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These are the author's presentation slides of a conference presentation made at the 20th Annual Green Chemistry & Engineering Conference.

School of Design
SUSTAINABLE MATERIALS RESEARCH GROUP

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Sustainable high-performance fibres from Himalayan giant nettle (*Girardinia diversifolia* L.)

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Ideal sustainable product

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- Provide an **equivalent function** to the product it replaces
- **Performs as well as or better** than the existing product
- Be available at a **competitive or lower price**
- Have a minimum environmental footprint for **all the processes involved**
- Be manufactured from **renewable resources**
- Use only **ingredients that are safe** to both humans and the environment
- **No negative impact** on food supply or water

Synthetic fibre revolution

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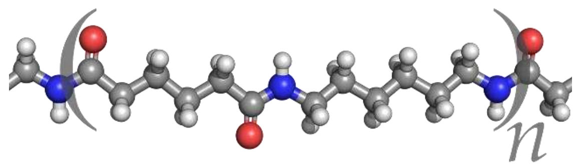
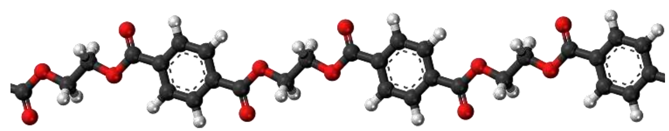
- 20th Century polymers
  - nylon, 1935
  - polyurethane, 1937
  - polyester
    - Terylene, 1941
    - Dacron, 1946
  - acrylic, 1944
  - polypropylene and HDPE,1951





Sustainable high-performance fibres

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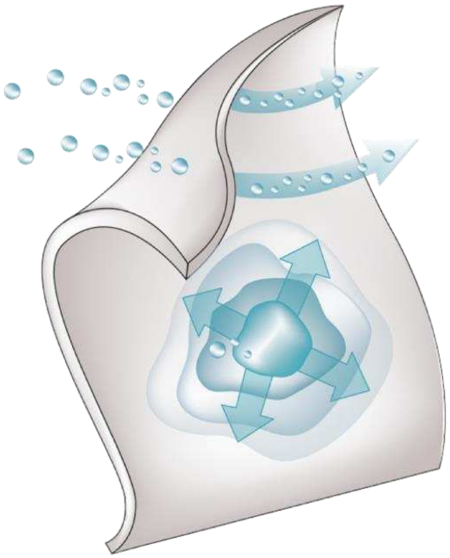
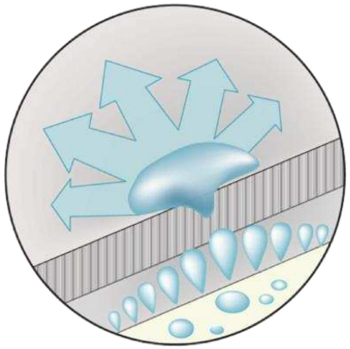


- Fibres for high performance applications are particularly desirable
  - high wear-resistance, breathability, thermal insulation, etc.
- Current market dominated by synthetic fibres
  - carbon fibre, polyethylene terephthalate, polyurethane, polytetrafluoroethylene
- How to balance need for sustainability with requirements of application?



Bast Fibres

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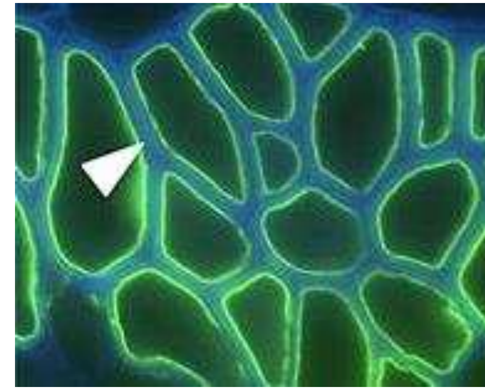
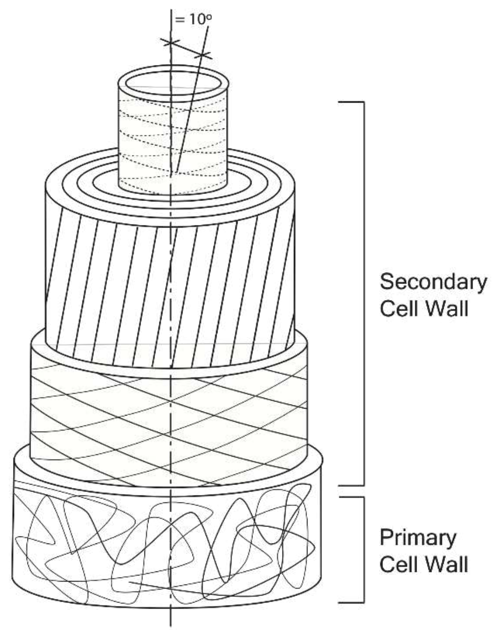
- Cellulosic fibres from stem of dicotyledonous plants
  - flax, hemp, jute, ramie, nettle, kenaf, abaca
- Characterized by their thinness, flexibility, and strength
- Generally less expensive than synthetic fibres
- Possess competitive mechanical properties
  - high tensile strength
  - volume fraction of cellulose and microfibrillar orientation





Himalayan giant nettle (*Girardinia diversifolia* L.)

