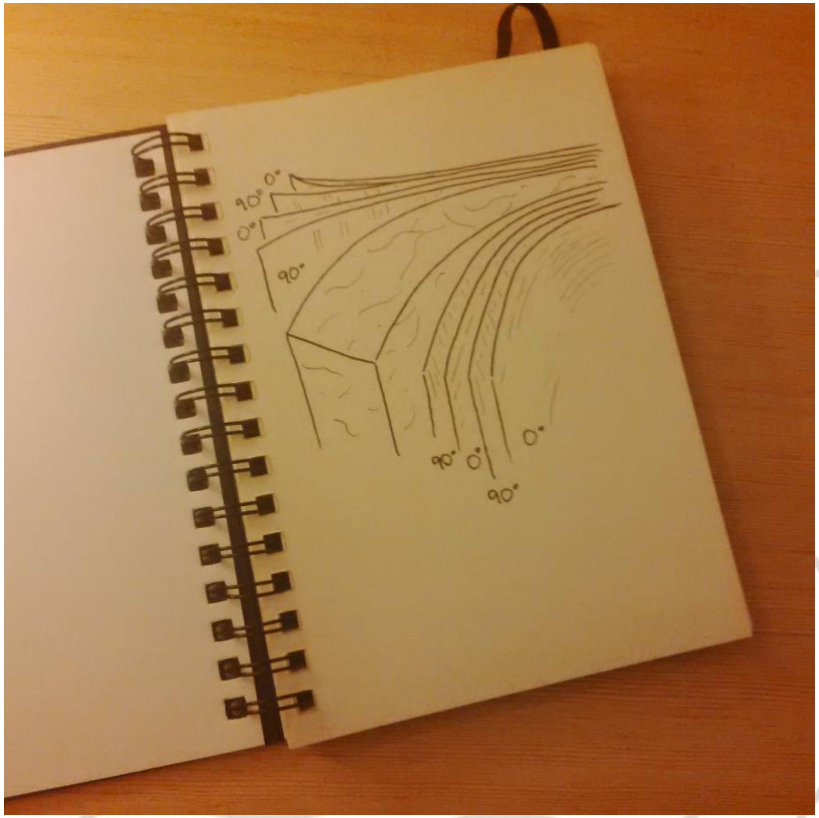
Sandwich Composites

- Strong element:
  - Sheet with orthotropic or unidirectional strength and stiffness
  - Location, location, location!
  - Outer faces of the three-ply construction
- Relatively weaker element:
  - Often lighter, e.g. a foam
  - Must provide good load transfer between surface and core
- Properties:
  - Below critical fibre length so shear lag model of stress transfer
  - Interfacial properties remain important

Sandwich composites

- e.g. Natural fibre cross-ply laminate on outer faces
- Biobased foam core

- Boat hulls frequently use this technique with glass fibre reinforced polyester (UPE)
- An option for biocomposite



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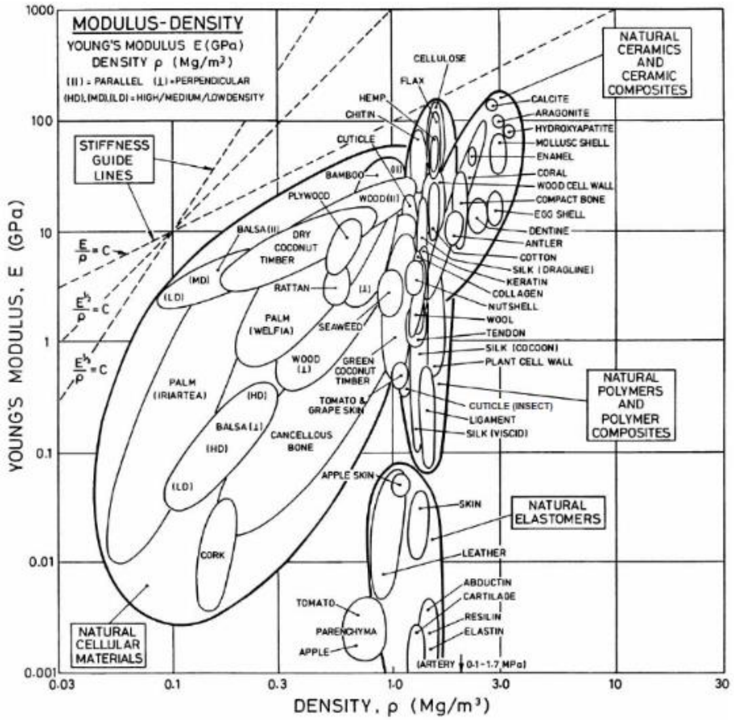


