Interfaces in composites based on wood and other lignocellulosic fiber

Mark Hughes

Department of Forest Products Technology

Helsinki University of Technology

Finnish-Japanese Workshop on Functional Materials
Espoo & Helsinki, Finland
25 & 26 May 2009

Contents

- Overview of research activities in the Wood Materials Technology group
- Wood veneer surfaces in relation to bonding
- Interfaces in lignocellulosic fibre reinforced polymer matrix composites

Research & teaching groups at the department

- Chemical Pulping and Wood Refinery
- Clean Technologies
- Forest Biorefinery
- Forest Products Surface Chemistry
- Paper Converting and Packaging
- Paper Technology
- Printing Technology
- Wood Chemistry
- **Wood Material Technology**
- Wood Product Technology

Current research themes in Wood Materials Technology

- Wood fracture (particularly in relation to its use as a structural material)
- Mechanics of wood and wood-based composites
- Physics of the veneer peeling process
- Non-destructive evaluation of veneer
- Wood modification (thermal, chemical, impregnation)
- Surface properties in wood (veneer)
- Wood and non-wood fibre reinforced polymer matrix composites, including “nanocomposites” (particularly interfaces)

Interfaces in wood based materials

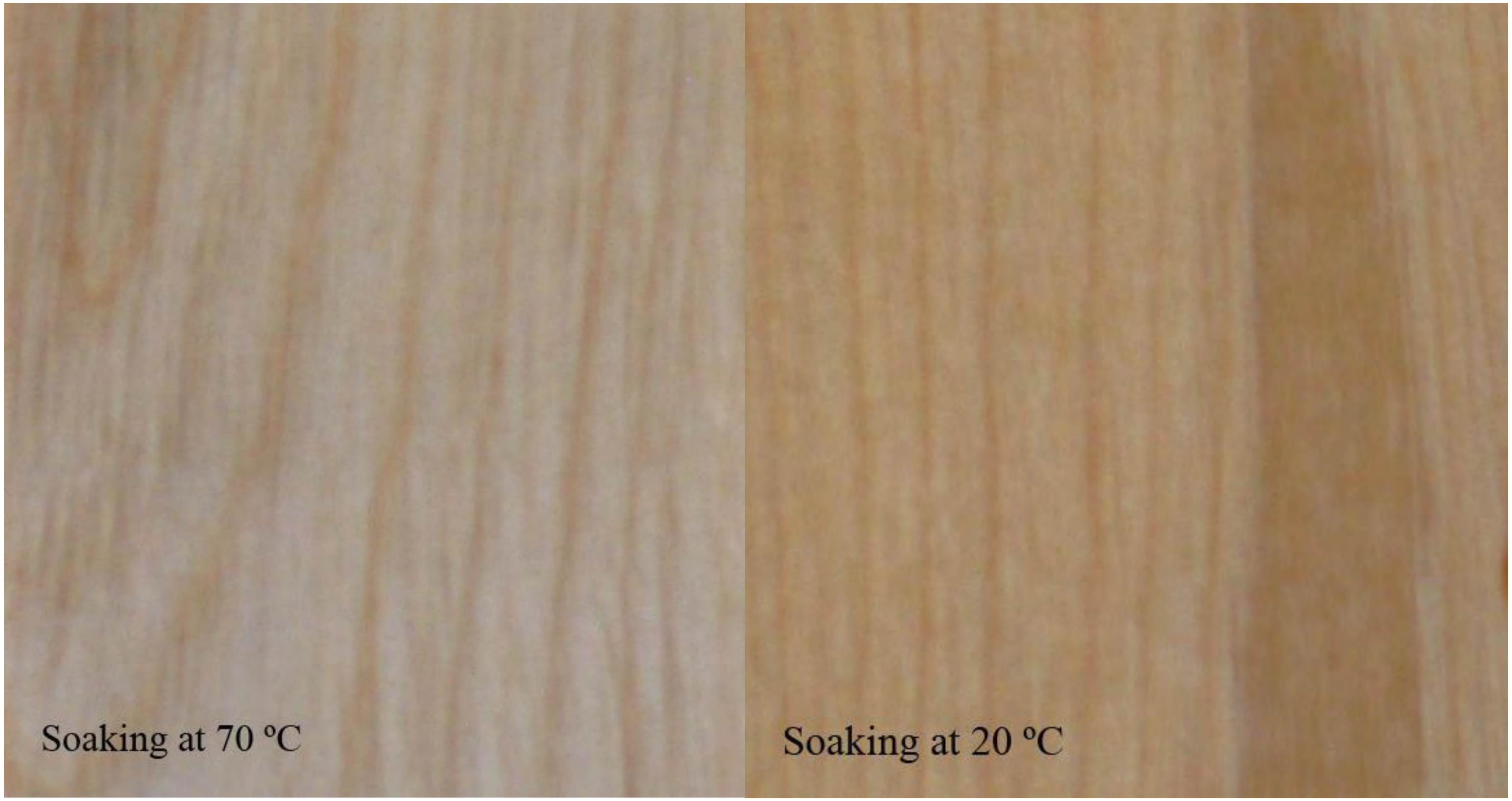
- Composite materials based on wood or other lignocellulosic fiber offer many opportunities for the development of new materials
- Interfaces (or interphases) created during the formation of wood and natural fibre-based composites largely control both the short and long term performance of these materials
- Interfaces are influenced by the physical and chemical properties of the substrate (fibre), the properties of the adhesive (matrix) and the interaction between the two in the formed system (micromechanics).