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- Grows in tropical Africa (from Ethiopia to Madagascar), Yemen, Nepal, India, Sri Lanka, southern China, Taiwan and Indonesia
  - Grows at 1000-2500 m above sea level, in areas of partial shade
  - Grows tall (1.5 to 3.0 m high), strong, and straight
  - Needs environment with good moisture content, high velocity winds, low temperatures (frost-resistant for 3-4 days), in fertile, deep, draine soil
- Harvest between August and December
  - Currently natural retting processes

- Bast fibres from the plant traditionally are used to make ropes, twine, fishing nets, sacking and some clothing
- Fibre production is currently very low in comparison with other natural fibres
- Himalayan Wild Fibers LLC (US Company) has already embarked on the industrial scale-up of *G. diversifolia* fibre production in Nepal

Bast fibre tensile properties

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Fibre	Fibre length (L; mm)	Cross-sectional area (A; µm²)	Tensile strength (σ; MPa)	Extensional strain (ε; %)	Young's Modulus (E; GPa)
G. diversifolia	478 (±21)	479 (±186)	4451 (±1313)	6.2 (±1.3)	73 (±22)
U. dioica	52 (±2)	456 (±199)	2196 (±809)	2.8 (±0.9)	79 (±29)
Flax	27 (±3)	183 (±87)	1339 (±486)	3.3 (±0.4)	54 (±15)
Hemp	20 (±5)	764 (±260)	270 (±40)	0.8 (±0.1)	19 (±4)
Ramie	135 (±15)	270 (±93)	560	2.5	24.5

$$\sigma = \frac{F}{A} \qquad E = \frac{\sigma}{\varepsilon}$$

- Mean length of *G. diversifolia* fibres substantially longer than European nettle (*U. dioica*) fibre, and longer than other common bast fibres
    - *G. diversifolia* has longest bast fibre reported

Nettle fibre tensile properties

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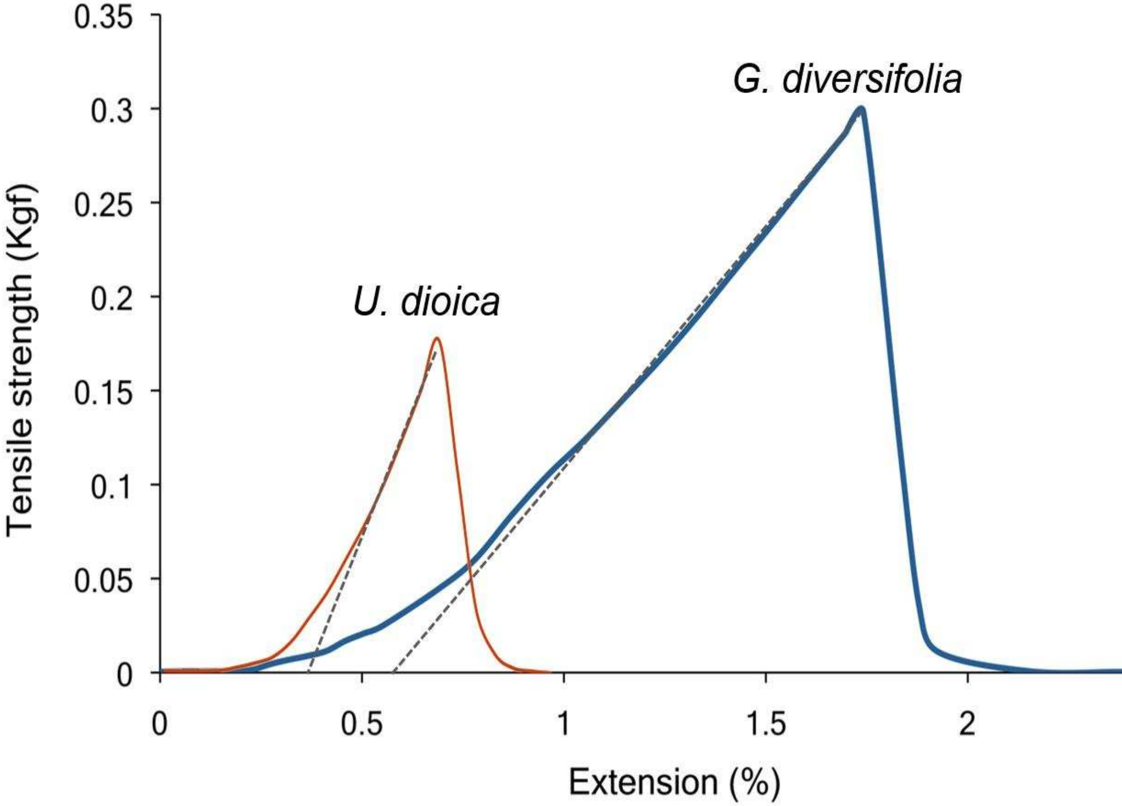
- σ for *G. diversifolia* twice that of *U. dioica* fibre
- highest of any bast fibre reported
    - S-glass (4570 MPa)
    - carbon fibre (4000 MPa)
- *G. diversifolia* fibre greater ε in comparison with *U. dioica* fibre
- greater than that of the most common bast fibres
- Young's modulus for *G. diversifolia* and *U. dioica* fibre similar
- Due to the greater extensibility of *G. diversifolia* fibre



- *E* for both nettle fibres is generally higher than those of other common bast fibres
    - E-glass (73 GPa)