Figure 2. A material property chart for natural materials, plotting Young's modulus against density. Guidelines identify structurally efficient materials that are light and stiff.

(Source: Wegst and Ashby, 2004)

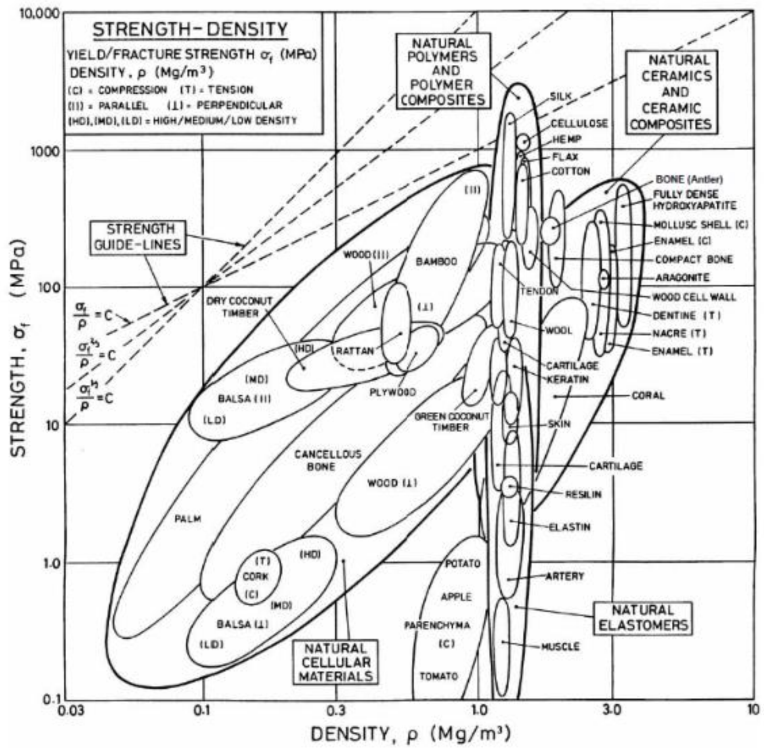


Figure 3. A material property chart for natural materials, plotting strength against density. Guidelines identify structurally efficient materials that are light and strong.

(Source: Wegst and Ashby, 2004)

WPCs or Long Natural Fibre Composites?

WPCs tend to include:

- Wood or recycled paper
- Bamboo
- Bagasse
- Many agricultural residues

Possible long fibres for NFTCs:

- Flax
- Hemp
- Jute
- Ramie
- Sisal
- Kenaf

Jute harvesting, transport and finished bales

Natural Fibres

- Cellulose in fibres gives plants strength
- Good mechanical properties
- Low density
- Long fibres are available from the stems, leaves or fruit of many plants
  - e.g. Hemp, jute and flax;
  - Sisal, abaca and curauá;
  - Coir, kapok and cotton