Veneer surfaces

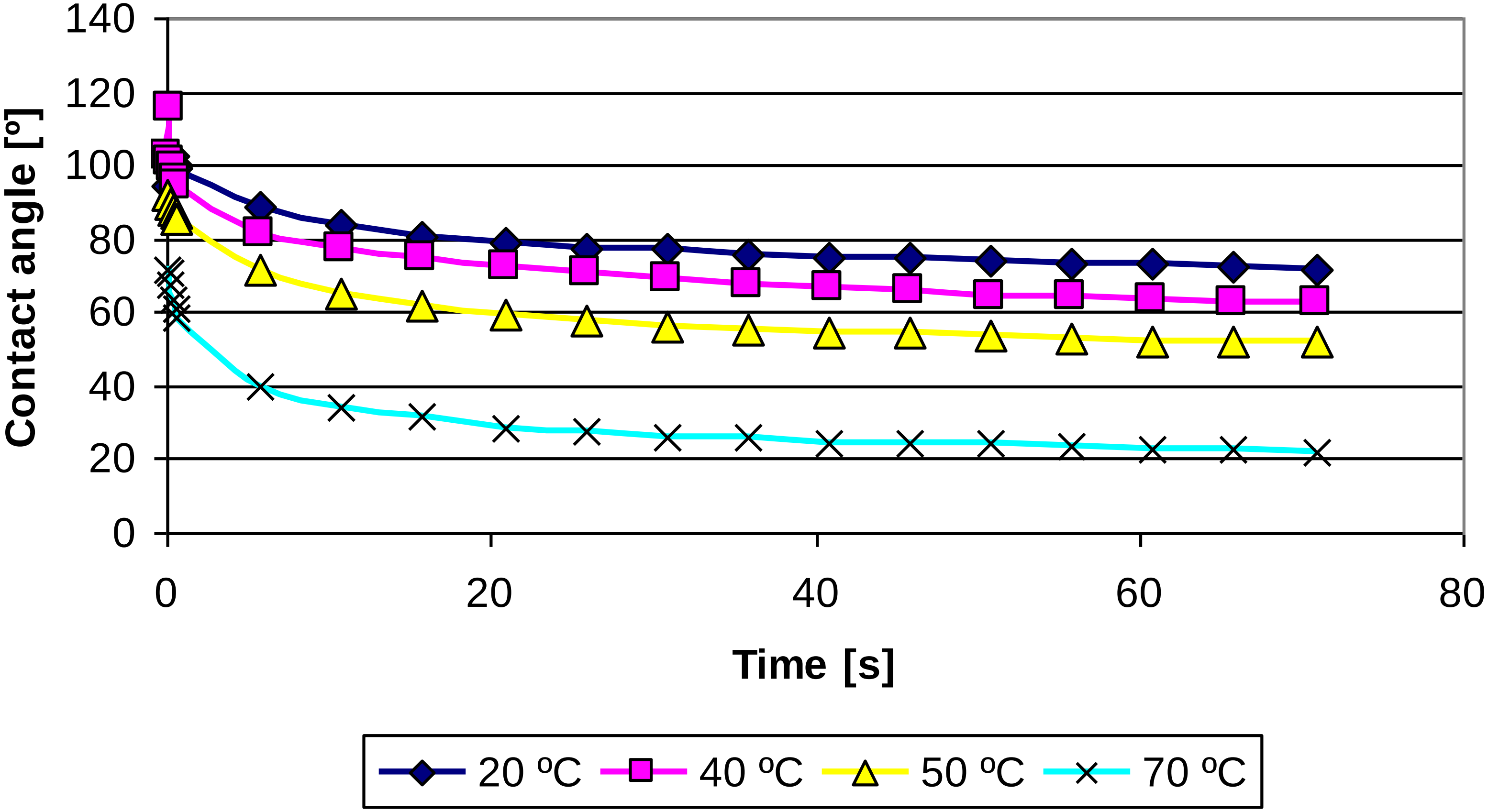
Peeled veneer production for plywood

- Industrially logs are soaked at temperatures of up to 70 ^{o}C before peeling or slicing into veneer
- This is known to affect the colour of the veneer
- But how does this affect the surface in relation to the formation of the adhesive bond with a liquid resin?

