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

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Goswami

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University of Leeds

 @RichardBlackb18

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

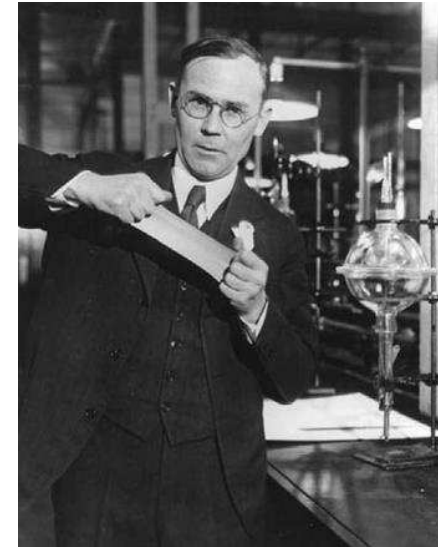
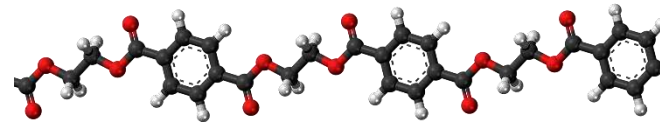
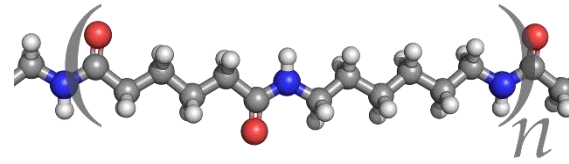
Synthetic fibre revolution



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- 20th Century polymers

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



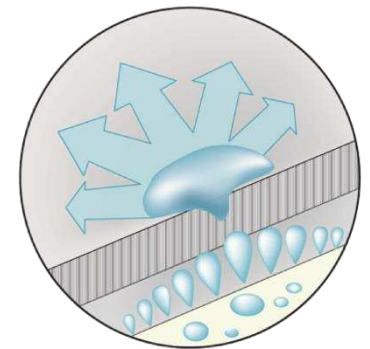
A vintage advertisement for DuPont Nylon. It features a woman in a light-colored, off-the-shoulder dress and stockings, sitting and holding a large sign. The sign lists various benefits of Nylon fibers, such as strength, lightness, and resistance to moth and respiration. The text on the sign includes: "Du Pont makes the nylon fibers used in the products shown. The manufacturer of these products use nylon because nylon products can have these outstanding properties: ✓ LONG WEAR ✓ EASY WASHING ✓ LIGHTNESS ✓ FAST DRYING ✓ ECONOMY ✓ FLAME RESISTANCE ✓ RESISTANCE TO MOths AND RESPIRATION ✓ CAN BE 'SET' TO HOLD SHAPE". The sign also includes the DuPont logo and the text "DU PONT" in a red oval. The advertisement is titled "news about NYLON" and includes the phrase "it all started with a stocking".

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?

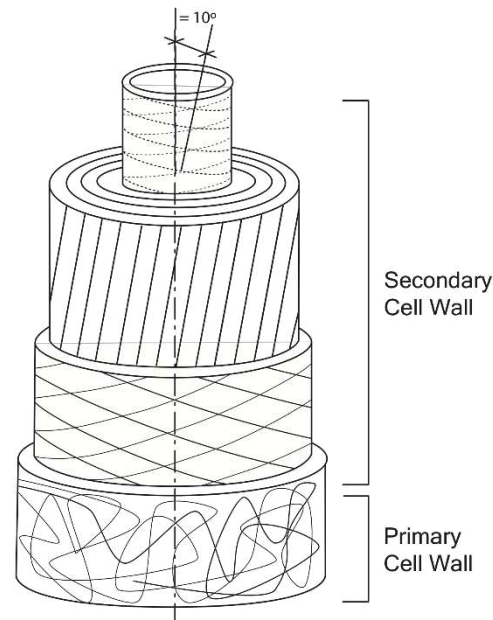
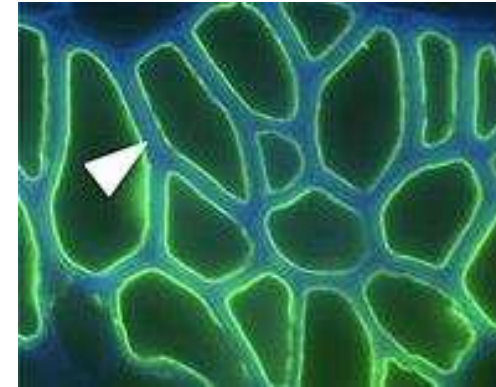


Bast Fibres



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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, drained 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; μm^2)	Tensile strength (σ ; MPa)	Extensional strain (ϵ ; %)	Young's Modulus (E; GPa)
<i>G. diversifolia</i>	478 (± 21)	479 (± 186)	4451 (± 1313)	6.2 (± 1.3)	73 (± 22)
<i>U. dioica</i>	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