Long natural fibres

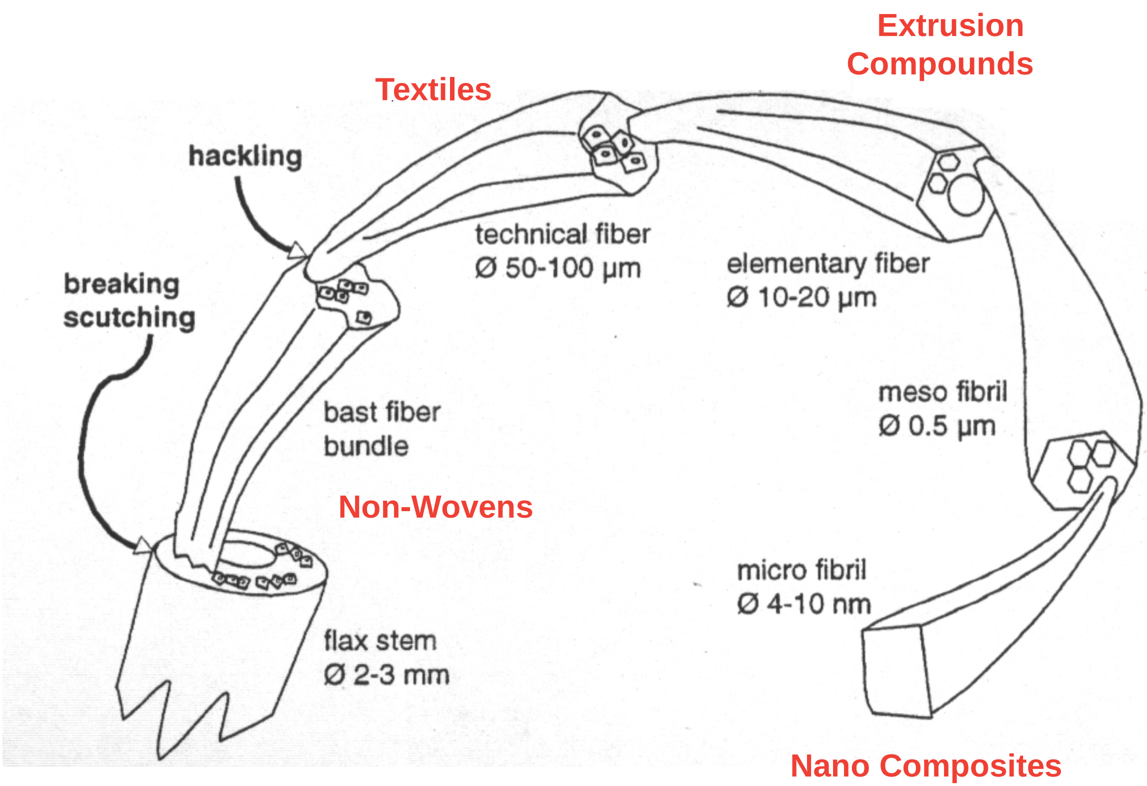
Fibre	Cellulose (%)	Microfibril angle (°)	Length (mm)	Aspect ratio	UTS (MN/m)
Sisal	67	20	2.2	100	580
Pineapple	82	15	4.5	450	650
Banana	65	12	3.3	150	540
Hemp	78	6	23.0	906	690
Jute	61	80	2.3	110	550
Flax	71	10	20.0	1687	780
Ramie	83	7.5	154	3500	8.7

Source: Mukherjee and Satyanarayana (1986)

Preparing Natural Fibres

	Wood	Bamboo	Bast	Leaf	Seed
Milling	✓	✓			
Refining	✓	✓			
Pulping	✓	✓	✓		
Steam explosion	✓		✓		
Retting			✓	✓	✓
Decortication			✓		✓
Splitting				✓	
Washing			✓	✓	✓
Carding			✓	✓	✓

Natural Fibres



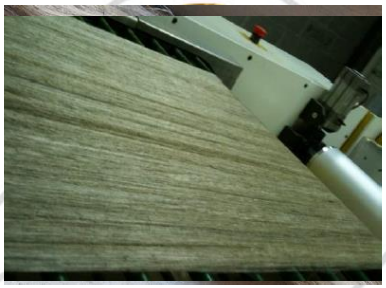
Bast Fibre Properties

- Flax:
  - Technical fibres: 0.3-0.6 m long
  - Tensile strength 345 to 1035 MPa
  - Young's Modulus 27.2 GPa
  - Elongation at break 2.7 to 3.2%
  - Fibre ultimates:
    - Average length 25 mm
    - 15 to 35 μm in diameter
    - aspect ratio 1200