Alkali treatment of cellulose

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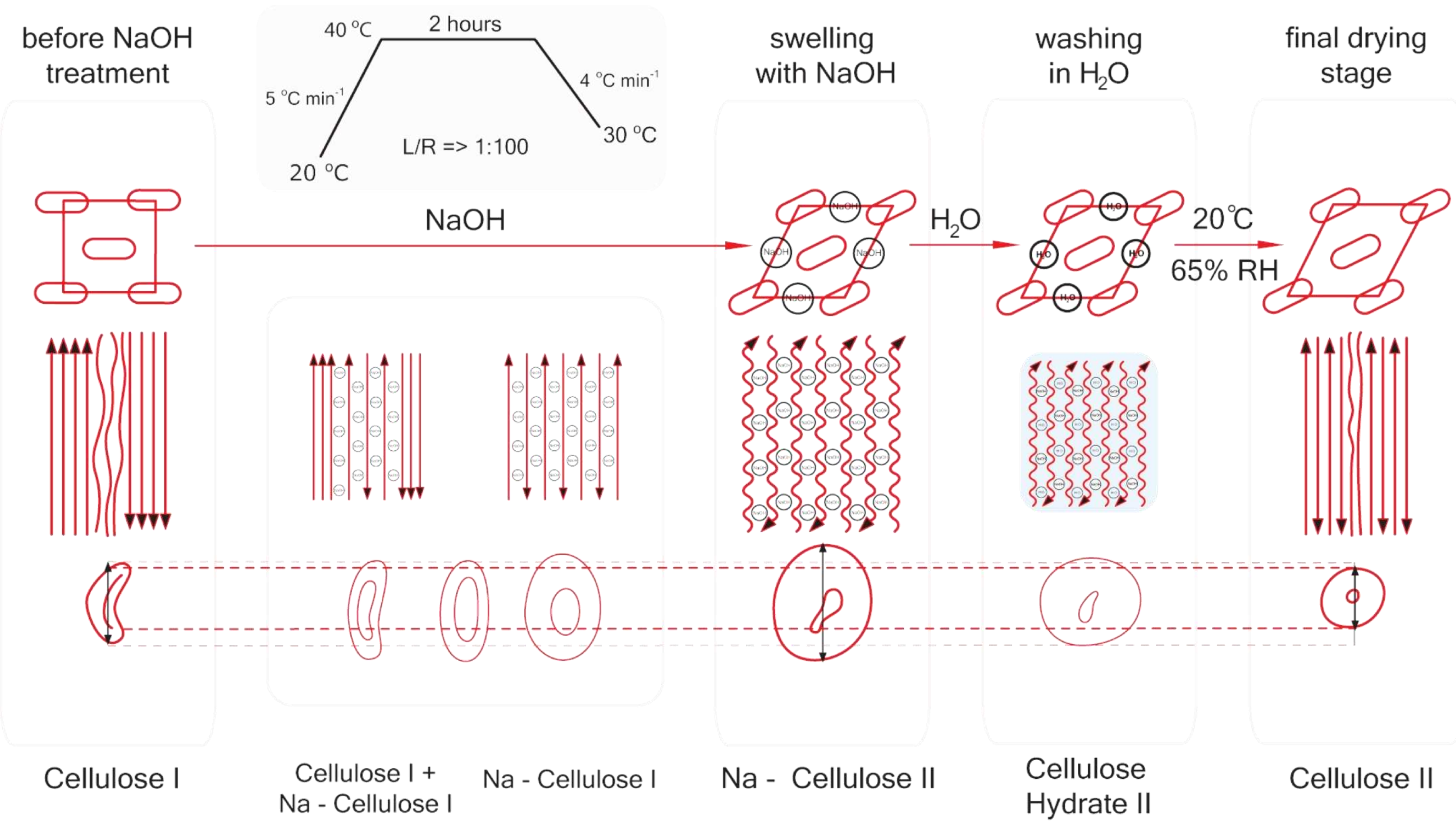
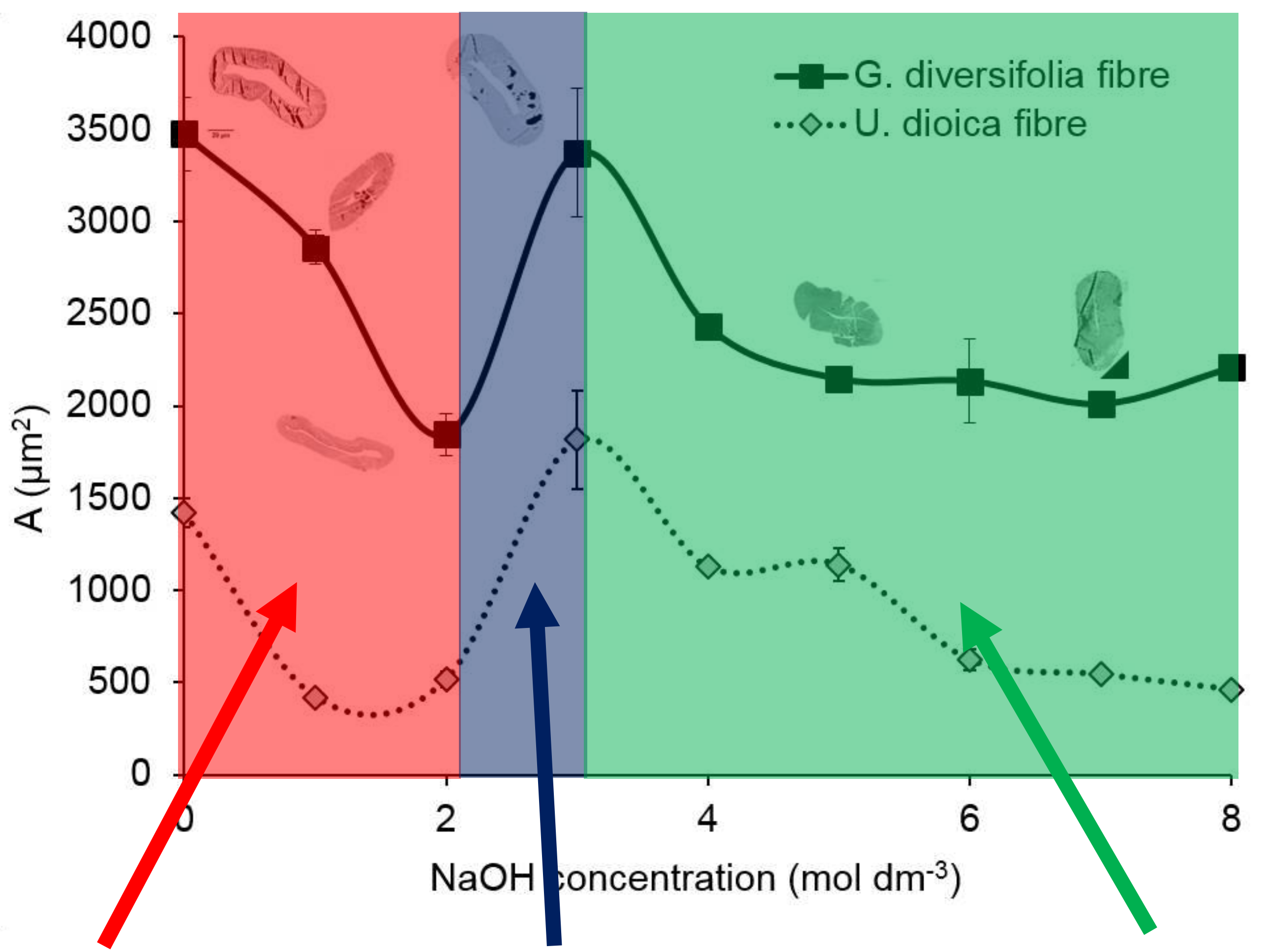