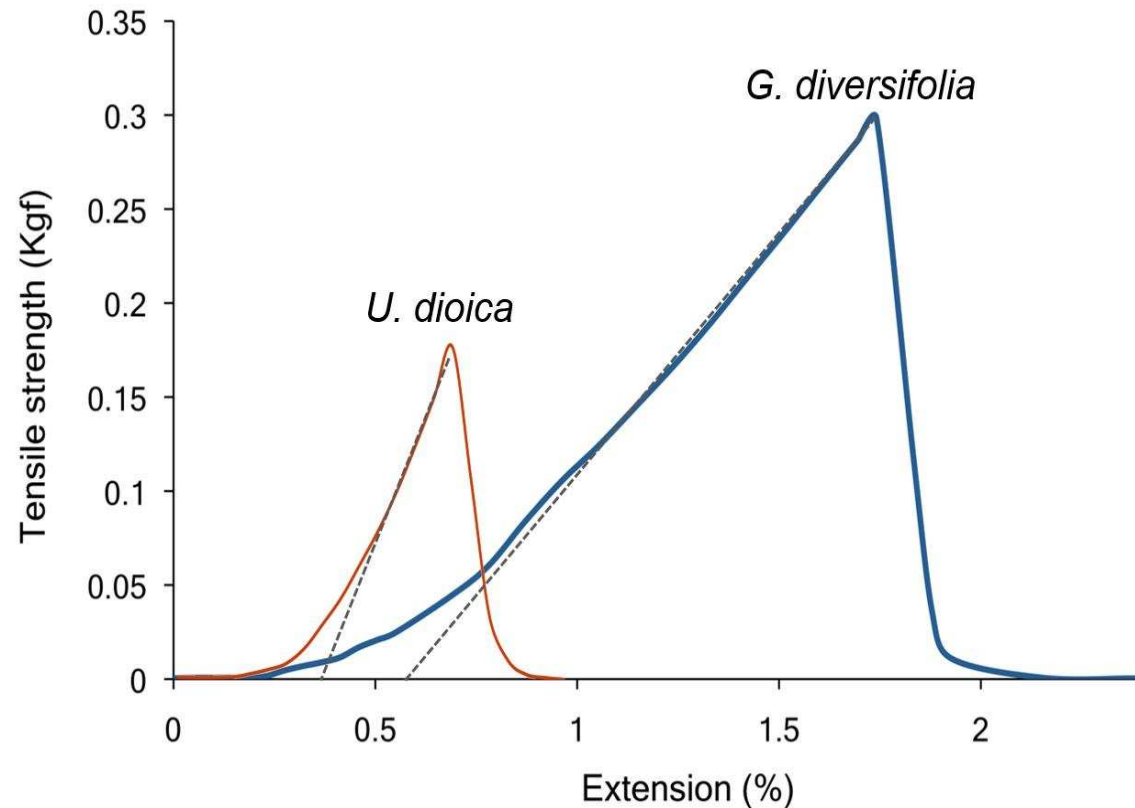
$$\sigma = \frac{F}{A} \qquad E = \frac{\sigma}{\epsilon}$$

- 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

- 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)

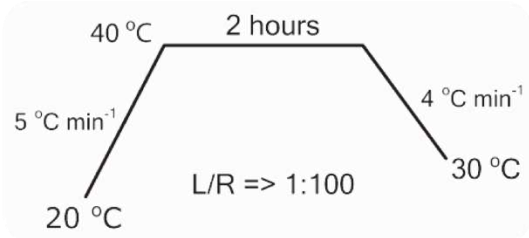


Alkali treatment of cellulose



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before NaOH treatment

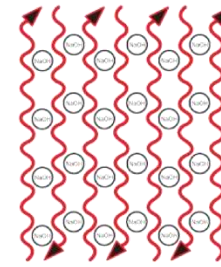
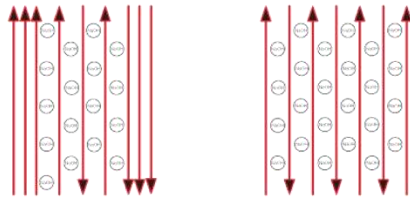
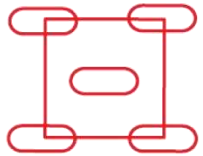