Natural Fibre Composites

- To better use the strength of the natural fibre the composite needs fibre lengths greater than the critical fibre length
- Long natural fibres can be used as reinforcement in traditional matrices
- Non-woven mats
- Woven fabrics such as linen or hessian
- Flax or hemp sliver can give unidirectional composites
- Tapes of unidirectionally aligned fibres





Thermosetting Natural Fibre Composites

Natural Fibre Composites (NFCs)

- Can substitute traditional fibre glass with unsaturated polyester or epoxy resin systems
- Components for high-end applications, e.g. car bodywork, sports equipment, boat hulls

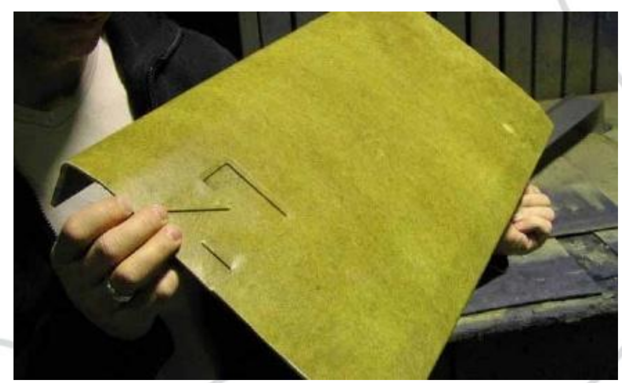
Schwinn NFC bike

Lineo - FlaxPreg

Bio-derived Thermosets

- Vegetable oil based polymers
  - –Triglycerides grafted with hydroxyl and acrylate, hydroxyl and maleate, acrylate and maleate etc.
- Oil based epoxies
  - –Epoxy functionality on unsaturated fatty acids
- Polyesters
  - –Replacing the styrene, e.g. methacrylated fatty acids
- Cashew Nut Shell Liquid
- Other Polymers
  - –Lignin derived, Shellac, Natural rubber

Oil based resin



Epoxy SMC

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Bio-derived Thermosets

Natural Fibre Composites (NFCs)

- Substituting petrochemical UPE or epoxy resin systems
- Replacing synthetic foams

Campion boats

Ocean Green - BioFoil

Natural Fibre Composites

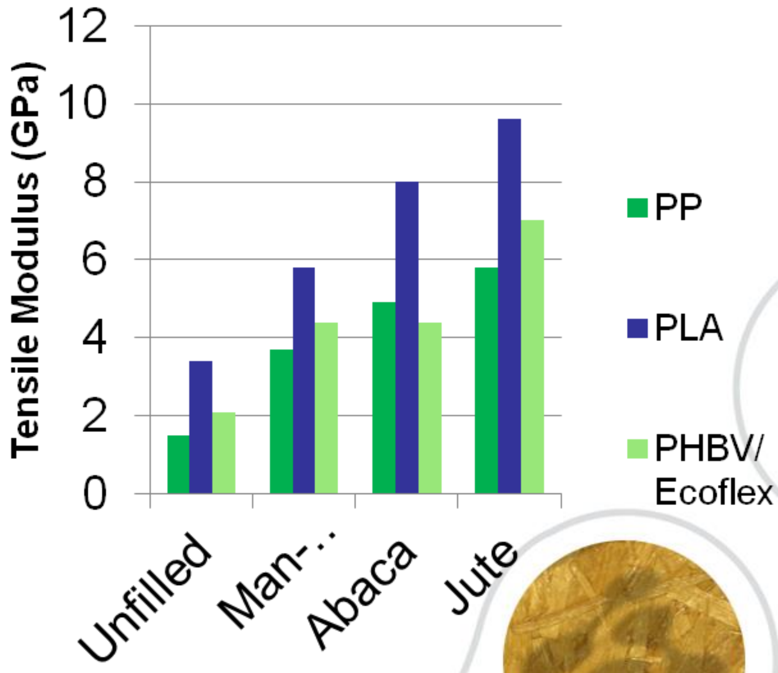
- Natural fibre-reinforced thermoplastics
- Flax was refined to separate fibres and clean it
- Matrix and fibre were compounded
- Mechanical properties comparable to glass-fibre reinforced polypropylene
- Reduced weight compared with glass fibre-reinforced equivalent