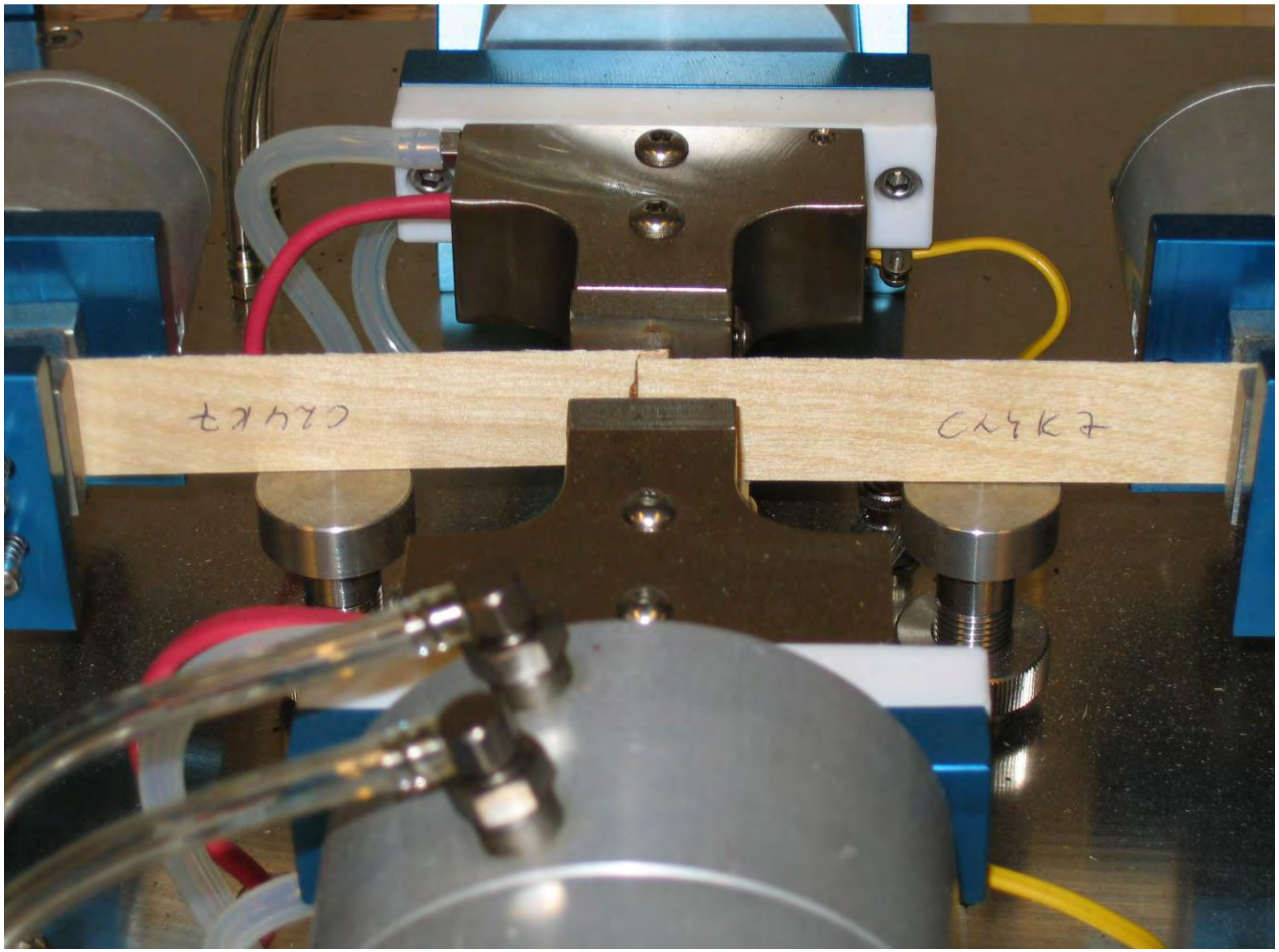
Effect of soaking on color



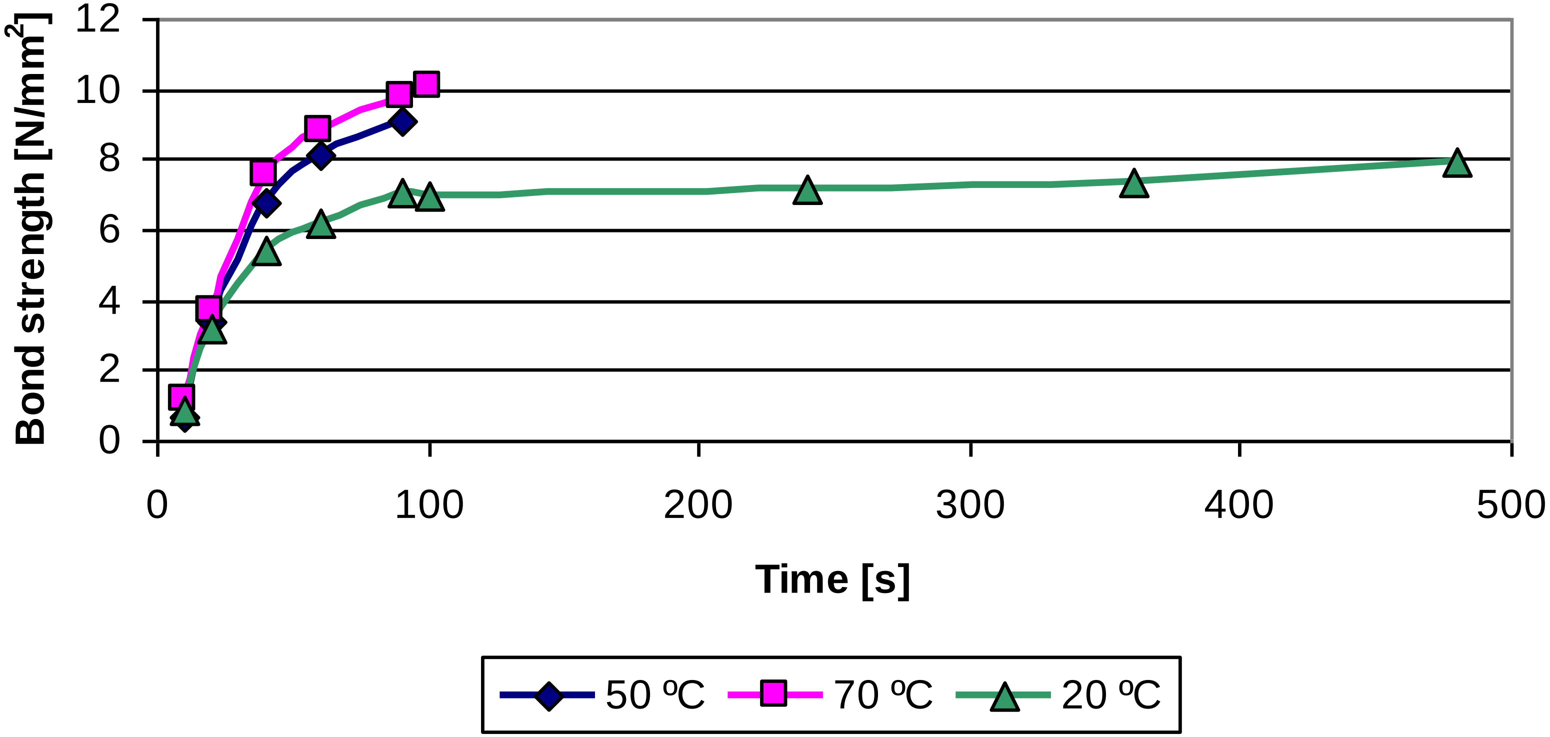
Effect of soaking temperature on wetting behavior of veneer



Automated Bonding Evaluation System



Effect of soaking temperature on bond development

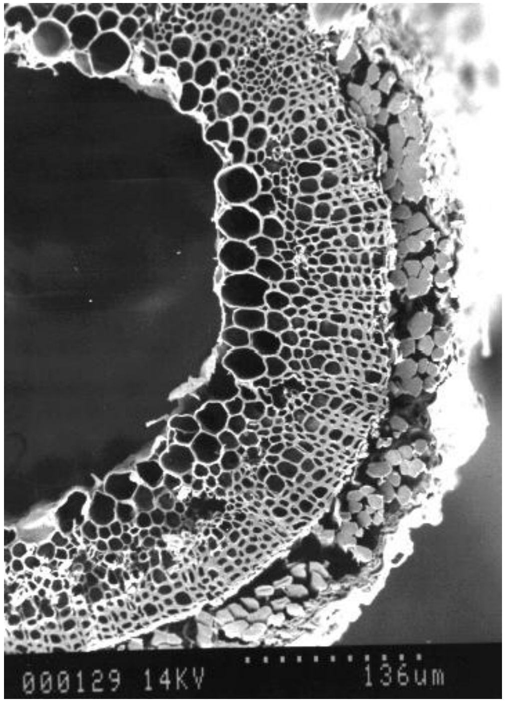


Conclusions

- History and processing influence the surface of the peeled veneer
- This in turn influences adhesive bond formation
- Implications for all wood-adhesive joints
- Current and future research is focussing on mechanisms behind these changes in wood (chemistry) and the impact on adhesion
- Subject of a forthcoming Tekes & industry funded 3 year project (starting in June 2009)

Interfaces in natural fibre reinforced composites

Bast fibre



Bast vs. glass…

- The reported properties of many natural fibres make them potentially suitable as reinforcement in high performance composite materials

Fibre type	*Density ($g\ cm^{-3}$)*	*Young's modulus (GPa)*	*Tensile strength (MPa)*
E-glass	2.56	76	2000
Flax	1.4-1.5	50-70	500-900
Hemp	1.48	30-60	310-750
Jute	1.4	20-55	200-450

(Sources: Hull & Clyne, 1996; Ivens *et al*, 1997)

Structural properties

- For thermosetting polymer matrix composites:
- Good stiffness (comparable with GFRP)
- Adequate strength
- Poor fracture properties (order of magnitude lower work of fracture)