NaOH

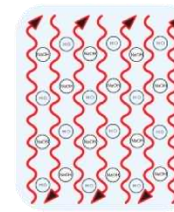
swelling with NaOH

washing in H₂O

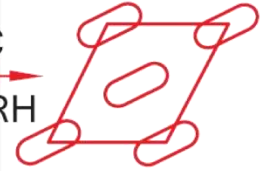
final drying stage



H₂O



20 °C
65% RH



Cellulose I

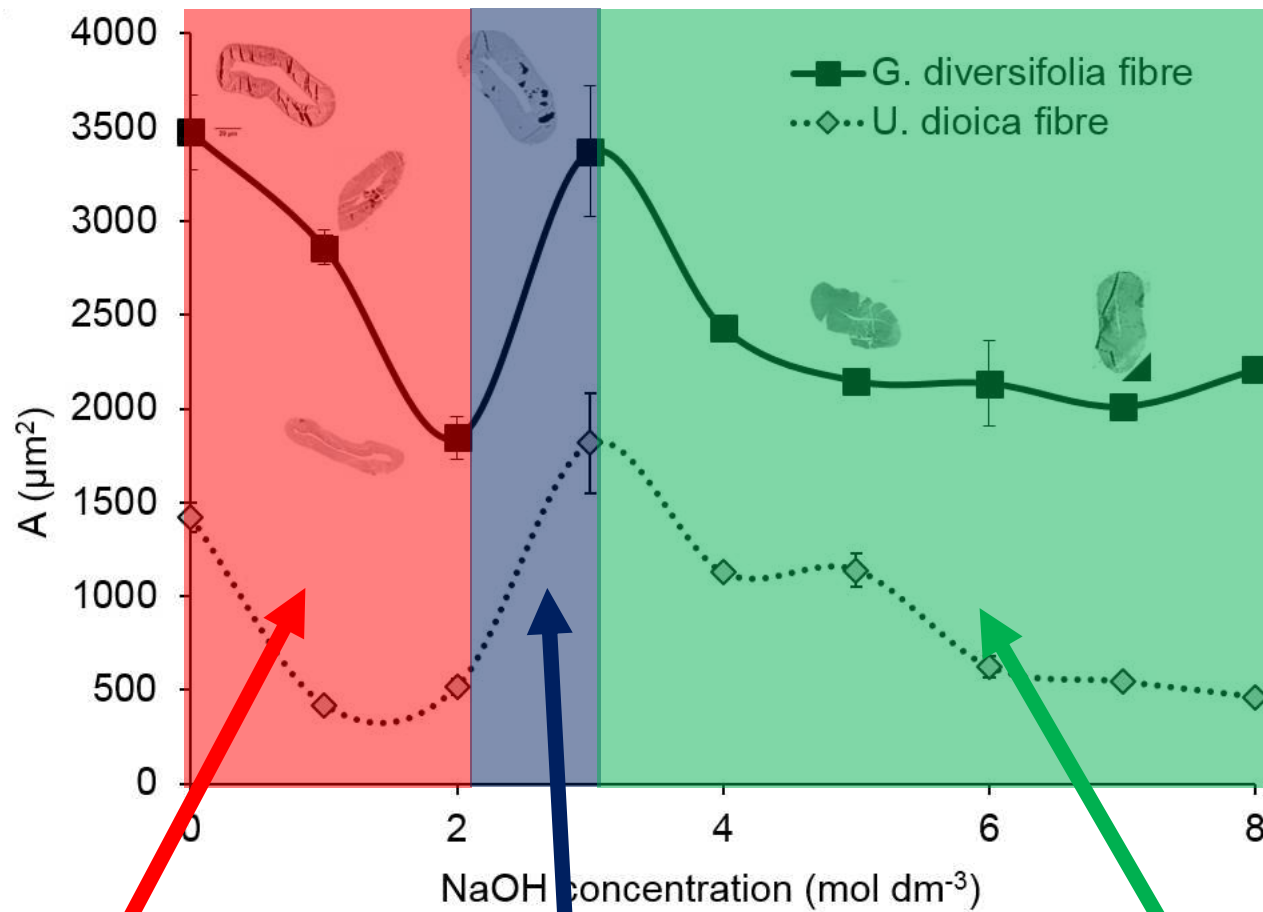
Cellulose I +
Na - Cellulose I

Na - Cellulose I

