Strength scaling mechanics of polymer composites

Torben K. Jacobsen, LM Glasfiber A/S
Bent F. Sørensen, Risø National Laboratory

LM in headlines

- Leading manufacturer of wind turbine rotor blades
- 8 plants worldwide
- 2,200 employees incl. 110 engineers in R&D
- 15,700 MW of rotor blades since 1978
- € 230 million turnover in 2003
- Accumulated market share app. 40%

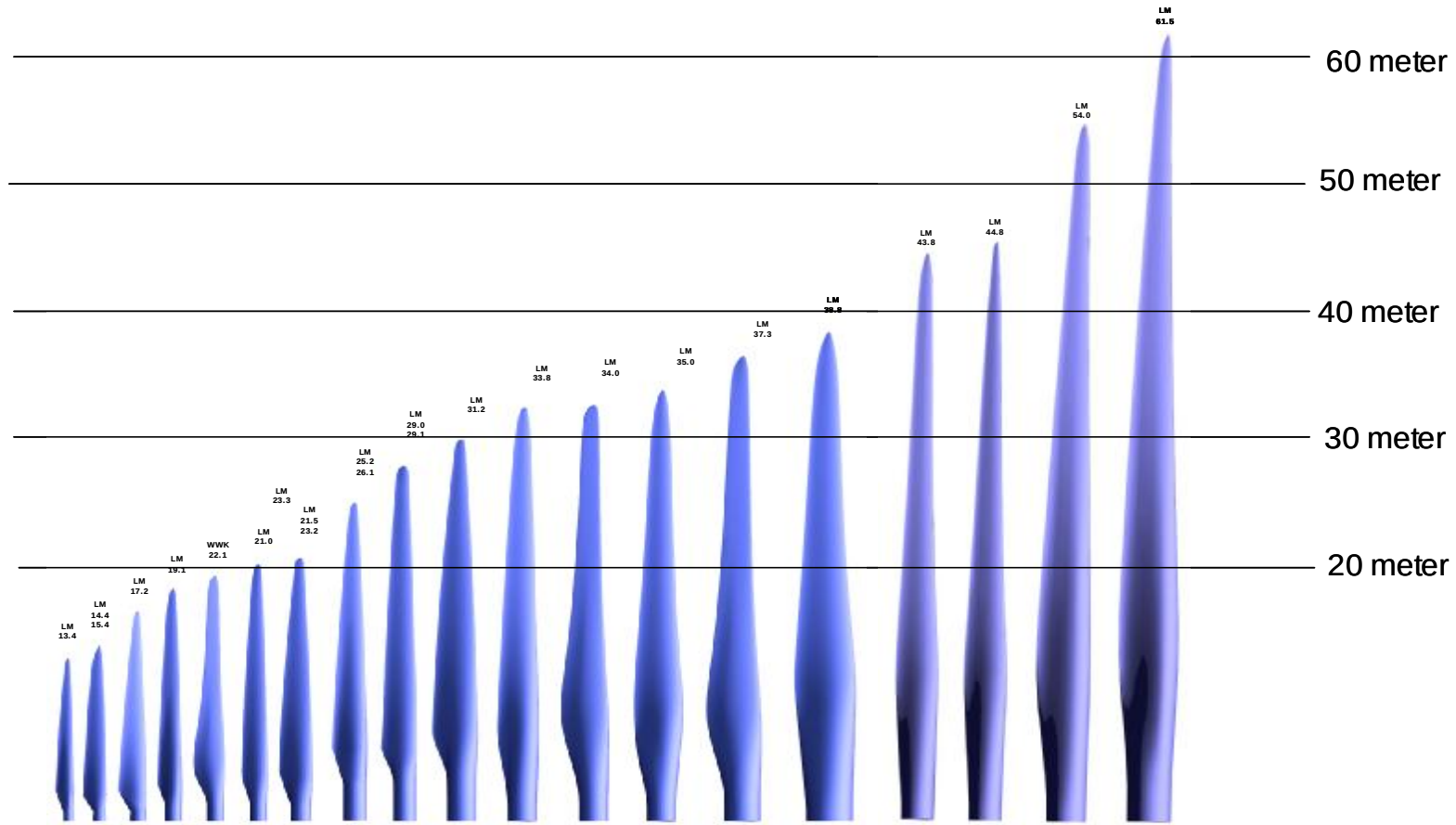
LM Worldwide

Segmentation of our production capacity

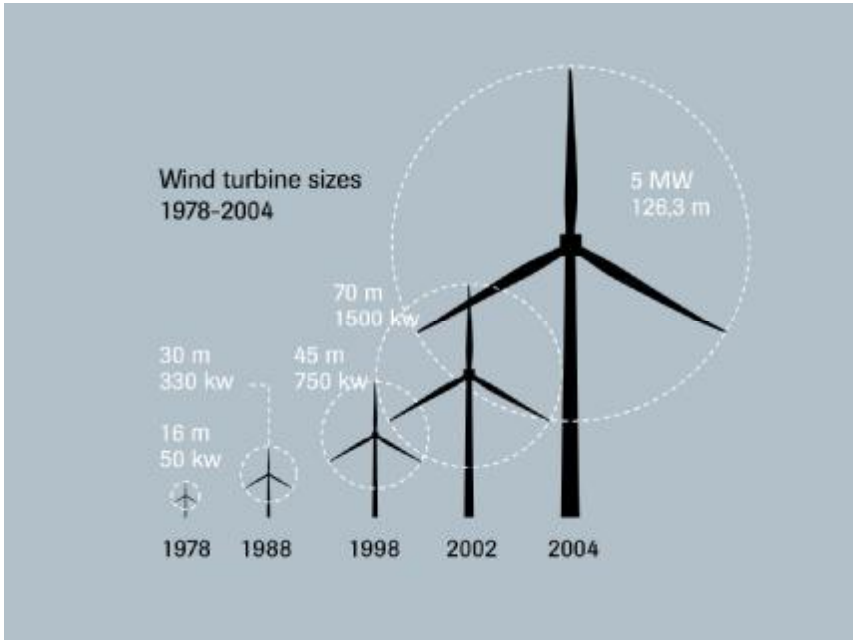
	No. of plants	MW*	Planned extensions
Northern Europe	2	2,300	400
Southern Europe	3	1,700	
North America	1	680	
Asia	2	450	
Total	8	5,130	
MW supplied in 2003		1,759	
Average capacity utilisation		34%	