Reinforcement efficacy

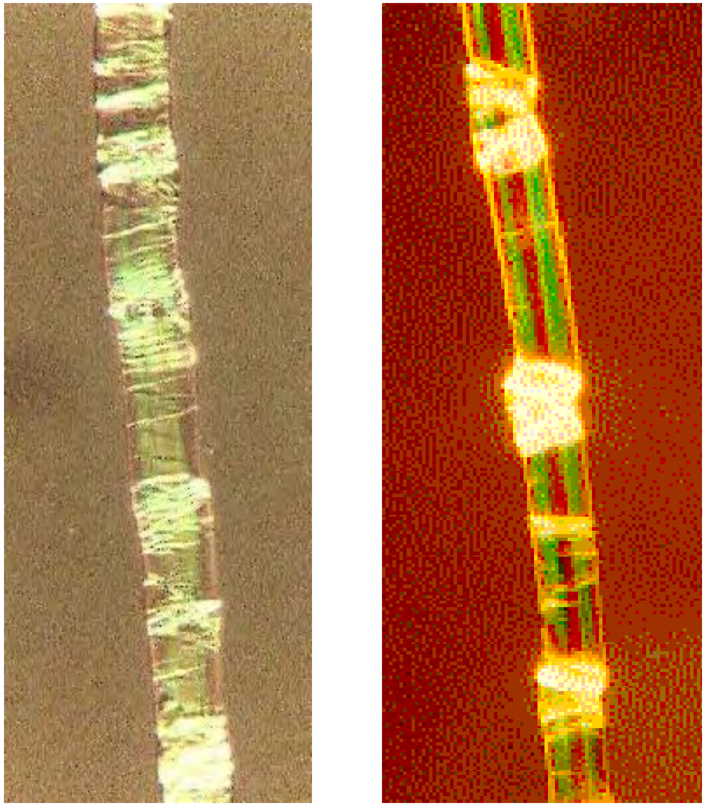
- For good reinforcement fibres of high aspect ratio are required
- Aspect ratio of e.g. flax ultimate fibres around 1200. Potentially good reinforcement
- But fibre damage may play a significant role

Fibre properties

- Bast (and wood fibre) fail in compression through the formation of kink bands
- In 1998, Davies and Bruce published a paper showing that the Young’s modulus and tensile strength of flax and nettle fibre are negatively affected by the presence of these so called micro-compressive defects or kink bands….