A decreases as cellulose I → Na-cellulose I

intermolecular H-bonds are broken

allows movement of the fibres longitudinally

compression of the fibre cross-section laterally

A increases as Na-cellulose I → Na-cellulose II

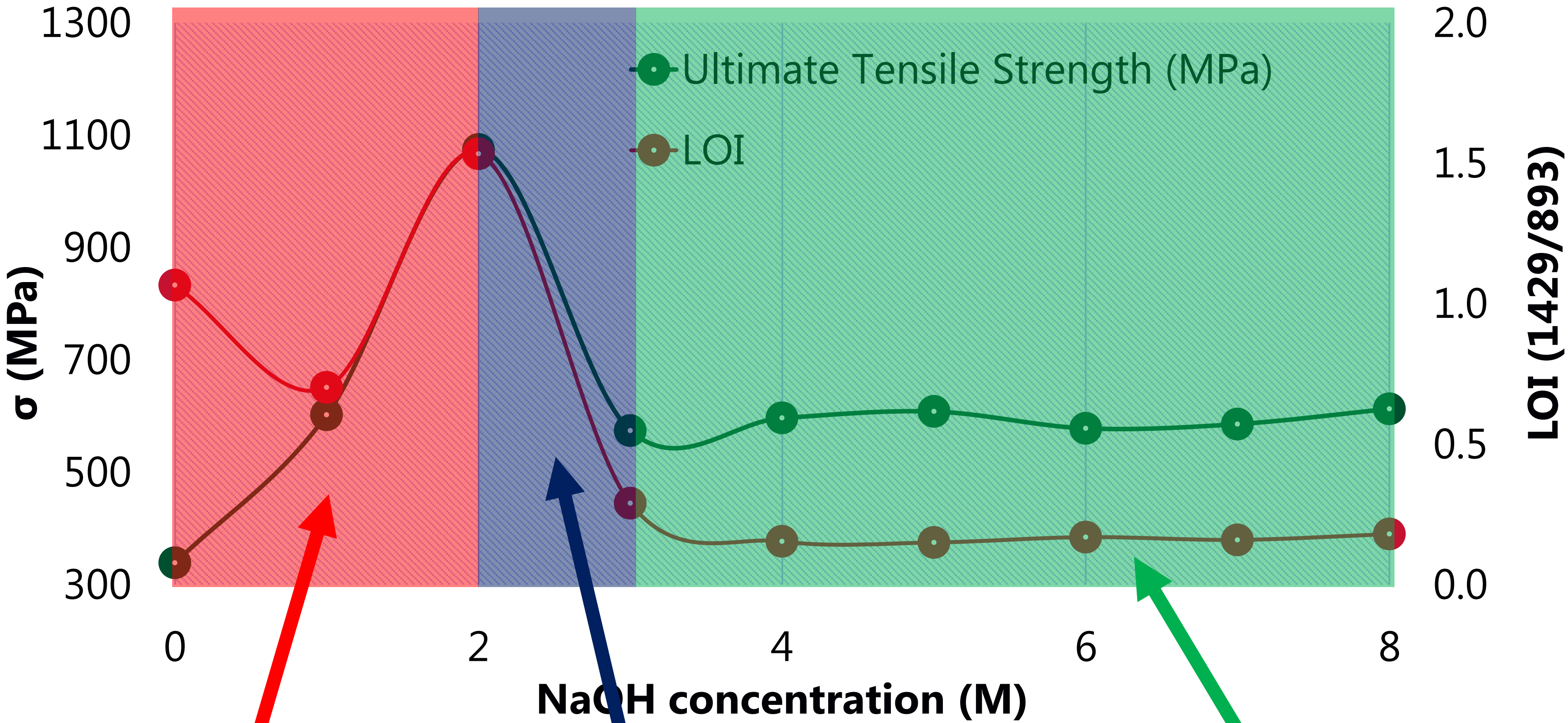
intramolecular H-bonds broken

allows swelling laterally

A decreases again to a plateau

reorganization to lower energy form of cellulose II

cross-section changes to more circular form and lumen almost disappears



As σ increases, lateral order index (LOI; representation of degree of crystallinity in fibre) also increases