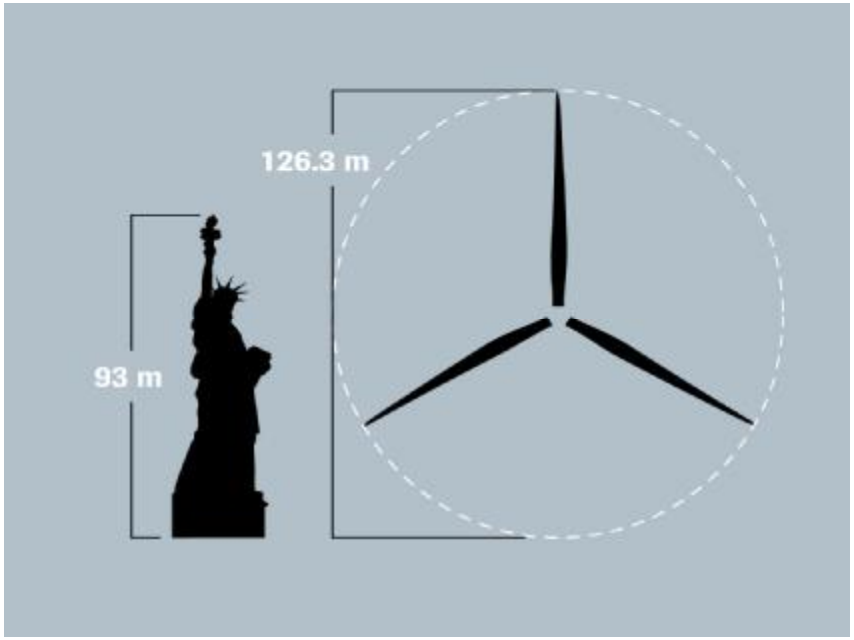
*The MW figures are based on the product mix for 2003