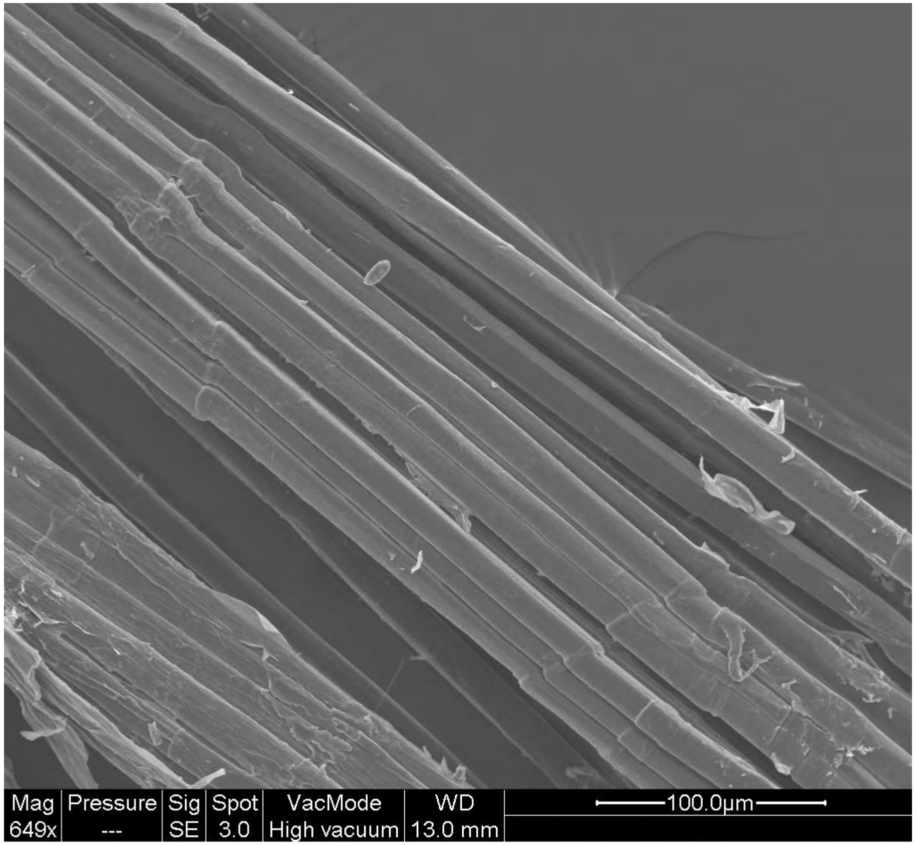
Polarised light

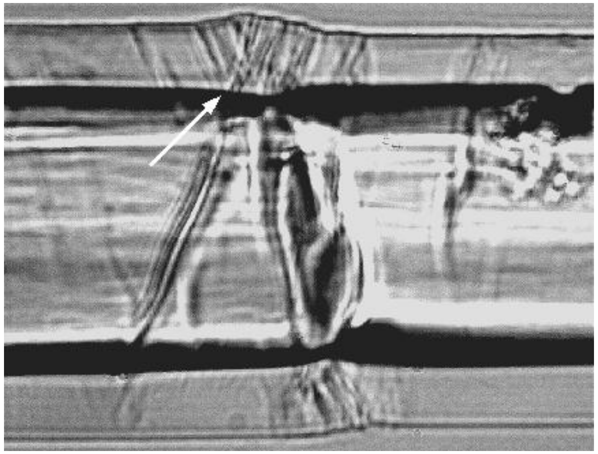
Unprocessed hemp fibre

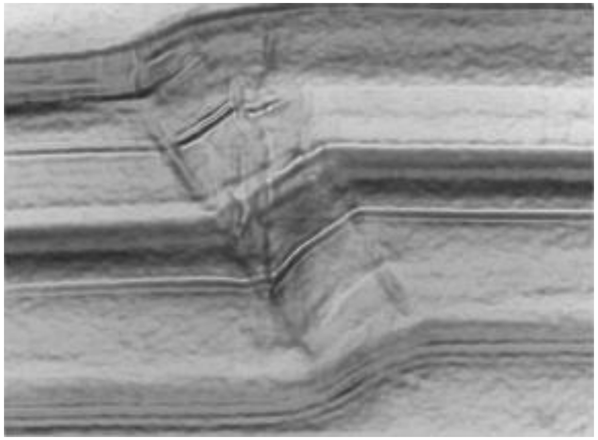


Mechanically processed hemp fibre

Fibre structure

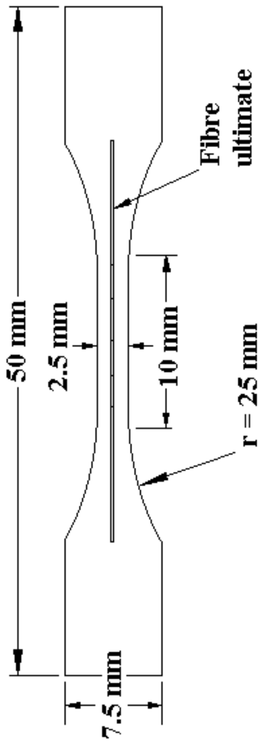






Failure through the formation of kink bands

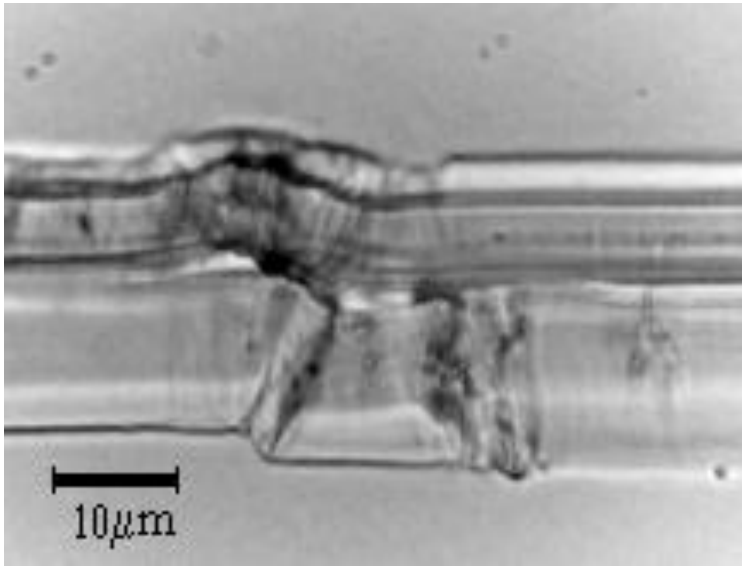
Effect on the interface

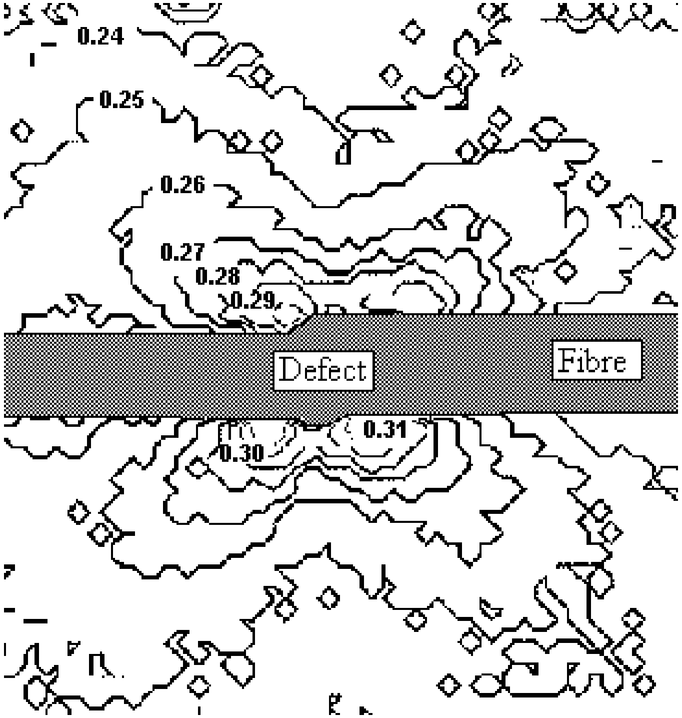


- Micro tensile specimen
- Half fringe photoelasticity system

Stress concentrations

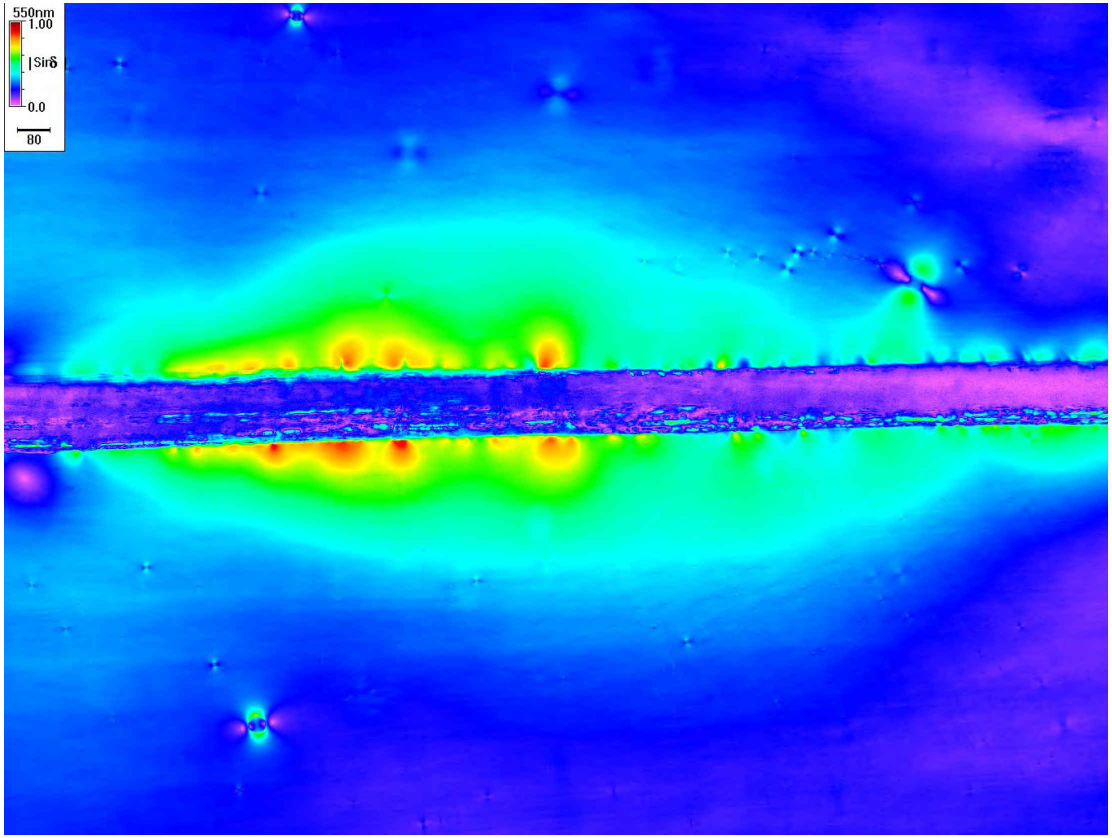
Shear stress distribution in an epoxy matrix adjacent to a defect in a strained specimen at small deformation