Natural Fibre Reinforced Biopolymers

- Biopolymer NFCs:
- Toyota used kenaf reinforced PLA to make spare wheel covers and floor mats for the Raum in 2003
- They report that the balance between cost and performance became prohibitive
- Recently announced intention to use bioplastics in 20% of the plastic components by 2015
- NEC, UNITIKA and DoCoMo used PLA with kenaf fibre in the FOMA phone

Properties

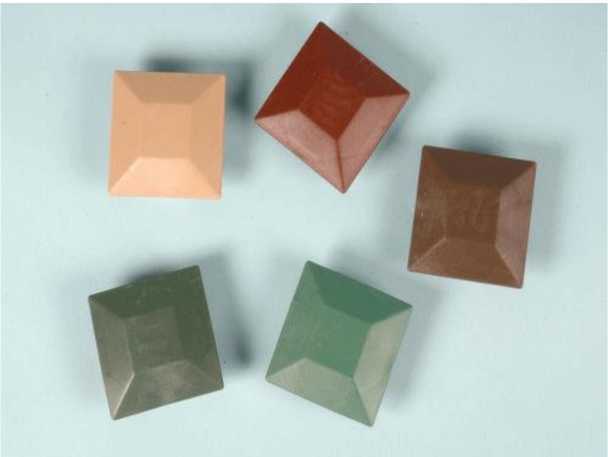
- Properties of injection moulded composites, 30% fibre
- For tensile modulus, PLA matrix showed the highest stiffness
- The same trend with matrix was seen with tensile strength
- For tensile strength, the regenerated cellulose showed highest values



Data: Bledzki and Jaszkiewicz (2010)

Wood Plastic Composites and Filled Plastics

- Wood fibre or wood flour can be blended with polyolefins such as PE, PP, PS or PVC
- Fibre loadings of 40 to 60% are typical
- Extrusion is used for blending, and often for forming the product
- Injection moulding can give more intricate shapes



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- Extrusion is used for blending, and often for forming the product
- Injection moulding can give more intricate shapes
- Compression moulding is used in automotive applications
- Many natural fibres can be used:
  - Wood fibre, Hemp, Jute, Sisal, Flax, Curauá, Kenaf, Coir
- So can flour from many agricultural residues
  - Straw, Rice husks, Olive stones, Corn stover, Oil palm empty fruit bunch

WPCs in construction

- What can we build?

  Decking
  Gazebos and garden structures
  Wall panels
  Short span bridges
  Pontoons and walkways

- What can't we build?

  Structural members of buildings
  Long spans
  Lightweight structures

- Bending strength is a challenge

Good compressive resistance

WPCs for Marine Piling

- Interest in the USA
- Large government funded project to investigate WPC for marine applications
- Large dimension extruded sections for use in sill plates and chock members

WPC Chock members in trials, Port Hueneme, California
Source: Smith and Wolcott (2006) Forest Products Journal 56(3):4-11

Biopolymers as matrices

- PHB-V, has better mechanical properties compared to PHB
- Mineral filler to alter HDT and stiffness
- Mechanical properties relate to crystallinity and nucleation rate
- Nucleating agent was needed for acceleration of the crystallisation
  - Increase nucleation density
  - Decrease the spherulite size
- Boron nitride was commonly used
- Films tend to stick to themselves after cooling

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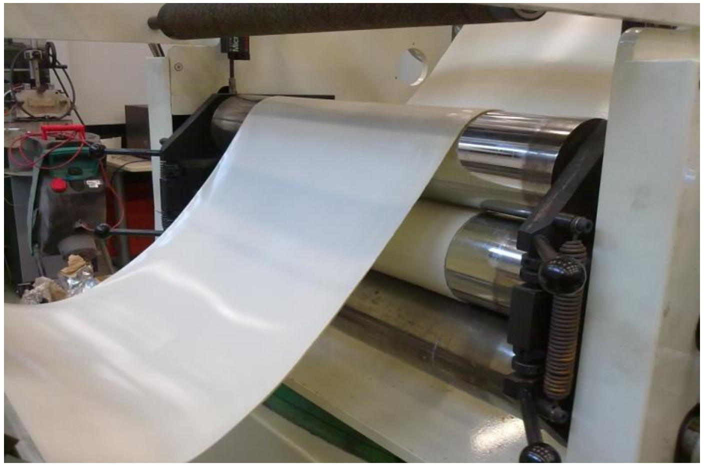
Approaches