Na - Cellulose II

Cellulose
Hydrate II

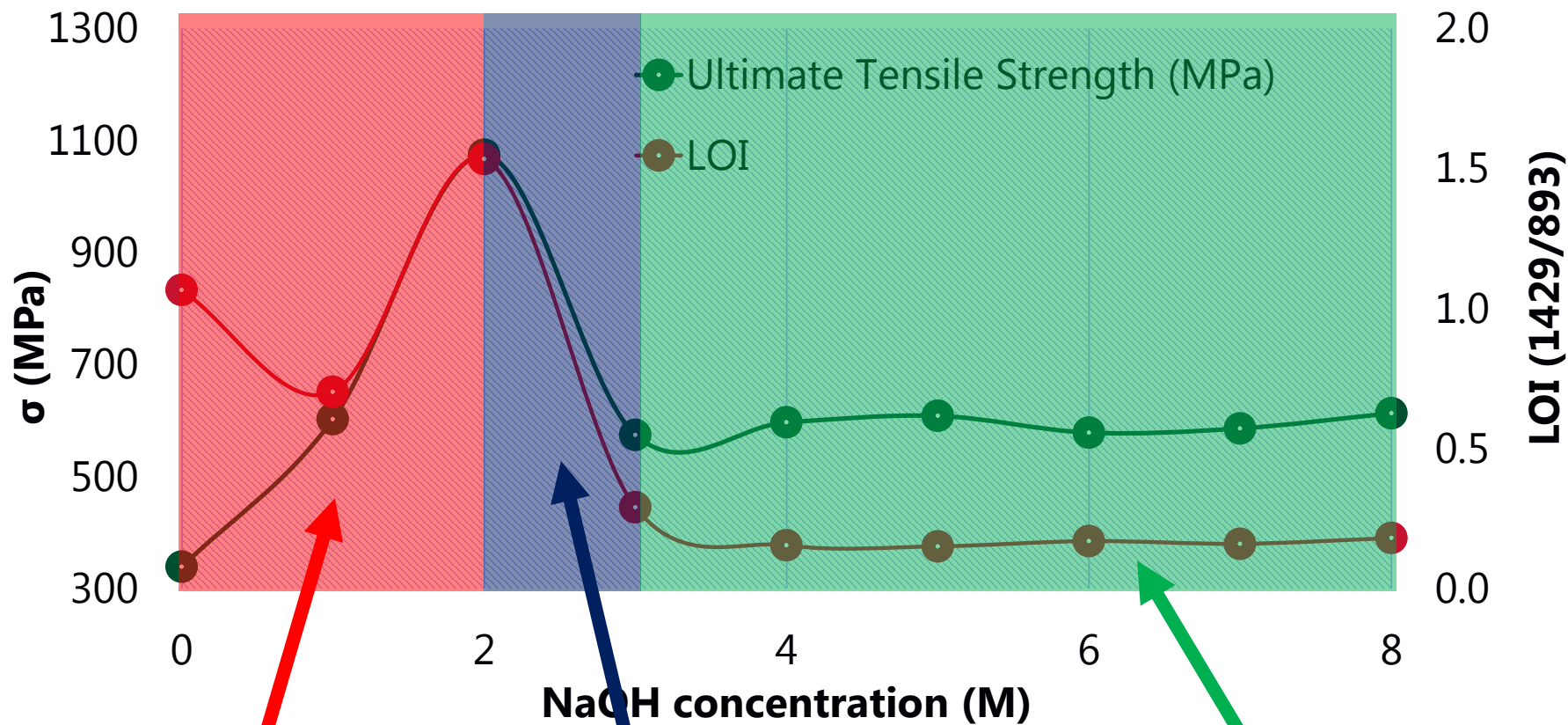
Cellulose II



A decreases as cellulose I \rightarrow 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 \rightarrow 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