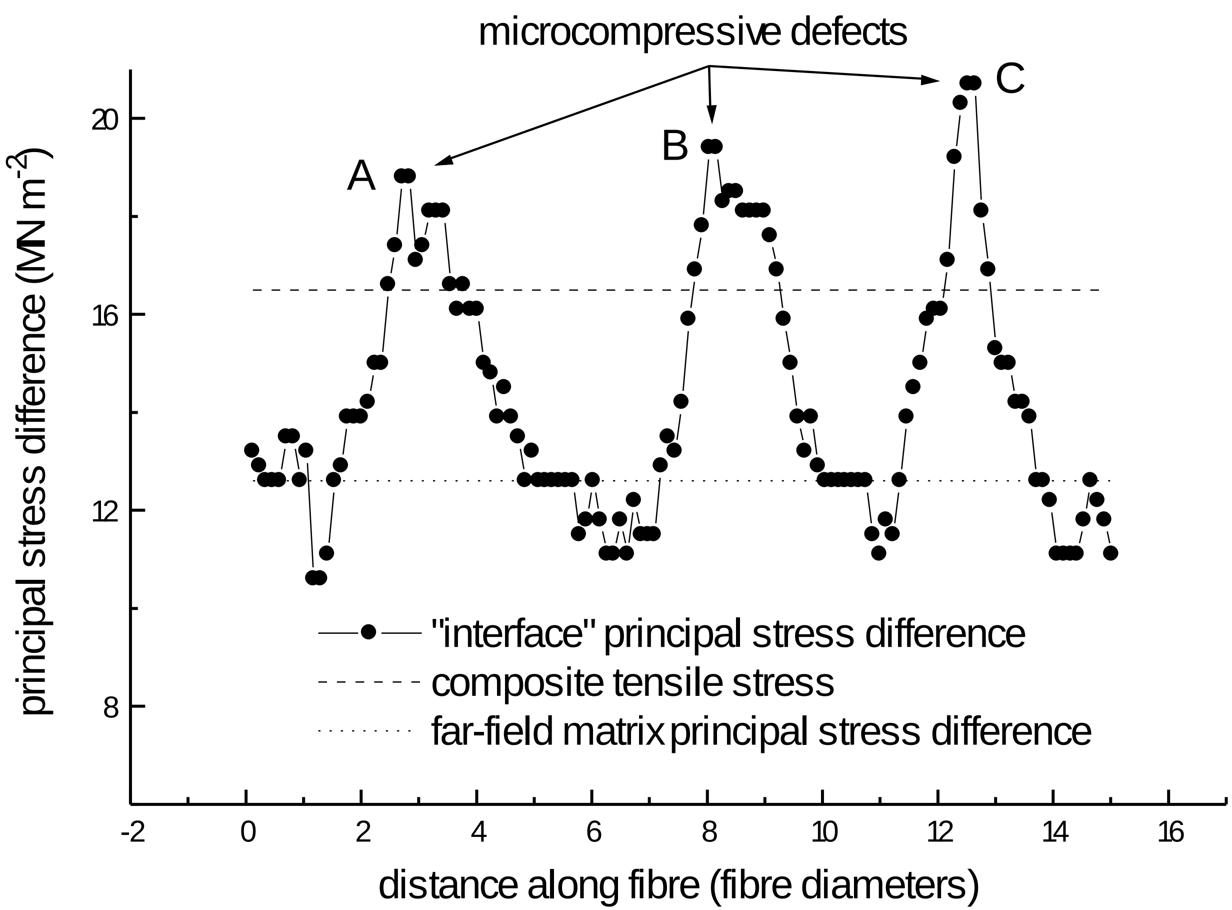


(Source: Hughes et al, 2000)