Product range

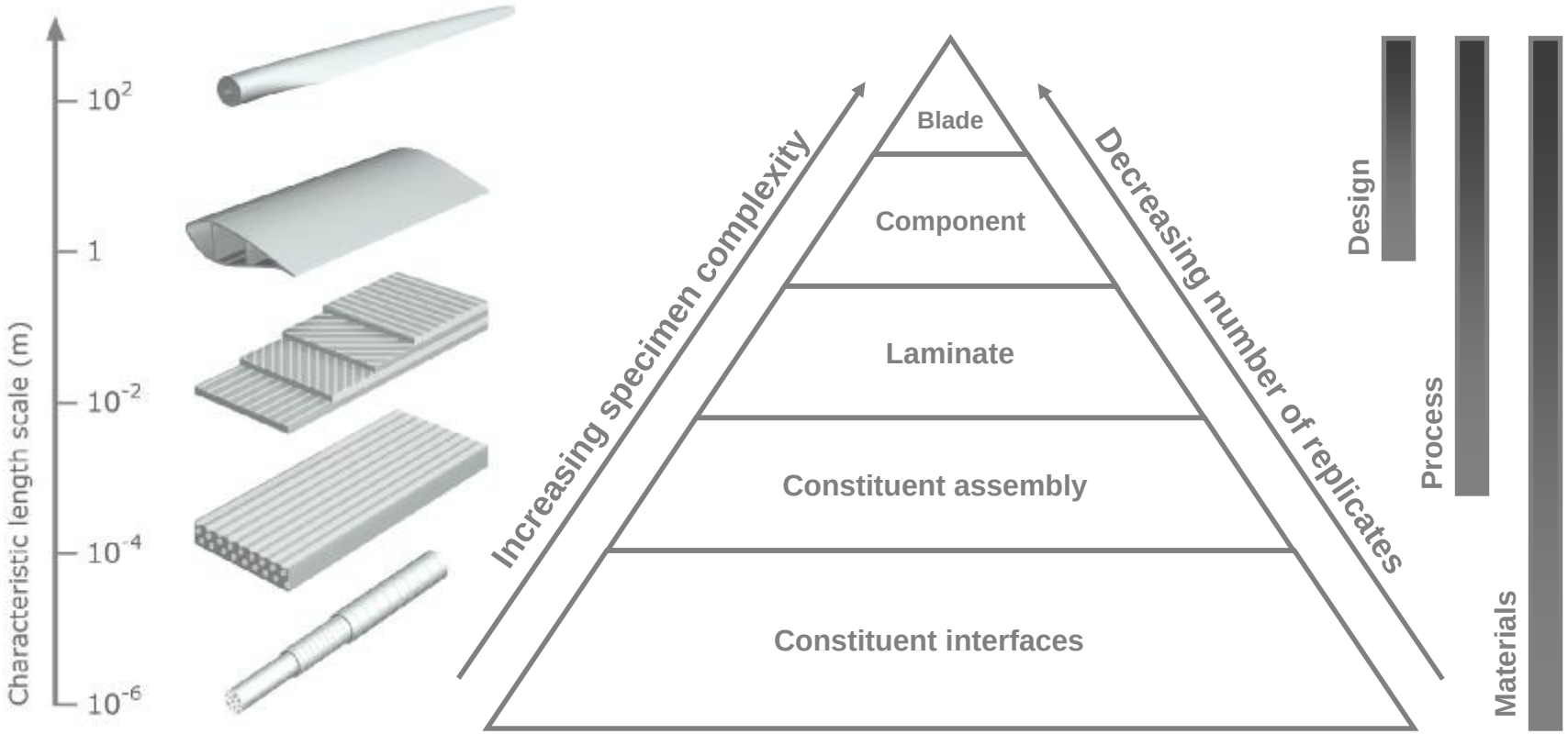


5MW rotor blade

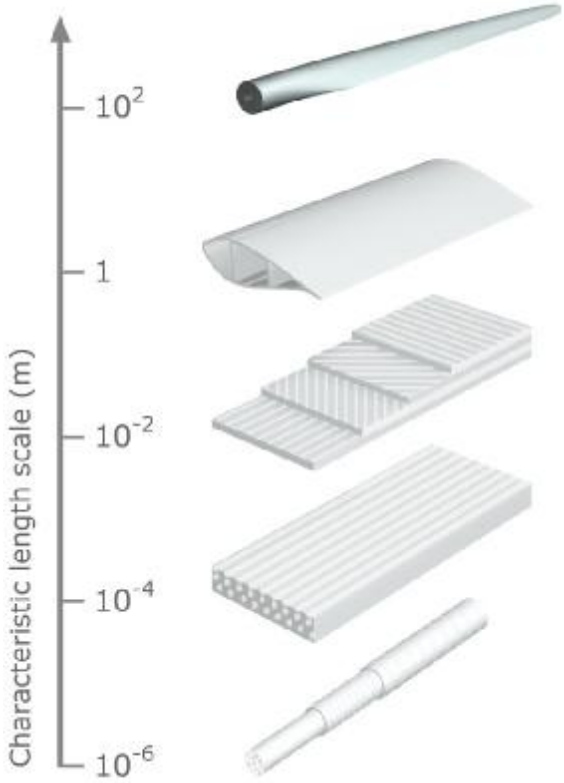


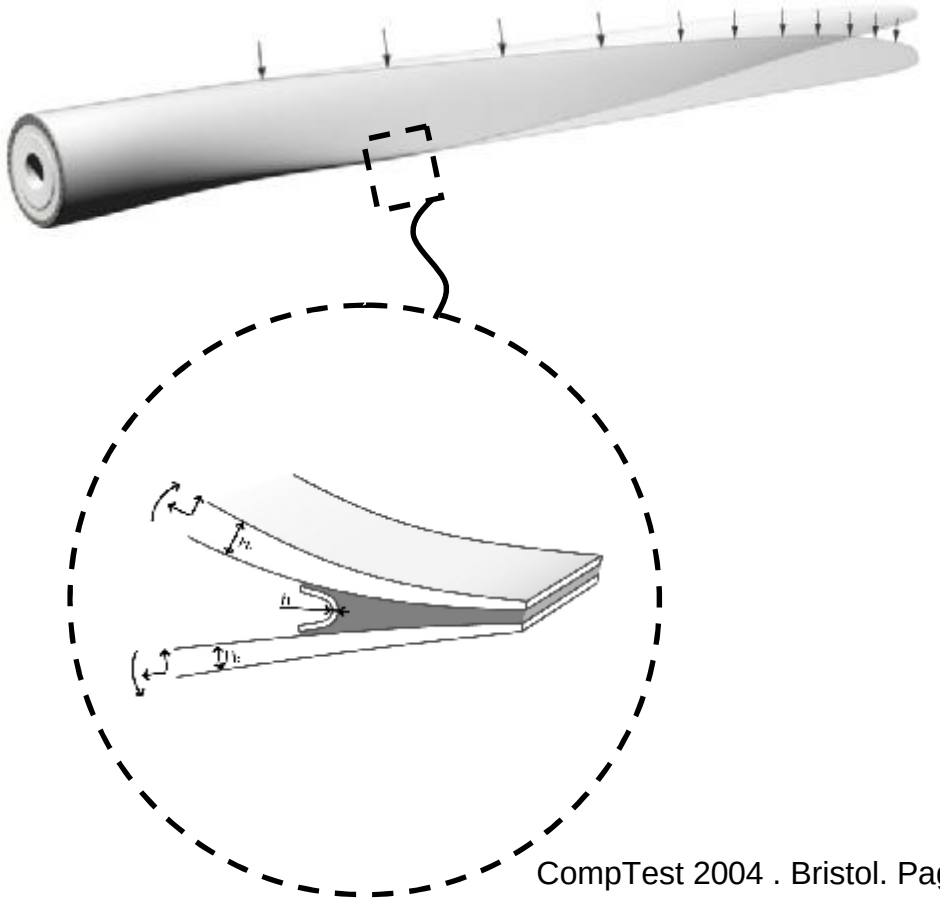


Integrated testing methodology

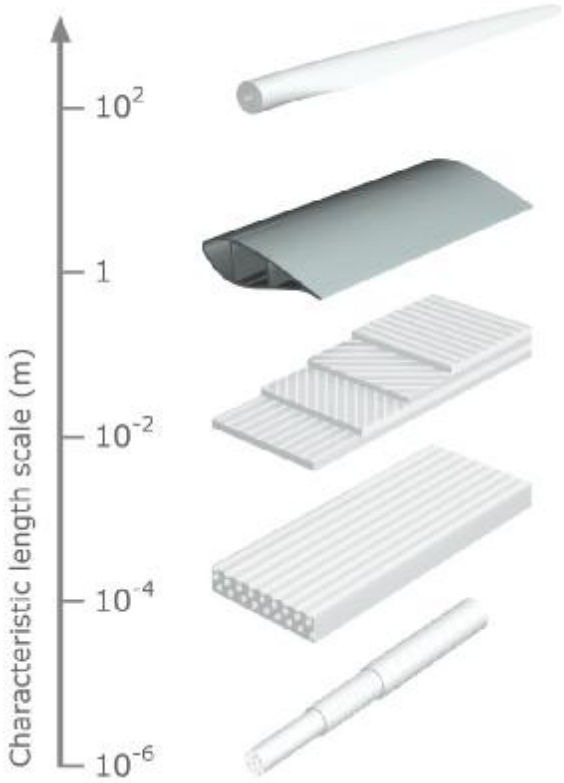