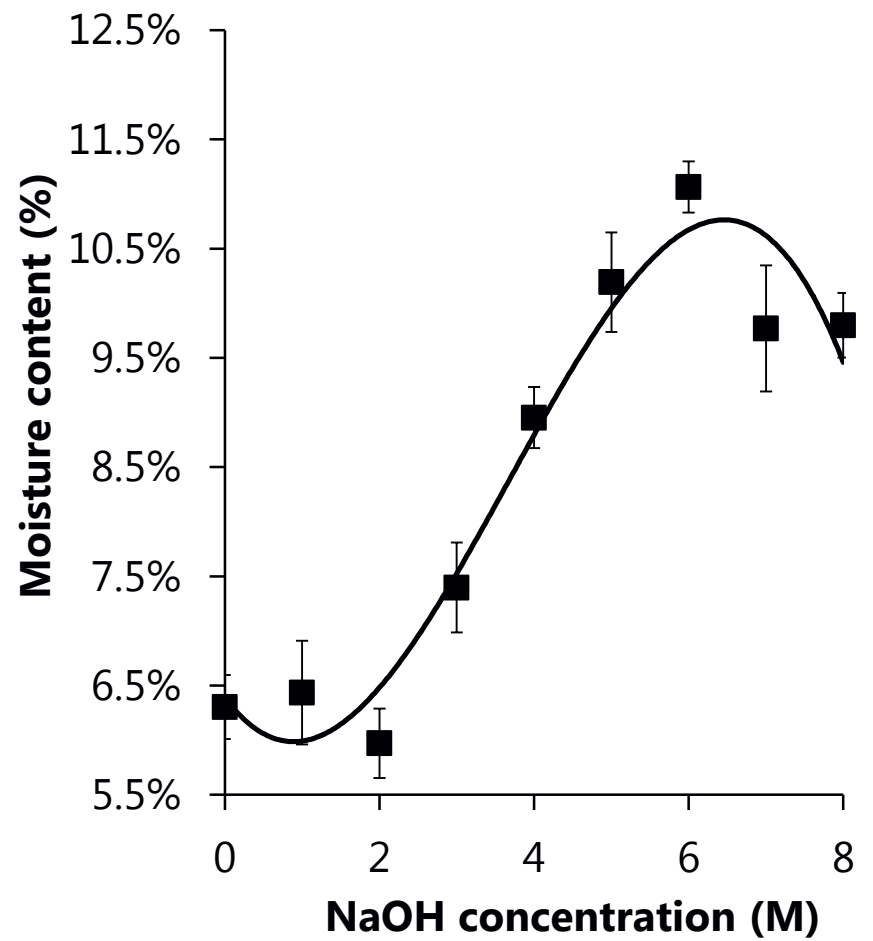
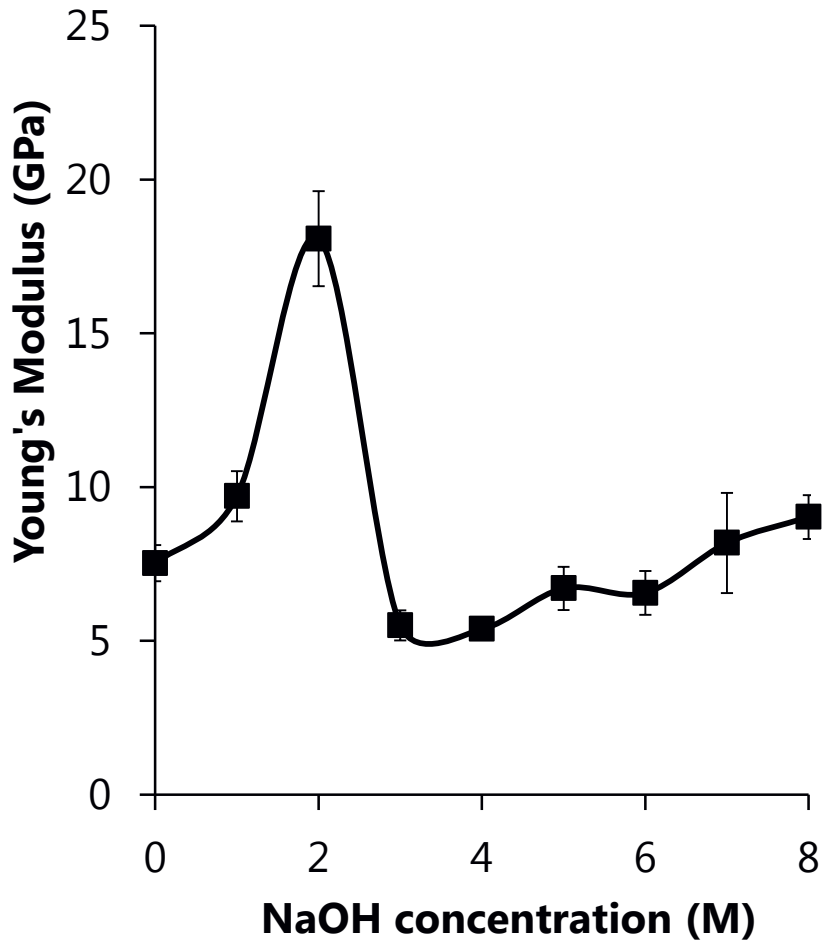
As σ increases, lateral order index (LOI; representation of degree of crystallinity in fibre) also increases

cellulose I \rightarrow Na-cellulose I
intermolecular H-bonds are broken

freedom of movement between adjacent cellulose polymer chains

σ decreases as Na-cellulose I \rightarrow 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