Matrix plastic deformation

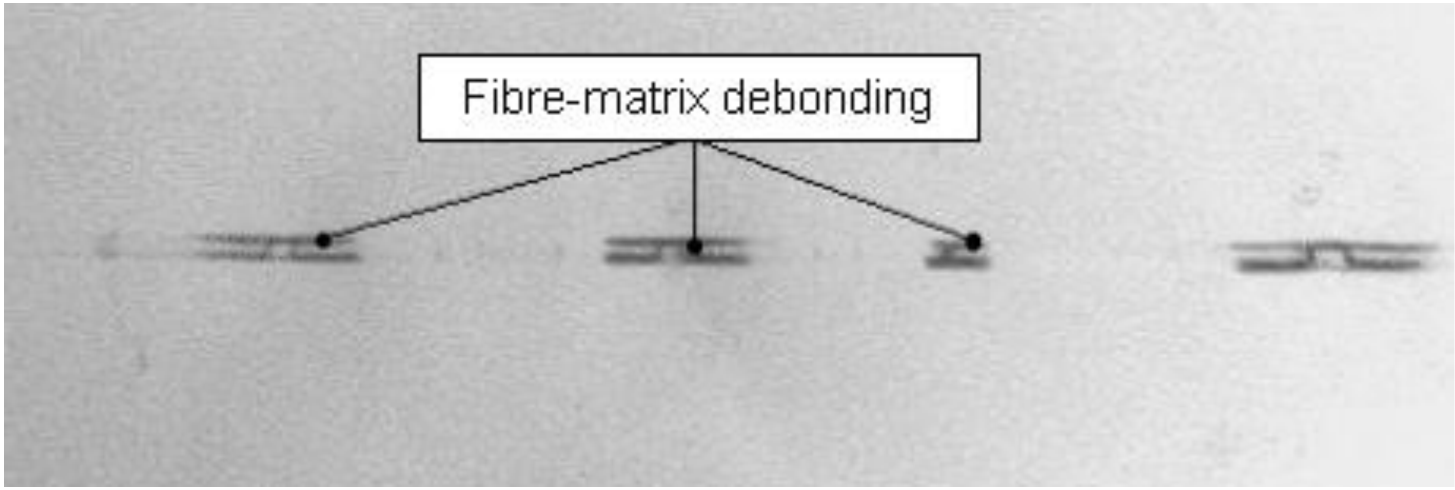


Interface behaviour



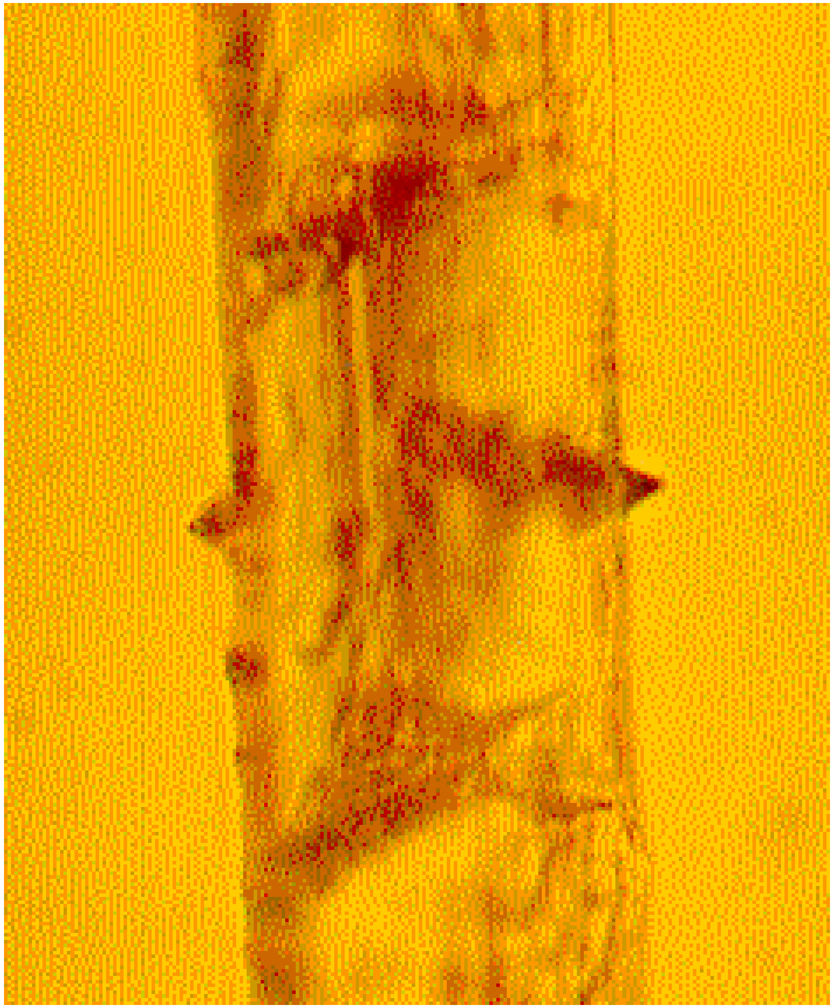
(Eichhorn et al, 2001)

Fibre-matrix debonding

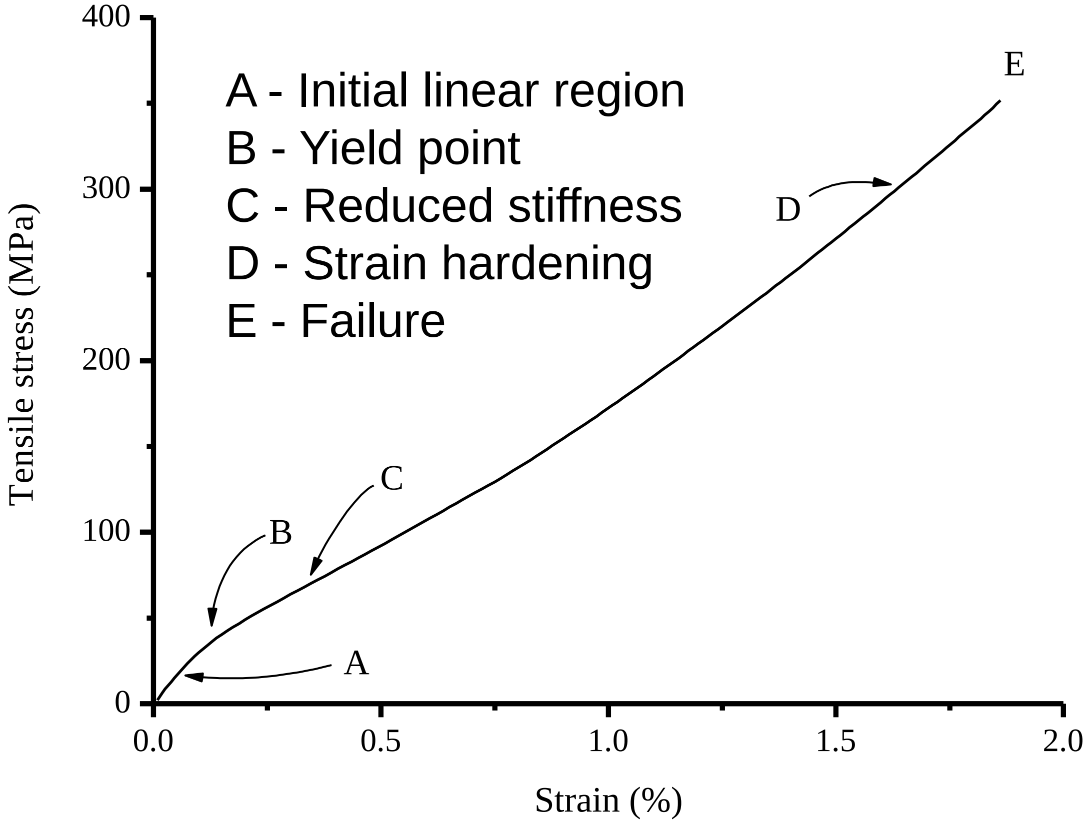


Failed single filament composites showing fibre-matrix debonding in regions of high shear stress concentration adjacent to fibre defects (and fracture)

Matrix cracking

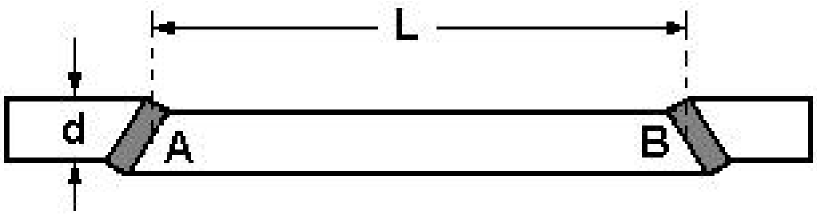


Deformation behaviour
(UD composite of ca. 55% volume fraction)



(Hughes et al, 2007)

Fibre model



- Continuous fibre acts as a series of shorter fibres or segments
- Kink bands act as the loci of microstructural failure
  - fibre fracture
  - fibre-matrix debonding
  - matrix cracking
- Affects composite macroscopic behaviour

Summary

- Composite properties are influenced by the fibre properties and particularly the presence of micro-compressive defects
- Micro-compressive can be removed, but not practicable in reality
- **Alter the fibre architecture to improve properties**
- **“Deconstruct” the cell wall and isolate the microfibrils – use these as reinforcement**