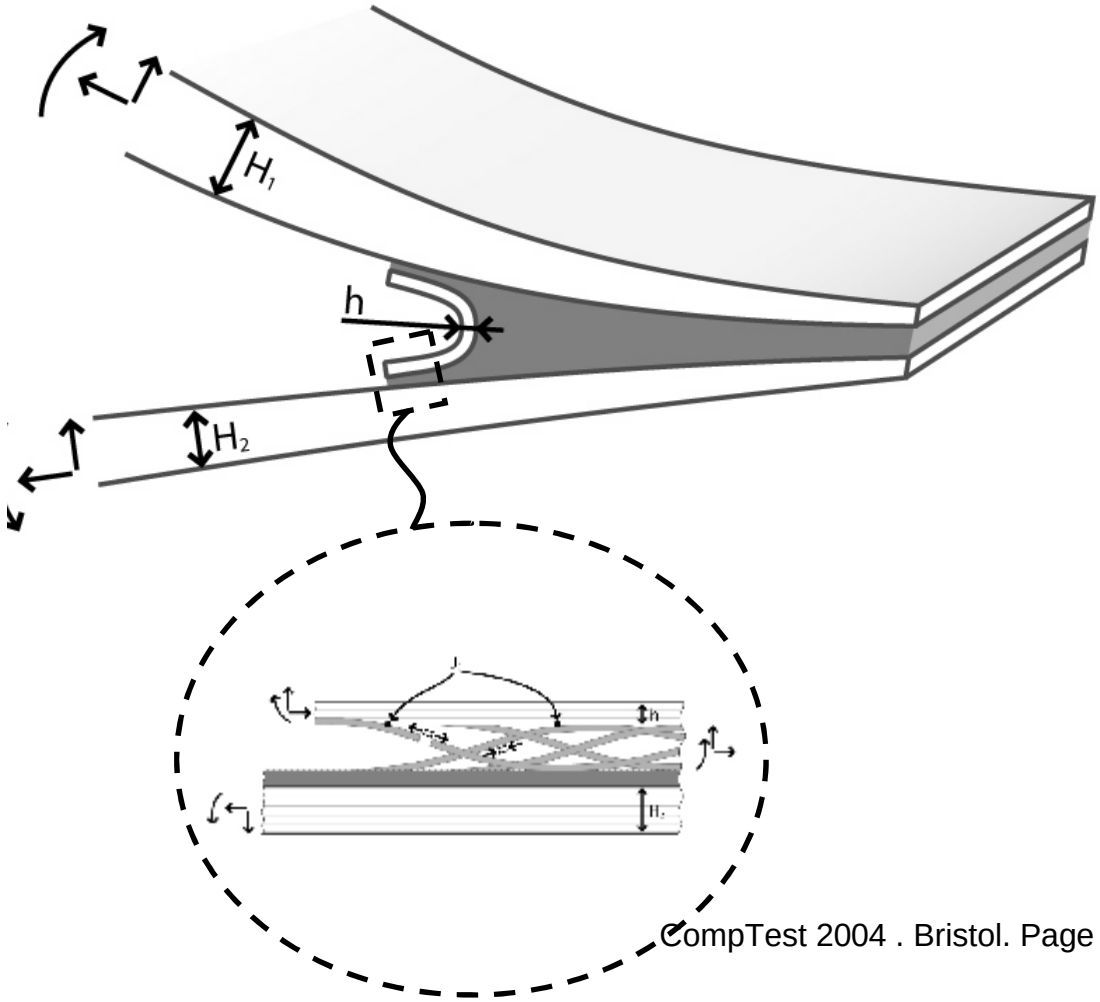
Multi-scale modelling of delamination



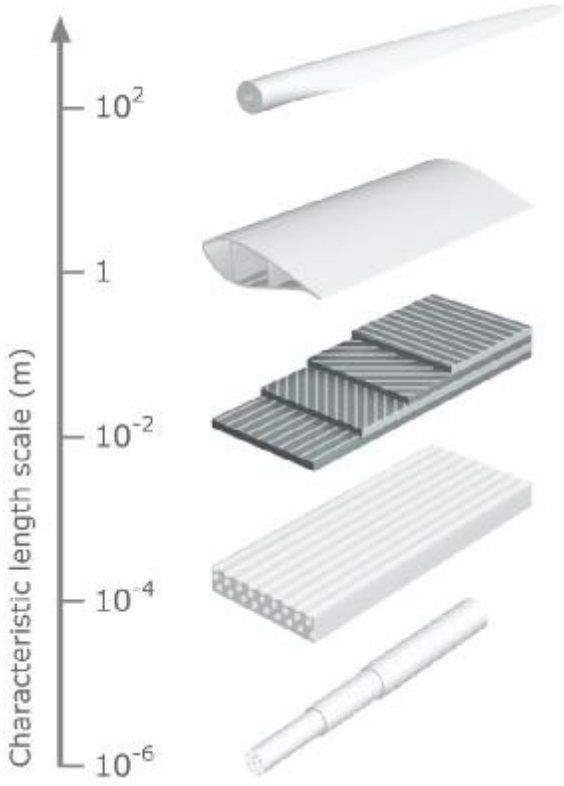


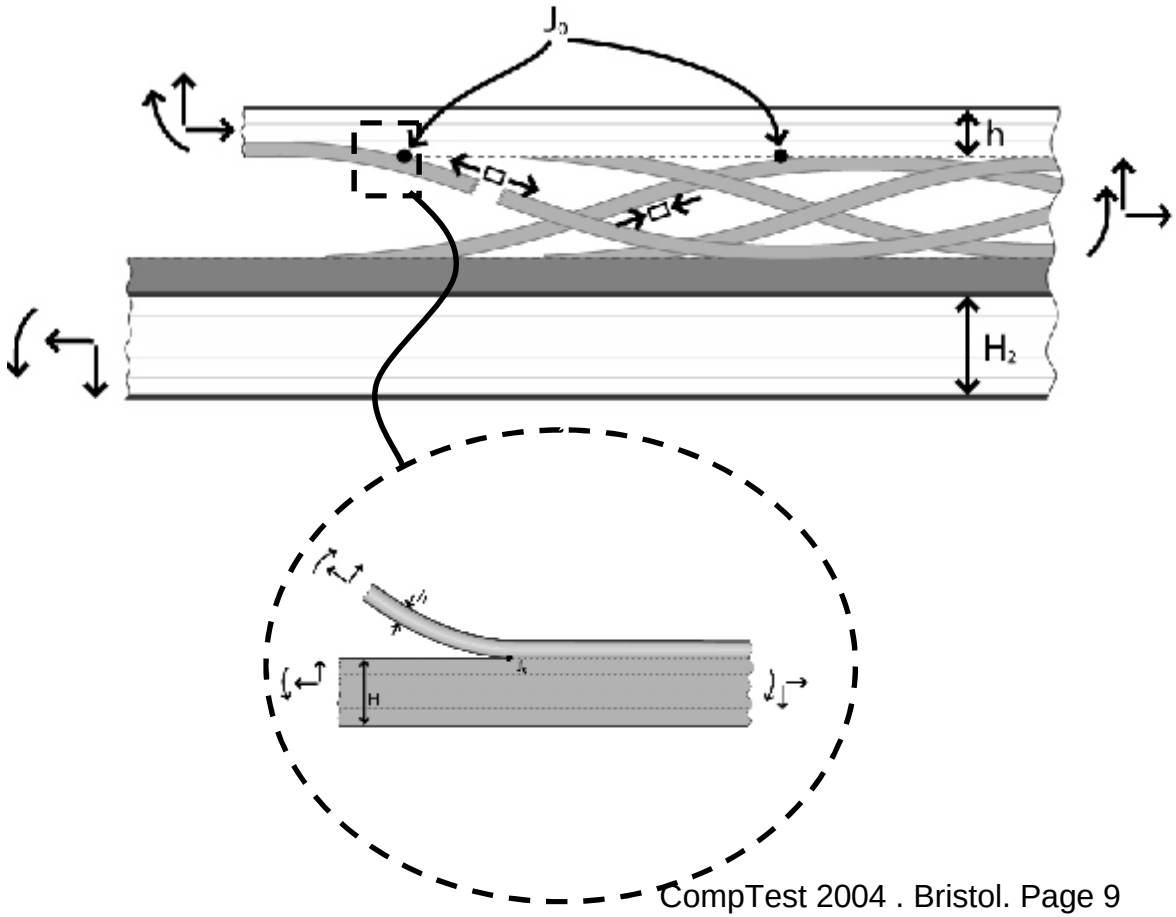
Multi-scale modelling of delamination



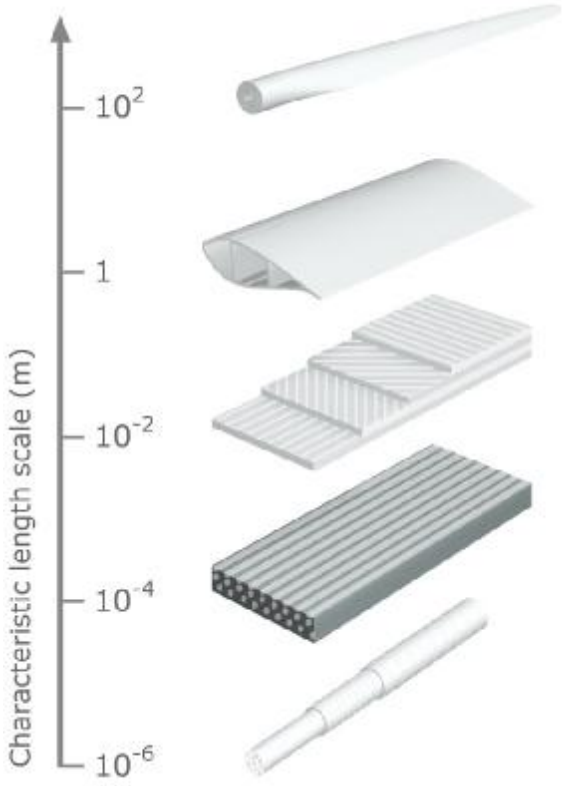