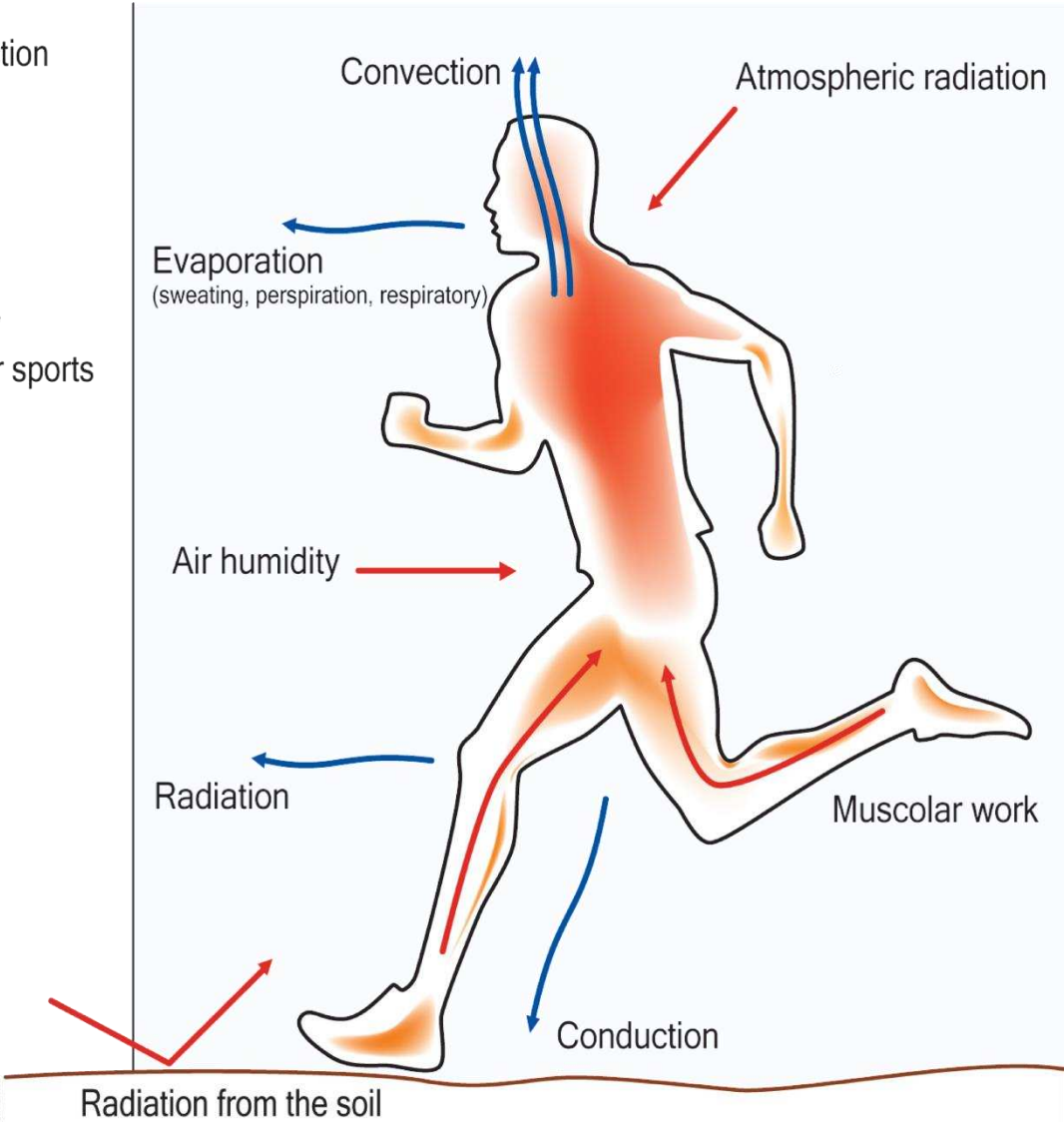
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→ Heat production

→ Heat loss



Thermogram of the body variations during outdoor sports

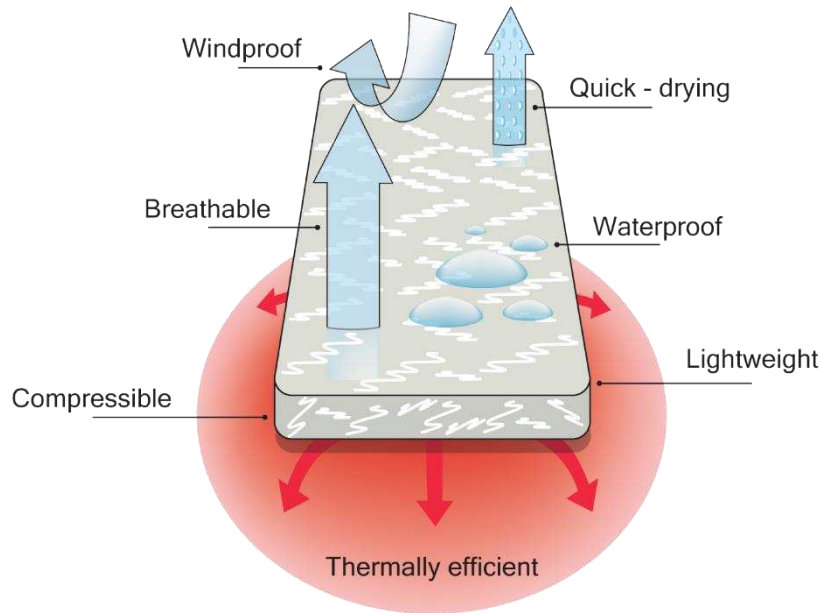


Three-layer outdoor clothing system



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Primaloft® jacket



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

Achievable with
G. diversifolia??