Brittleness and narrow processing window

- PHBV/Ecoflex blends

Slow crystallisation and stickiness to tooling

- Nucleation agents
- Roller temperature control
- Antiblock agents

Thermal stability

- Processing conditions (temperature profile, pre-drying etc)
- Minimum thermal cycling
- Chain extension agent

Cost reduction

- Mineral fillers - Imerys
- Extrusion foaming

Benefits of combining bio-fibre and bio-matrices

- Plant materials are grown, harvested and processed by clean methods,
- Fibre may be a co-product of food or industrial grain production,
- Bio-refining allows other by-products to be extracted and used in other processes,
- Customers are demanding greener or more sustainable materials
- Biopolymers filled with natural fibre increases chance of composting or anaerobic digestion at end of life for packaging
- Durable biocomposites in high performance applications offer a carbon storage benefit

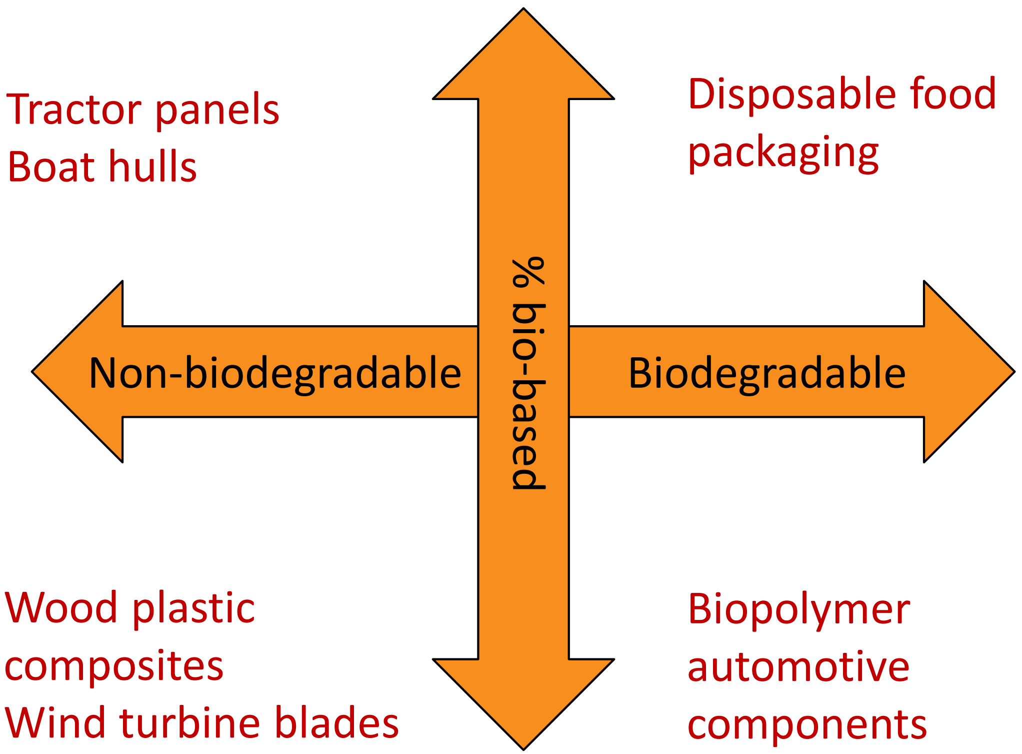
Potential savings

- Low energy requirements
- Reduced abrasion in moulds and tools
- Many fibres offer a cost saving
- Reduced carbon tax

Barriers to exploitation

- Secure supply of raw materials
- Development of production processes
- Optimization of compounding or moulding

What do we want from our biocomposites?