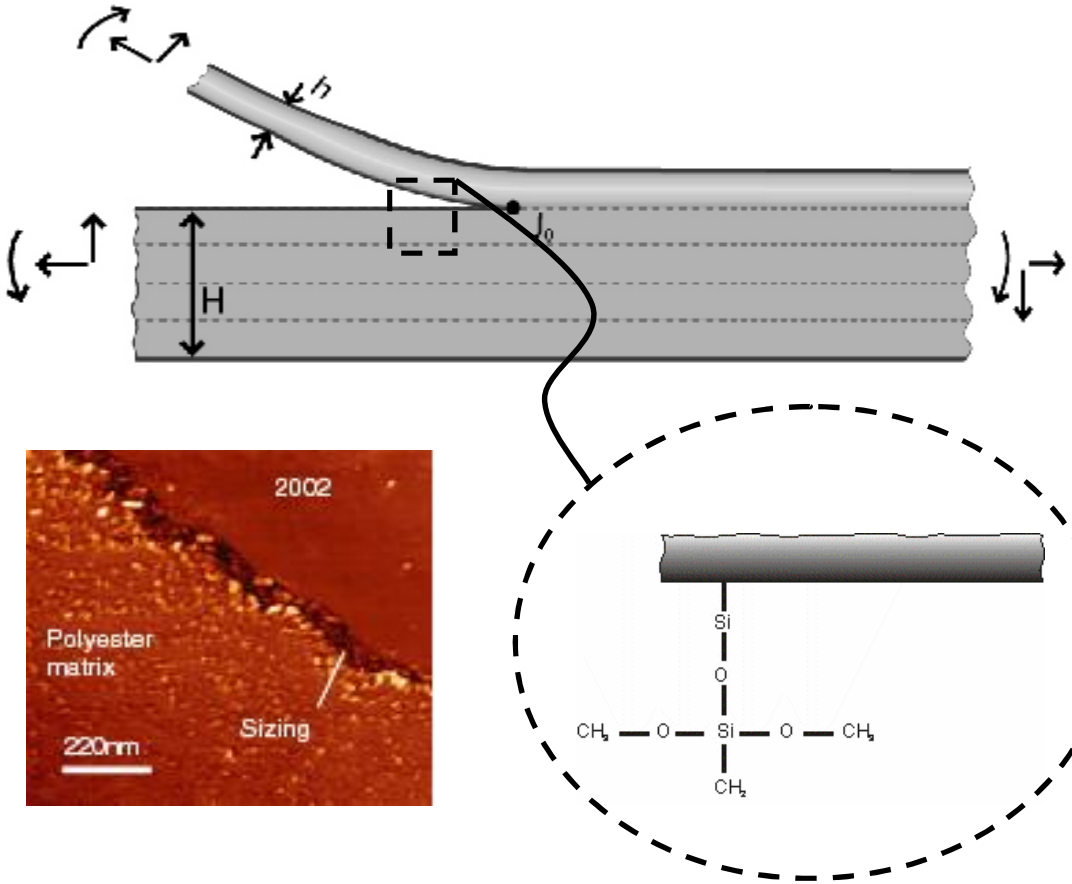
Multi-scale modelling of delamination



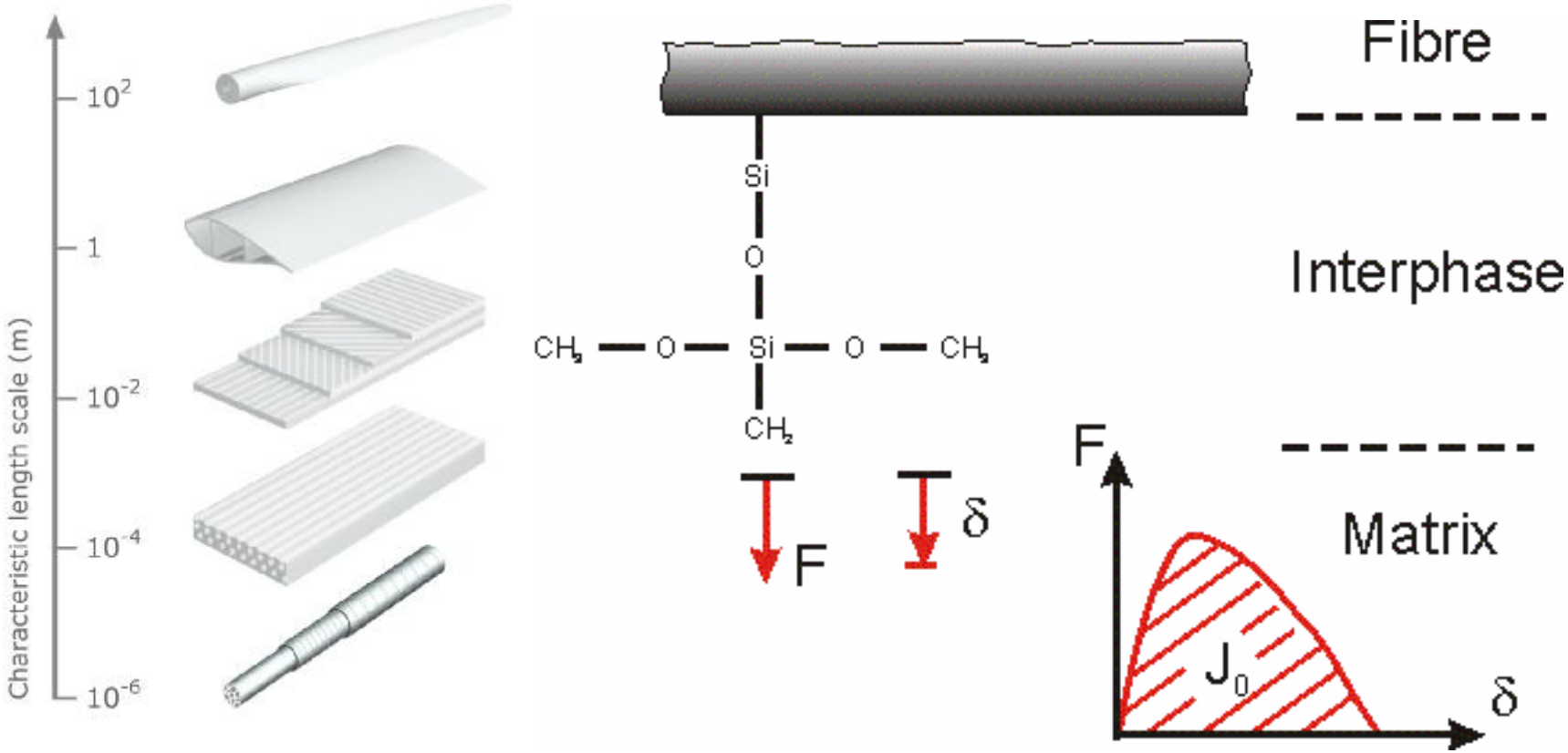


Multi-scale modelling of delamination

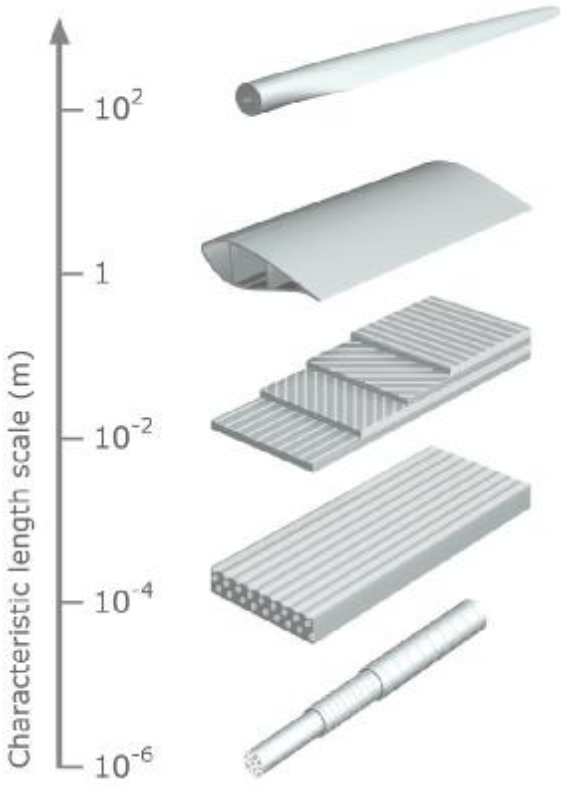


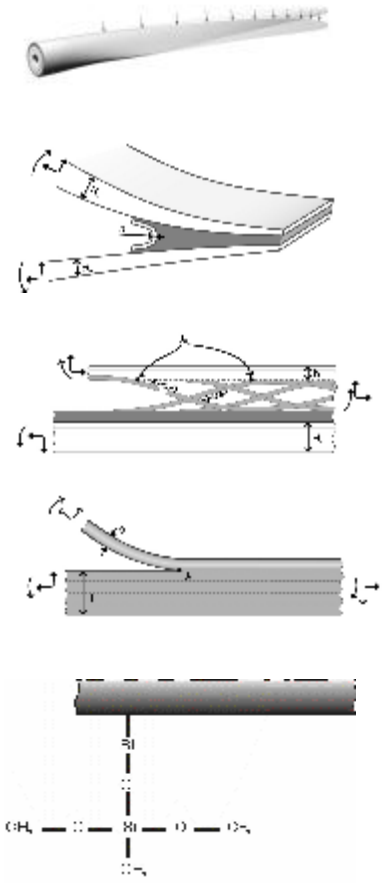