base

4 mol dm⁻³ NaOH

Breathability

middle

0 mol dm⁻³ NaOH

Thermal insulation

shell

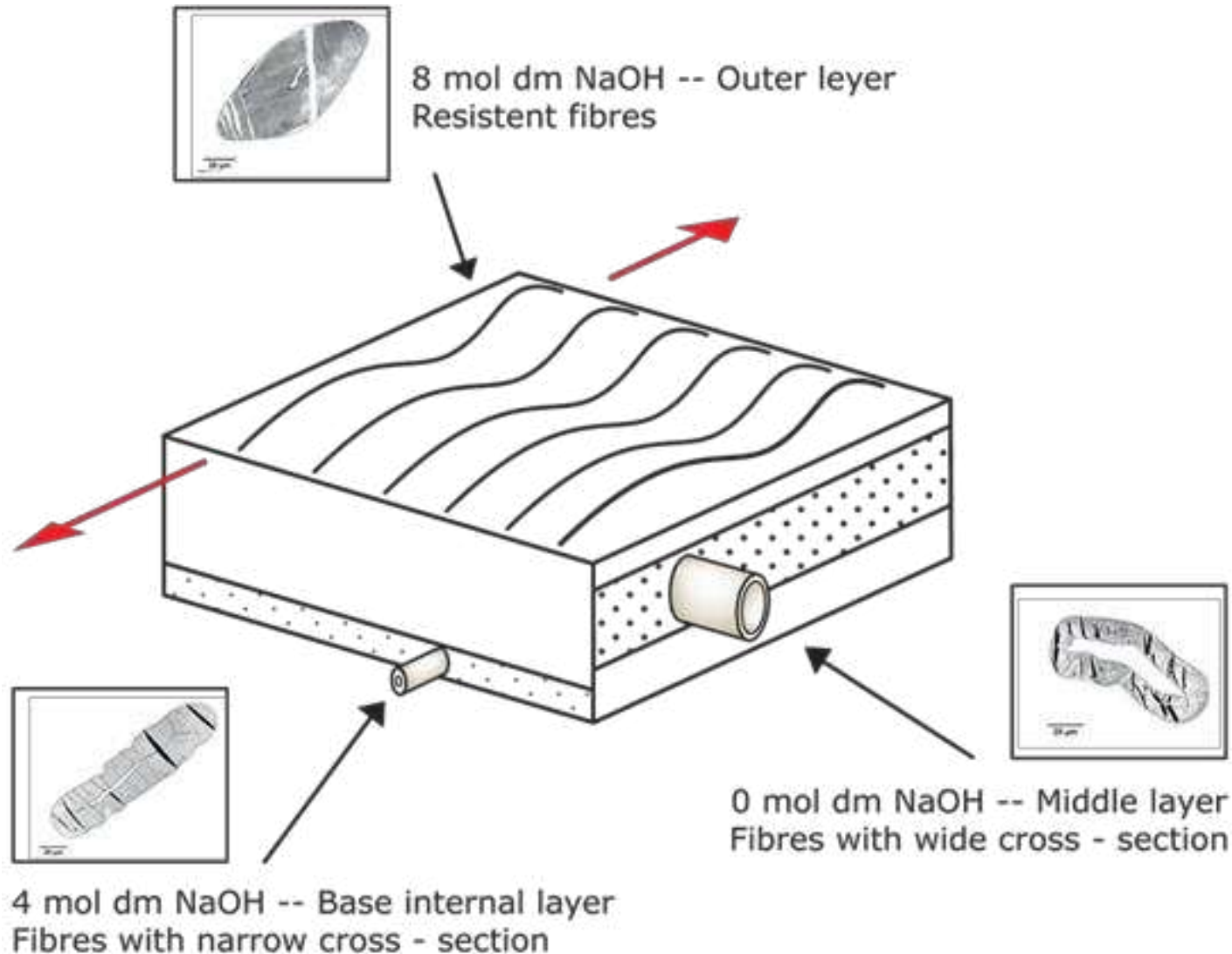
8 mol dm⁻³ NaOH

Resistant to abrasion

Three-layer performance material from *G. diversifolia*



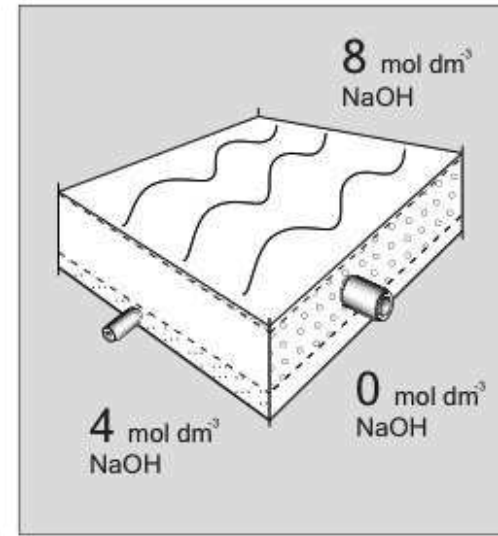
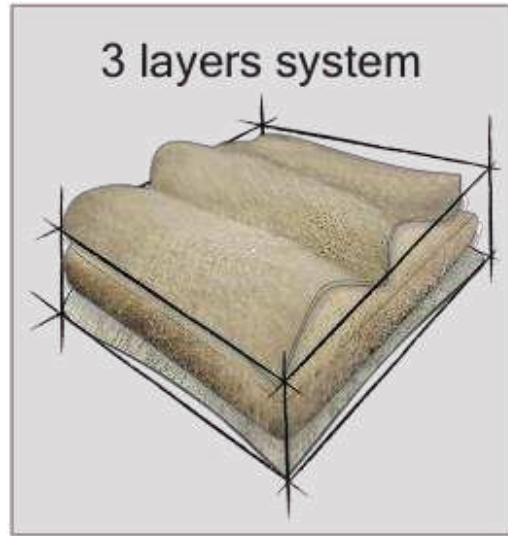
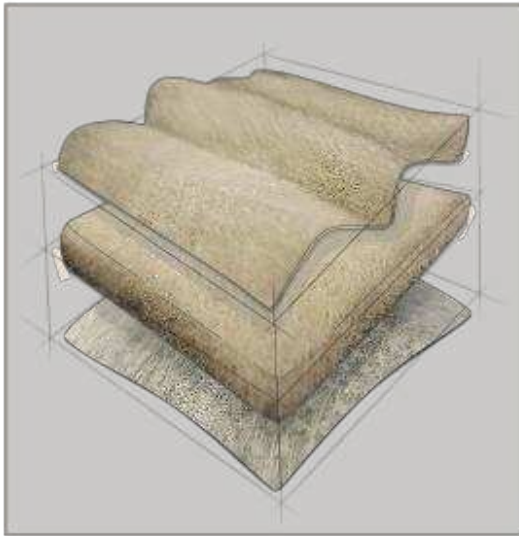
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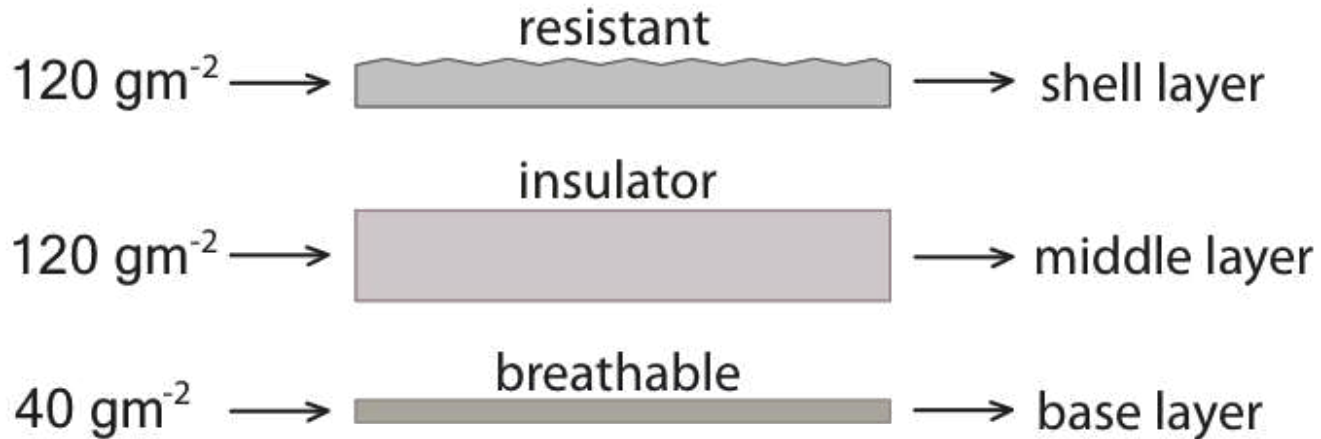
Three-layer performance material from *G. diversifolia*