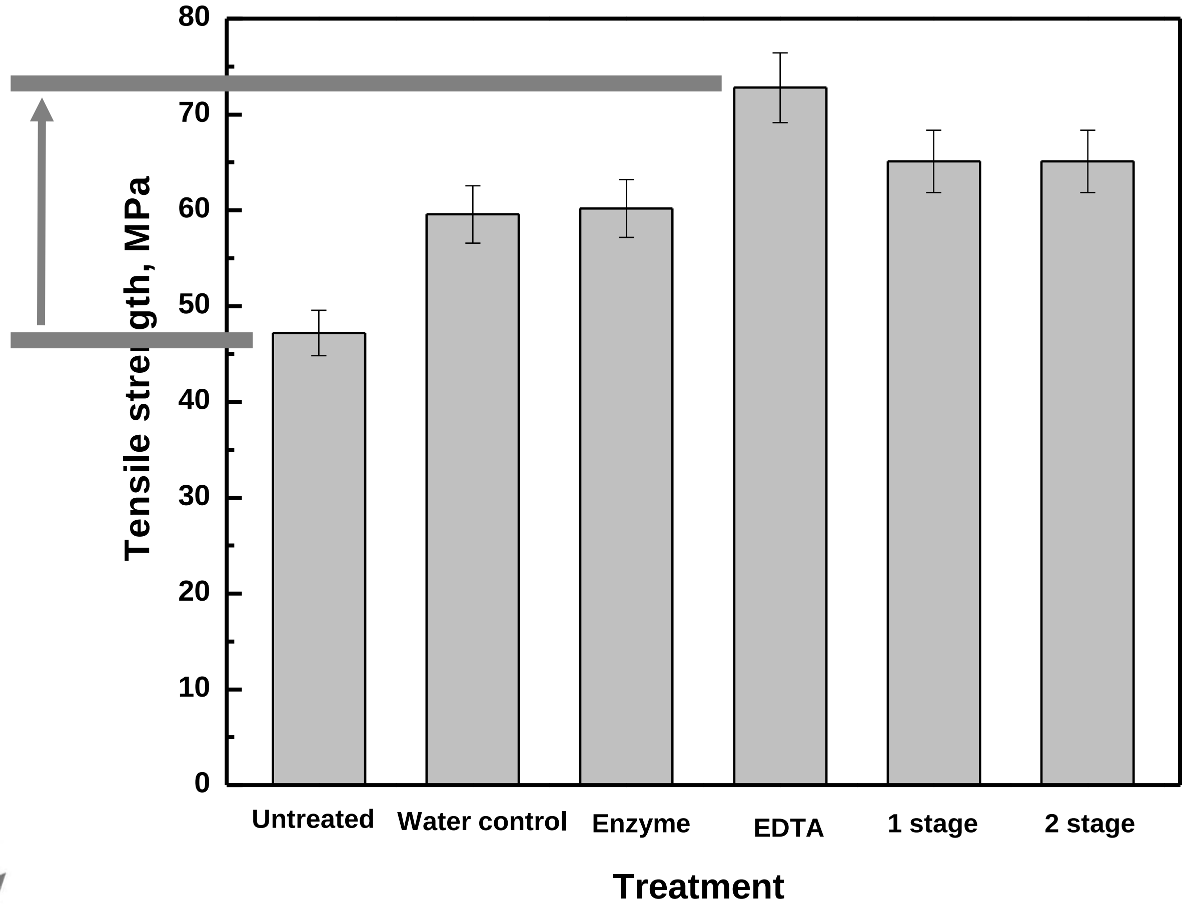
Fibre architecture & interface engineering

- Manipulation of the “fibre architecture” at macroscopic and microscopic levels, as well as “interface engineering” to improve composite performance
- “Fibre architecture” includes:
  - fibre geometry (aspect ratio)
  - fibre orientation
  - packing arrangement
  - fibre volume fraction (V_f)

Fibre modification

- Pectinolytic enzymes were used to preferentially remove the inter-cellular binding substances and degrade any extraneous adhering tissue
- Chelating agents for calcium (EDTA), which forms part of the pectin structure, was used to remove pectin
- Combinations of chelating agents and enzymes were employed, applied sequentially and together

Tensile strength



(Stuart et al, 2005)

Ongoing research

- Continue to develop an understanding of the effect of fibre defects and other structural features on interface behaviour
  - Wood and non-wood fibre
  - Micro-fibrillated cellulose
- Interface engineering
  - Bulk and surface modification
- Development of NF textiles for composite applications
  - Bi- and multi-axial fibre structures; woven and non-woven
- Nanocomposites
- The above mentioned research is the subject of several ongoing research projects funded by: The Academy of Finland, the European Commission and Helsinki University of Technology

References

- Davies, G.C. and Bruce, D.M. (1998). Effect of Environmental Relative Humidity and Damage on the Tensile Properties of Flax and Nettle Fibers. *Textile Res. J.*, **68**(9): 623-629
- Eichhorn, S.J., Baillie, C. A. and Zafeiropoulos, N., Mwaikambo, L.Y. and Ansell, M.P., Dufresne, A., Entwistle, M., Herrera-Franco P.J., and Escamilla, G.C., Groom, L., Hughes M. and Hill, C., Rials, T.G., Wild P.M. (2001). Current International Research into Cellulosic fibres and Composites. J. Mat. Sci. 36: 2107-2131
- Hughes, M., Carpenter, J. and Hill, C. (2007). Deformation and Fracture Behaviour of Flax Fibre Reinforced Thermosetting Polymer Matrix Composites. J. Mat. Sci. 42(7):2499-2511
- Hughes, M., Hill, C.A.S., Sèbe, G., Hague, J., Spear, M. and Mott, L. (2000). An Investigation into the Effects of Microcompressive Defects on Interphase Behaviour in Hemp-Epoxy Composites Using Half Fringe Photoelasticity. *Composite Interfaces* **7**(1): 13-29
- Hull, D. and Clyne, T.W. (1996). *An Introduction to Composite Materials*. Cambridge University Press, Cambridge, UK
- Ivens, J., Bos, H. and Verpoest, I. (1997). The Applicability of Natural Fibres as Reinforcement for Polymer Composites. *In: Renewable Biproducts: Industrial Outlets and Research for the 21st Century*. June 24-25, 1997, EC-symposium at the International Agricultural Center (IAC), Wageningen, The Netherlands
- Stuart, T., Liu, Q., Hughes, M., McCall, R.D., Sharma, S. and Norton, A. (2005) Structural Biocomposites from Flax – Part I: Effect of Bio-technical Fibre Modification on Composite Properties. Compos Part A-Appl S **37**(3): 393-404 2006