Multi-scale modelling of delamination



Multi-scale modelling of delamination





Global load set

Sectional forces and moments

Fibre bridging and breakage

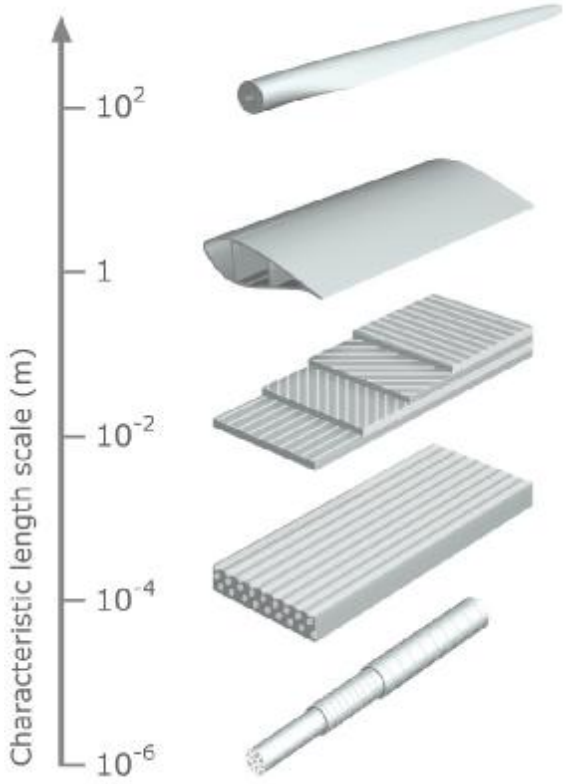
Interface mechanics:
Single fibre peel off