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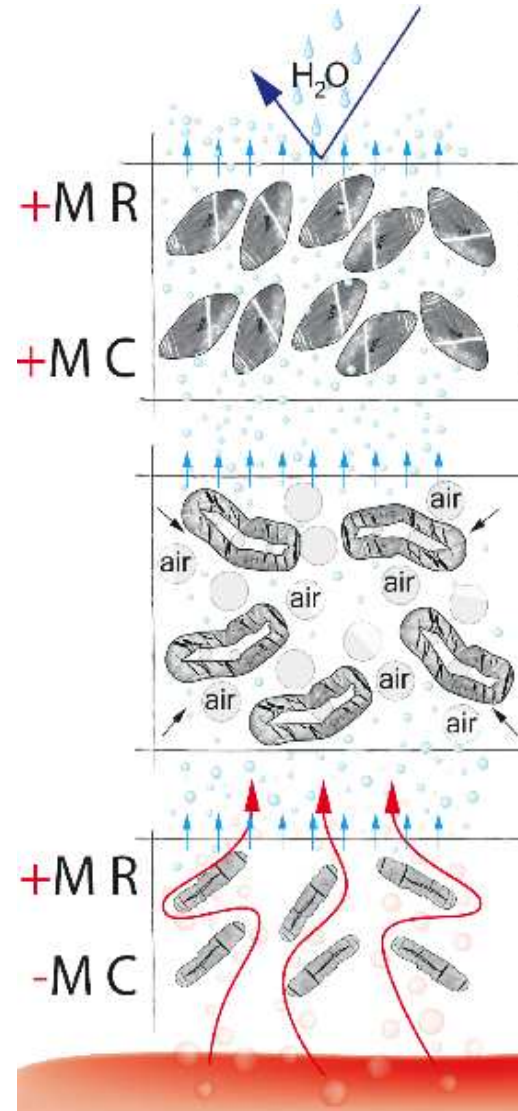
3 layers



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 originating 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 + capillary structure created by narrow fibre cross-section allows good permeability

- 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**

School of Design

SUSTAINABLE MATERIALS RESEARCH GROUP



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Thank you

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