cellulose I → Na-cellulose I

intermolecular H-bonds are broken

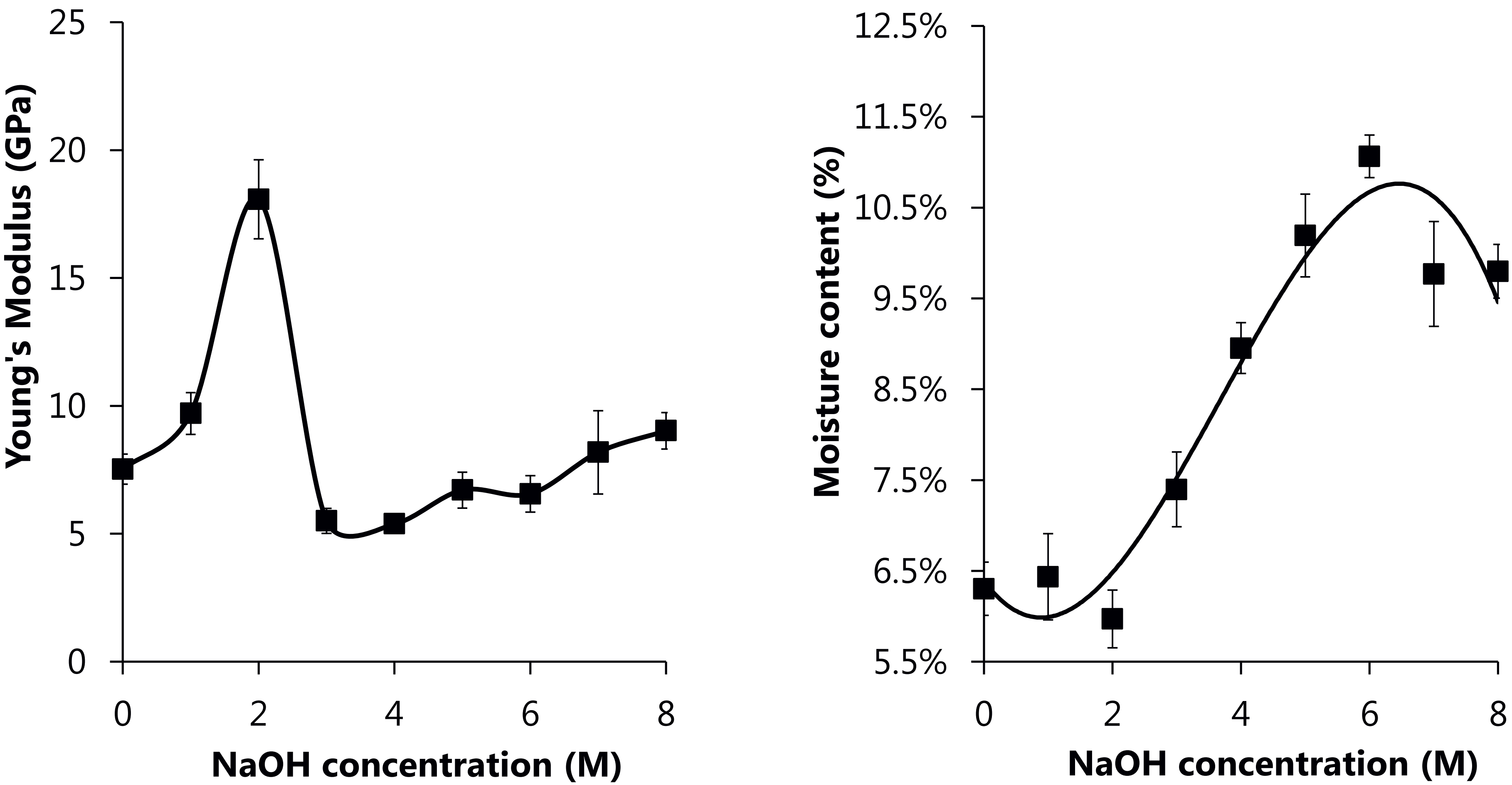
freedom of movement between adjacent cellulose polymer chains

σ decreases as Na-cellulose I → Na-cellulose II

intramolecular H-bonds broken

LOI decreases significantly

reorganization to lower energy form of cellulose II



- Possible to use same sustainable raw material to create materials with different properties?