Interphase strength:
Molecular and atomistic

Multi-scale modelling of an adhesive joint

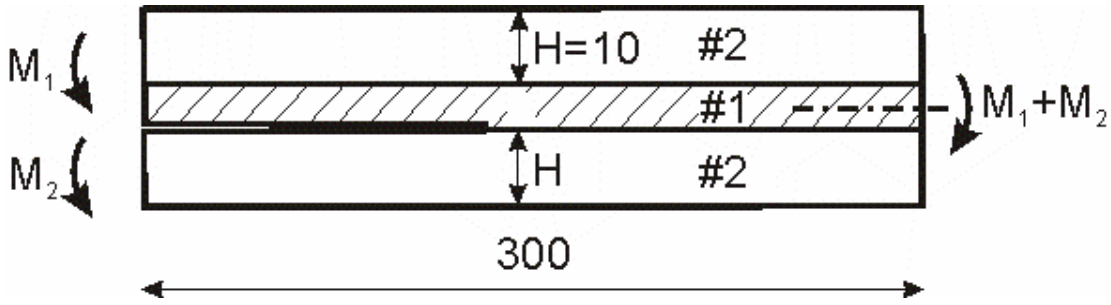
- The delamination strength of a ten times larger component can be calculated by material properties determined on a smaller scale.
- We verify that the steady-state fracture energy is a material property.
- We can calculate the influence of changes in geometry of the larger component.