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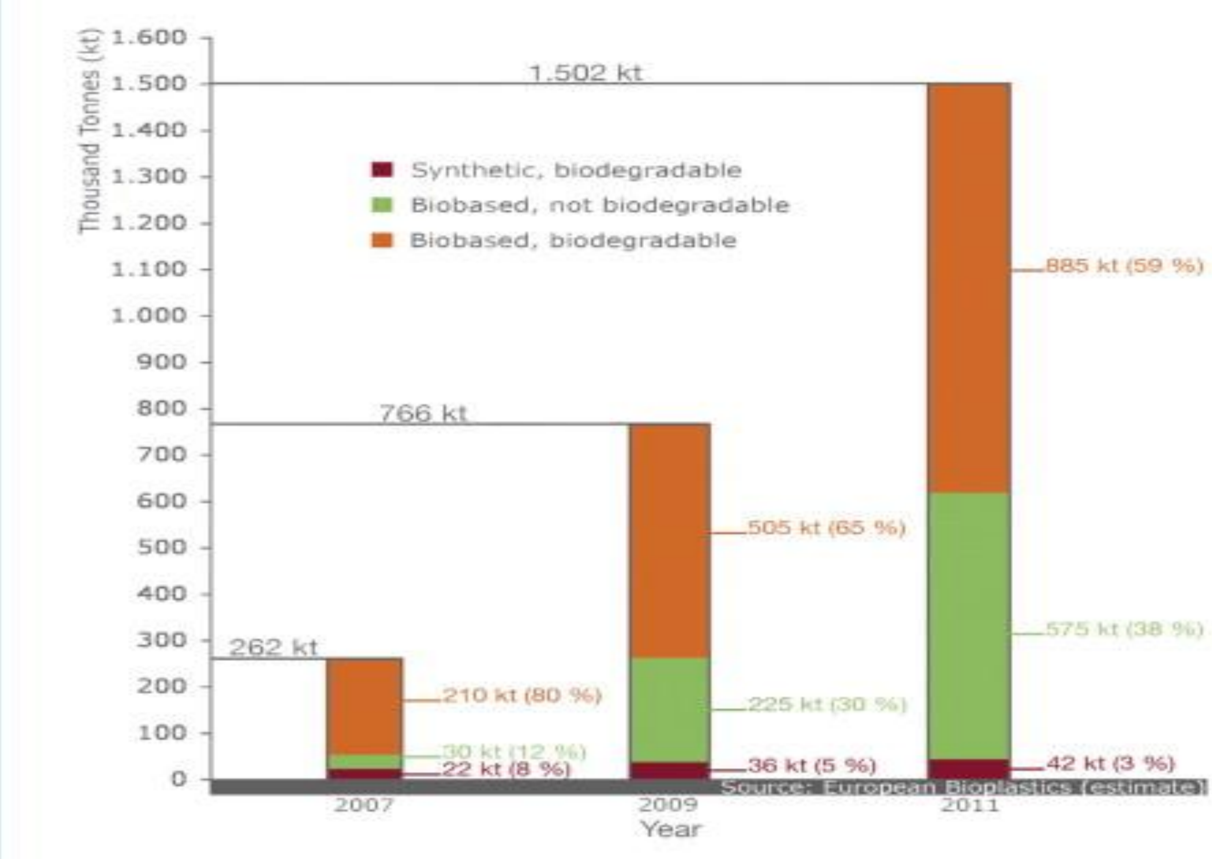
Biopolymer market overview



WPC Market

- A growth market
- Global production increased in 10 years
- 2002: 595,950 tonnes
- 2012: 2.5 to 3 million tonnes
- Europe in 2010, 220,000 tonnes
- 172,000 WPC decking, fencing
- 50,000 automotive
- Biopolymer based WPCs increasing for small mouldings

Conclusions

- Great progress has been made in developing natural fibre composites during the past two decades
- Ongoing developments in biopolymers will further increase the sustainability of these materials
- Future challenges will include improving the handling and processibility of long fibre composites, e.g. SMC options and fibre mat format
- Let’s see which applications are next to take up NFCs to meet sustainability goals



The sky's the limit!

Thank-you for your attention

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