Comfort in outdoor sports

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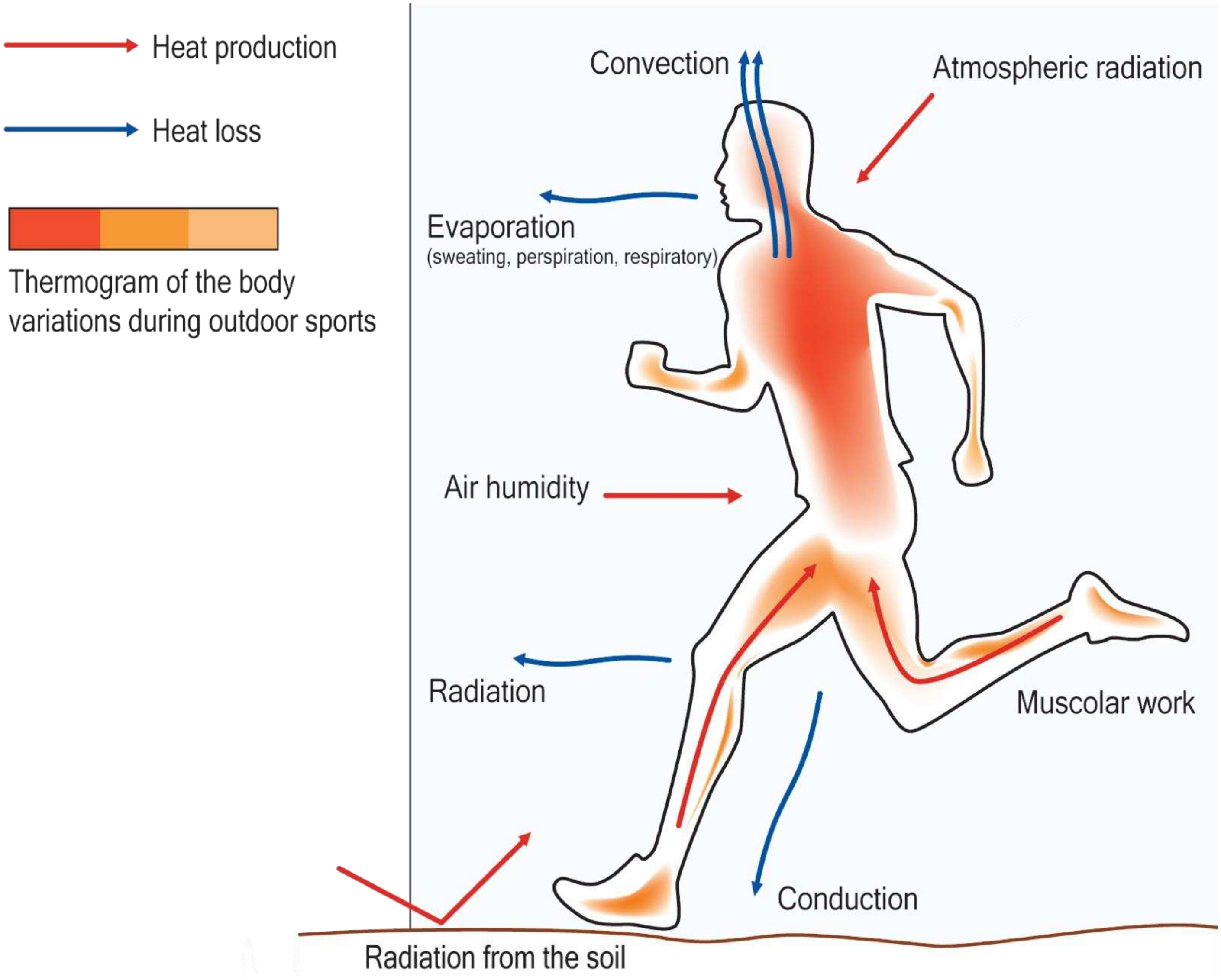

Three-layer outdoor clothing system

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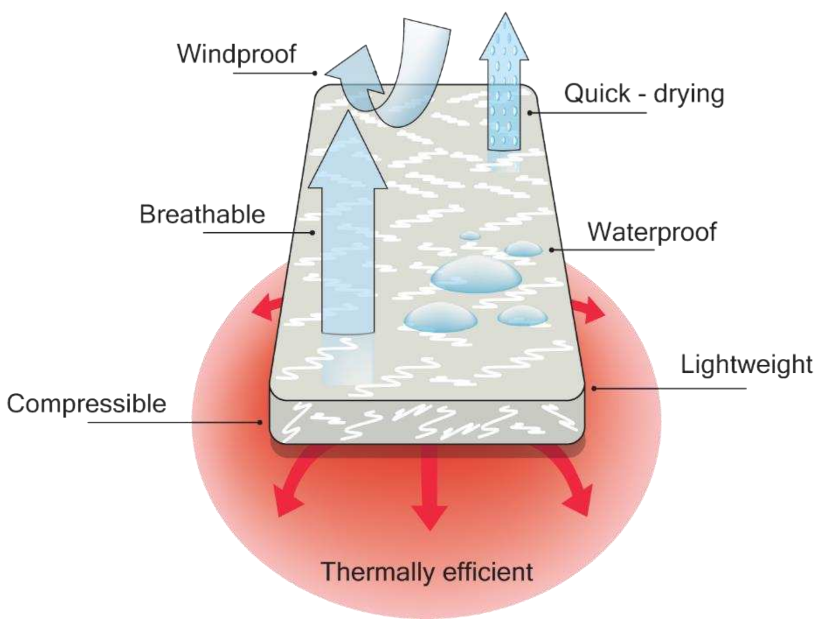
Primaloft® jacket



- **base layer** next to the skin, breathable and moisture regulator[i]
- **middle layer**, insulating, protects from cold
- **shell layer**, outer, resistant to abrasion, protects from external environment, wind and rain

Achieveable with *G. diversifolia*??

base	4 mol dm^{-3} NaOH	Breathability
middle	0 mol dm^{-3} NaOH	Thermal insulation
shell	8 mol dm^{-3} NaOH	Resistent to abrasion