Case study: Adhesive joint



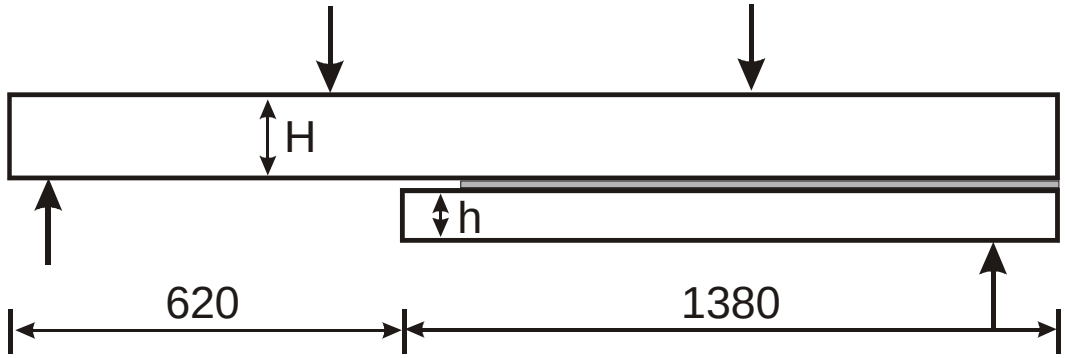
DCB specimen

Mode mixity: 0°-90°



4 pt flexure

Mode mixity ~ 41°-49°

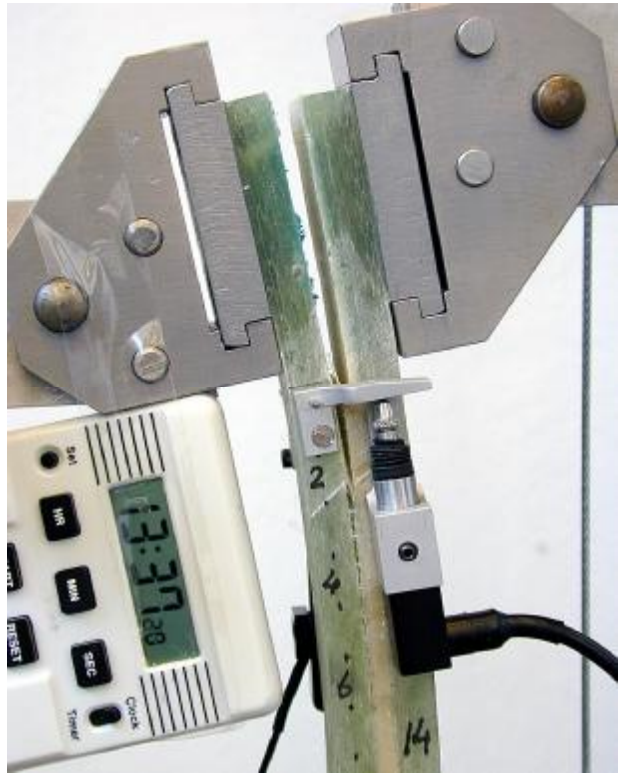


The mixed-mode DCB specimen

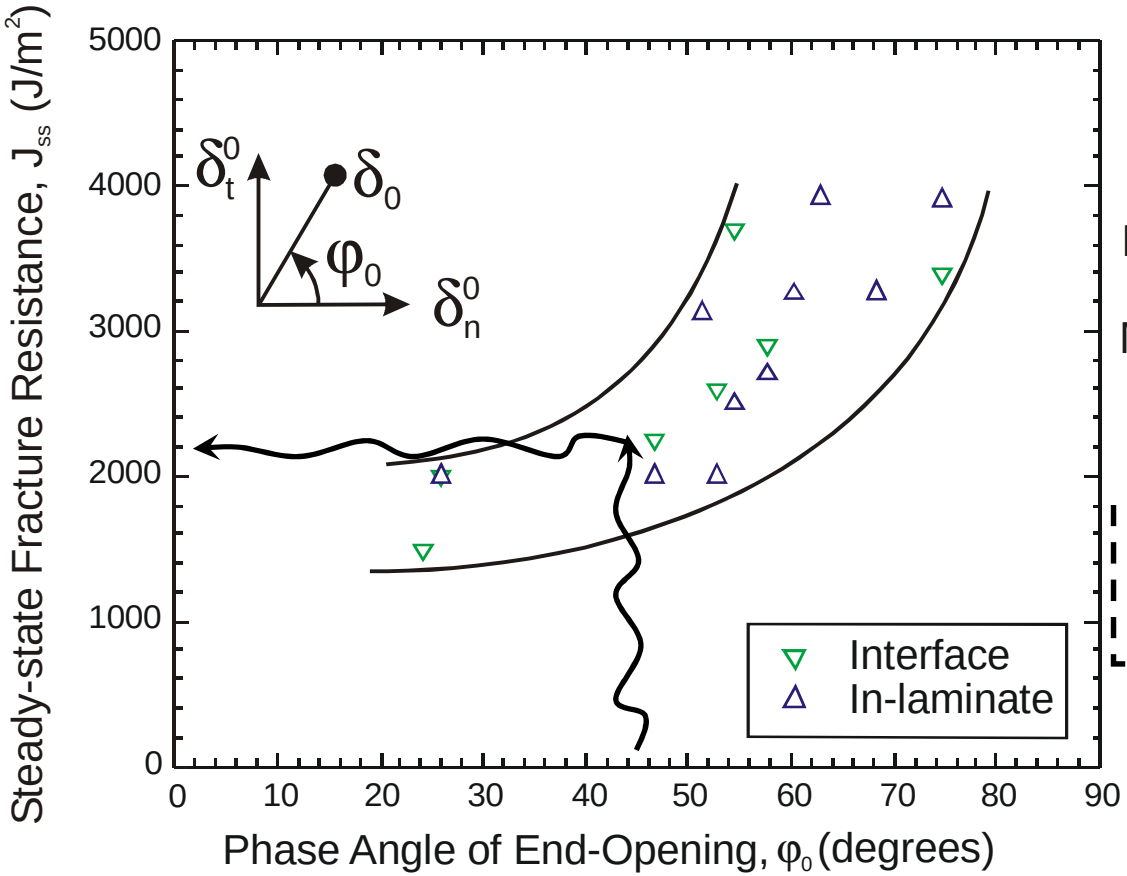
26°

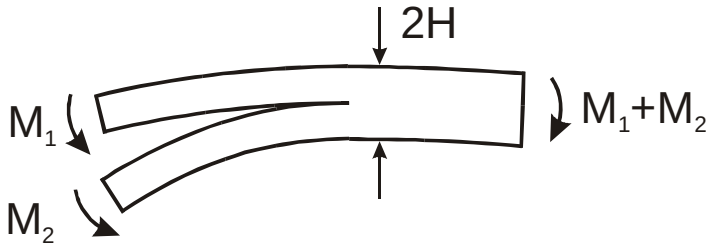
53°

68°



DCB test – Steady state fracture energy

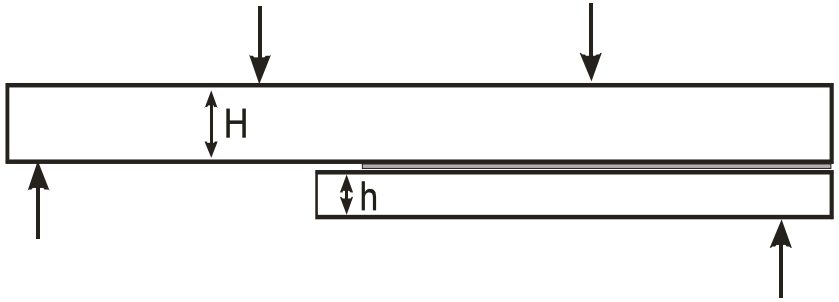




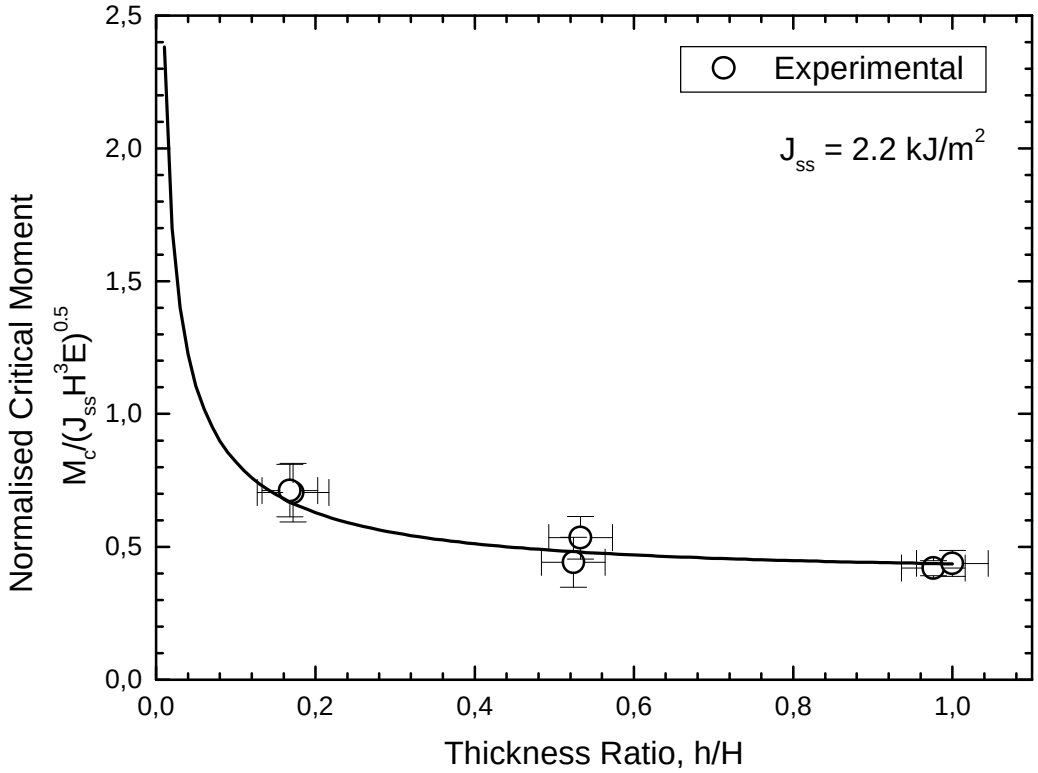
$$J_{ss} = \left(1-n^2\right)\frac{21\left(M_1^2+M_2^2\right)-6M_1M_2}{4B^2H^3E}$$

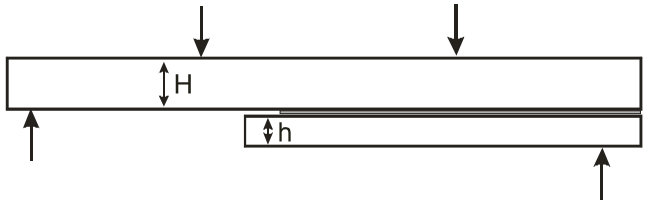
$$J_{ss} = 2200\ \text{J/m}^2$$

The large adhesive joint



Strength prediction of large joint





$$M = B\sqrt{\frac{J_{ss}H^3E}{6\left(1-\frac{1}{\left(1+h/H\right)^3}\right)}}$$

LM perspective

- Intelligent testing protocols
  - Material parameters need to be identified between each scale
  - Reduction of material qualification programmes
- Virtuel component testing
  - Fracture mechanics holds the key to scale predictions of strength.
- Implementation of advanced fracture mechanics in FE-codes.
  - Component modelling and efficient calculation routines for sub-structures
- Material design
  - Molecular and atomistic modelling
  - Optimise interphase properties

Large scale testing is only for verification purposes

Q & A

The presentation can be downloaded at www.lmglasfiber.com

Torben K. Jacobsen, LM Glasfiber, Tel. +45 79 84 00 00 Email: tkj@lm.dk

Acknowledgement: EFP2001 fund (no.1363/01-01-0007)
from the Danish Ministry of Environmental and Energy