Three-layer performance material from *G. diversifolia*

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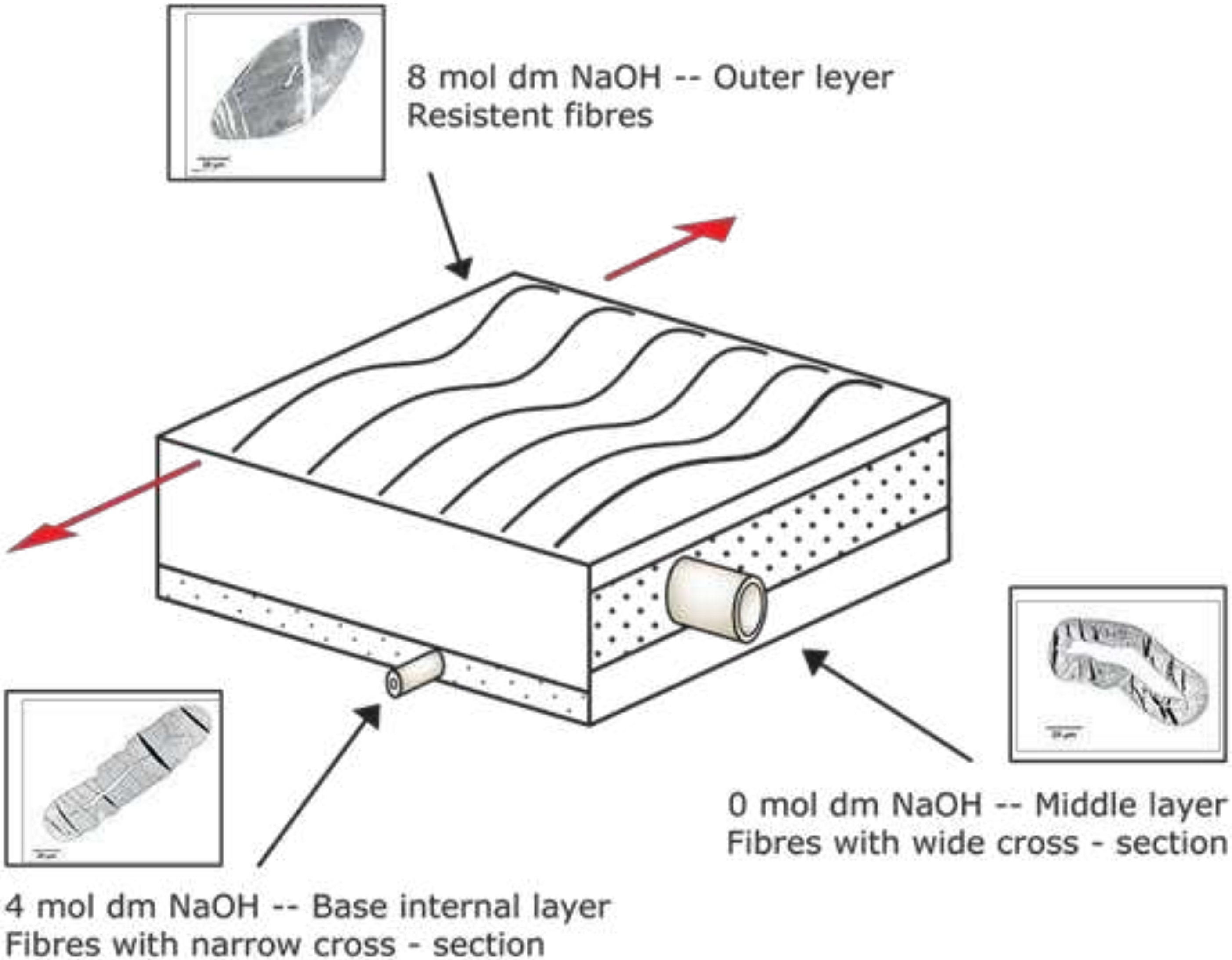

Three-layer performance material from *G. diversifolia*

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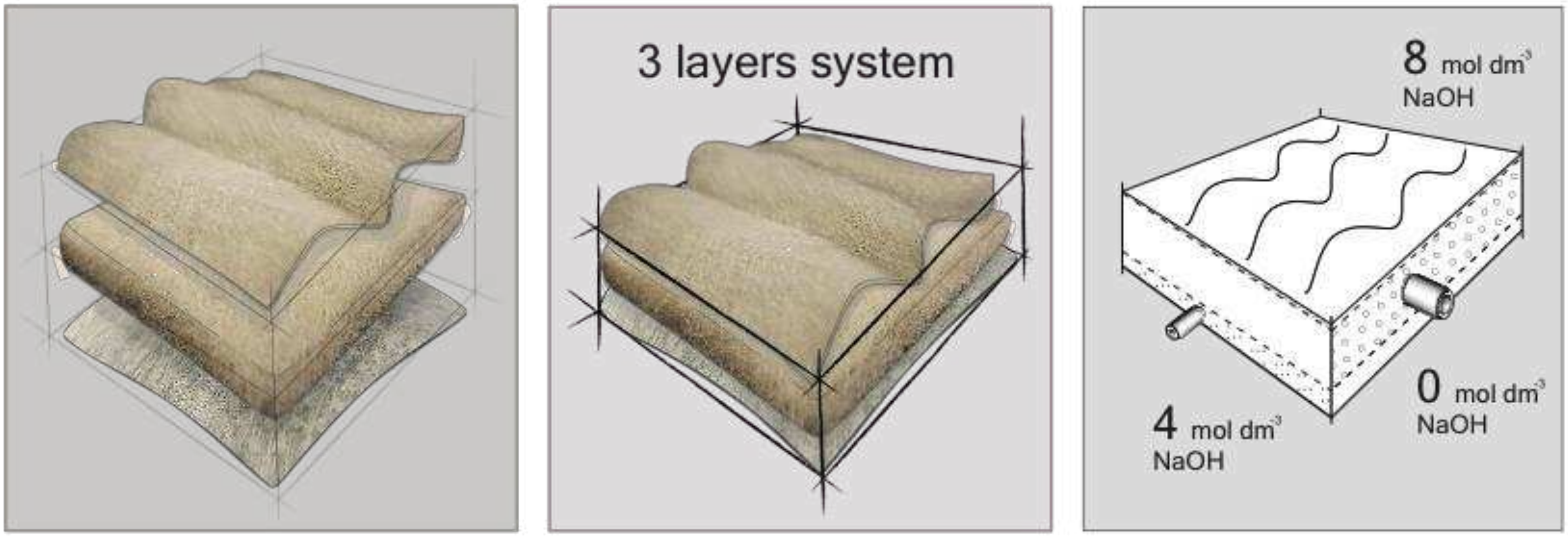

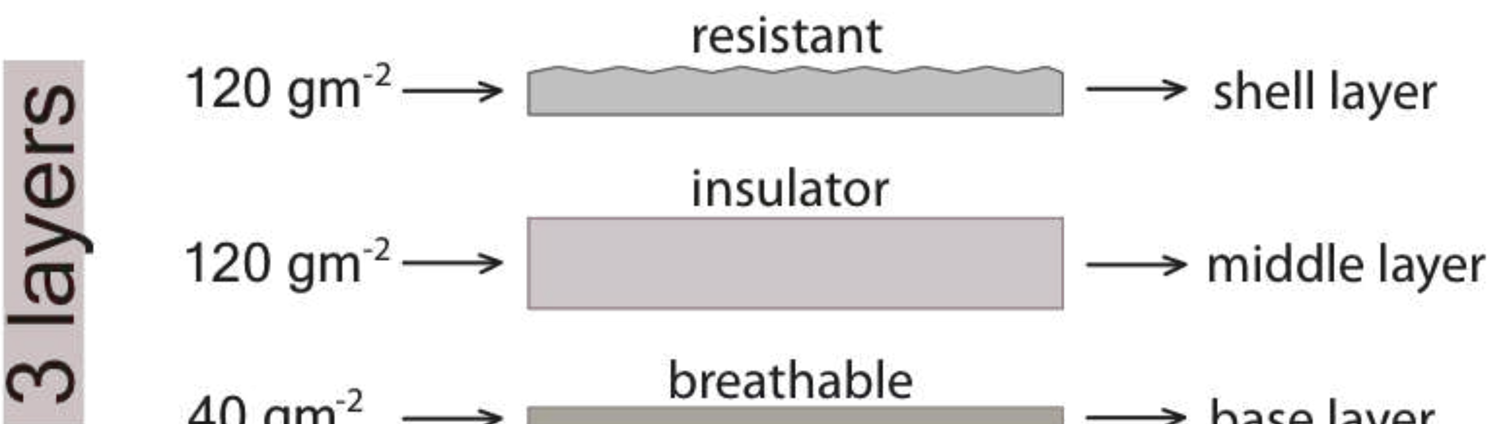

Three-layer performance material from *G. diversifolia*

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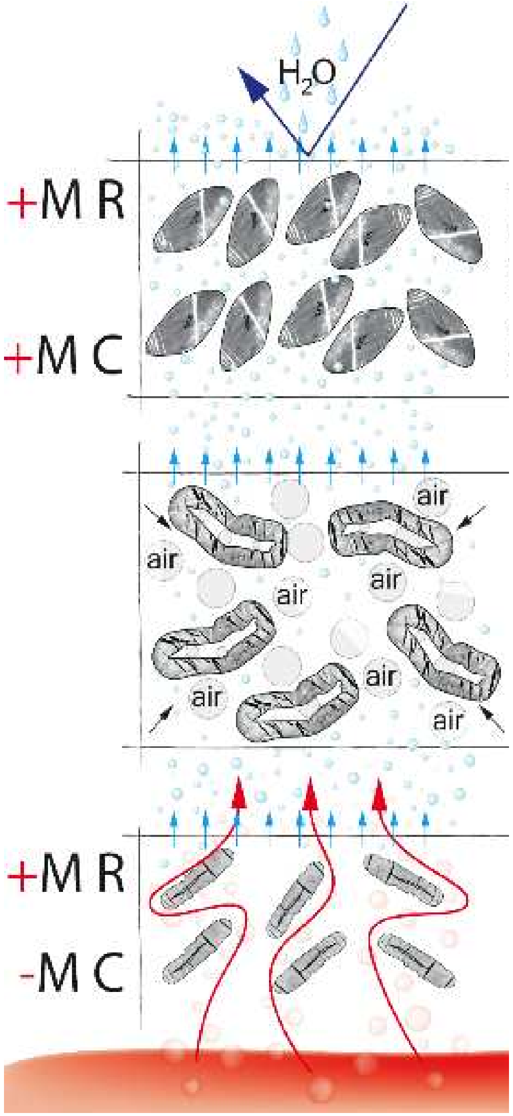

Shell (8 M)

- Fibres with wide cross-section, narrow lumen and high moisture regain (MR) permit water vapour flow originiating from the body
- High moisture content (MC) reduces penetration of external water

Middle (0 M)

- Wide section of the hollow fibre traps air, providing good insulation
- Lowest MC allows air to permeate

Base (4 M)

- Lower MC and higher MR + capilliary structure created by narrow fibre cross-section allows good permeability

Conclusions

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- Development of sustainable fibres for high performance applications is challenging
  - high mechanical strength properties demanded and general lack of such properties in natural fibres
- *G. diversifolia* fibre has the **longest fibre length** reported for any bast fibre
- **Ultimate stress value** for *G. diversifolia* fibre is over twice that of *U. dioica* fibre, and the **highest of any bast fibre** reported
- *G. diversifolia* and *U. dioica* fibre have **higher Young's modulus** in comparison with other common bast fibres
- Treatment of *G. diversifolia* fibre with aqueous sodium hydroxide solution causes **changes to the morphological, mechanical and chemical properties**
  - Cross-sectional area, tensile strength, Young's modulus, and moisture properties all change
- Changes are related to **fibre crystallinity changes**

cellulose I → Na-cellulose I → Na-cellulose II → cellulose II

- **Opportunities for using Himalayan Giant nettle fibres in performance applications**

Thank you

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