

# Blade Materials Fatigue Testing and Modelling

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R.P.L. Nijssen,

E. Stammes, T. Westphal,

C. Qian, D. Zarouchas, F. Lahuerta,  
P. Bortolotti, WMC

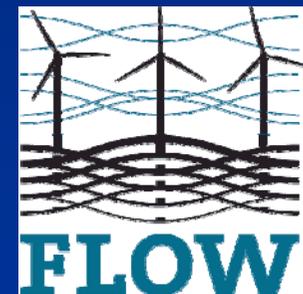


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Wind turbine Materials and Constructions

# Content

- Intro
- Fatigue of blade materials
- Recent results, e.g.:
  - Micromechanical modelling
  - Thick laminates
  - Effect of temperature and frequency
  - Subcomponent development
- Outlook

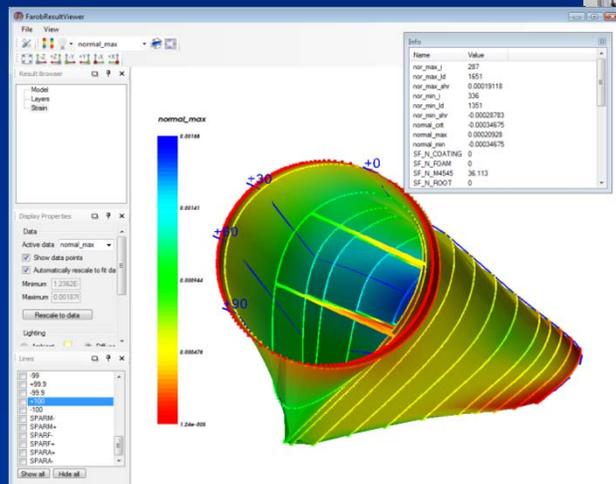


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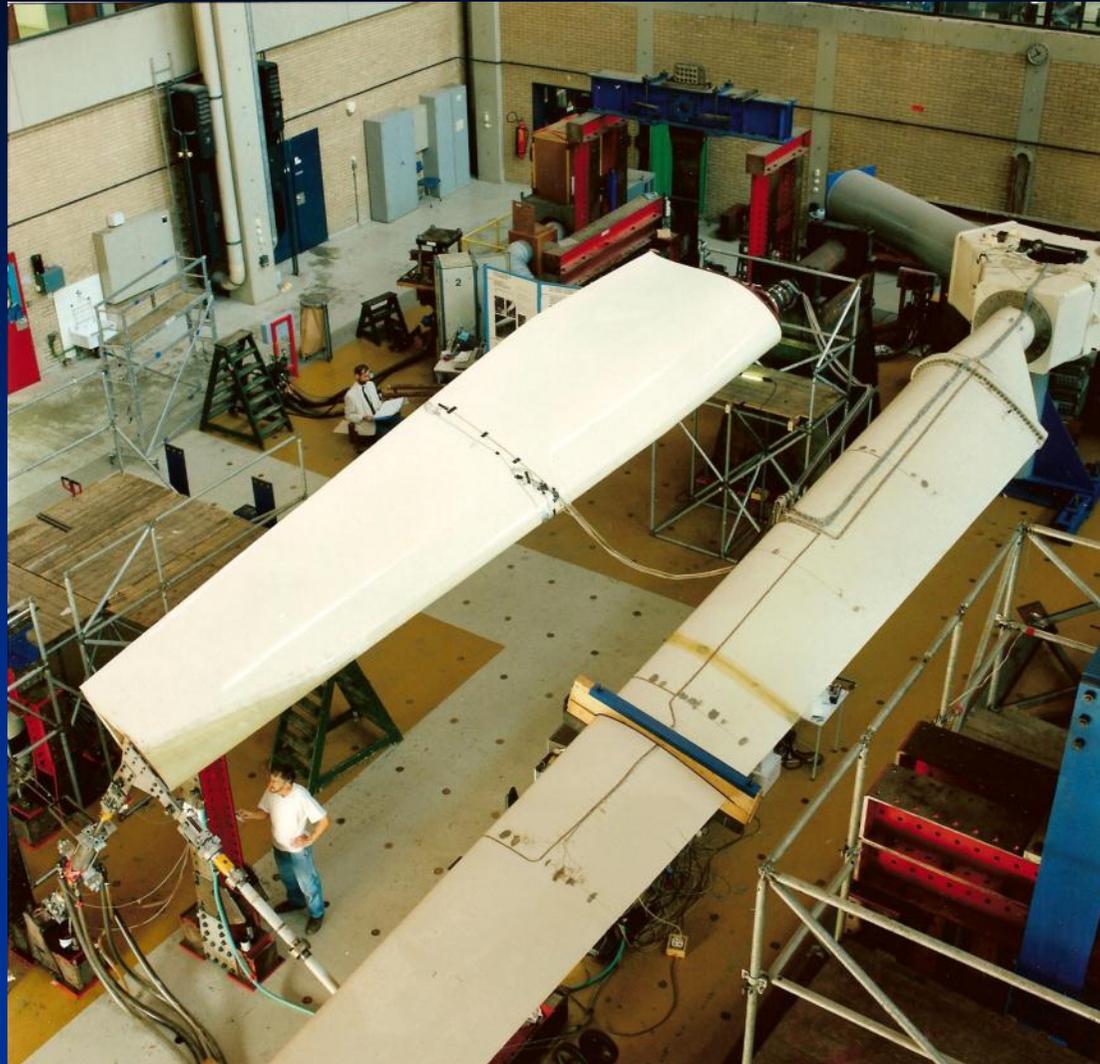
Wind turbine Materials and Constructions

# Wind turbine Materials & Constructions

- Full-scale structural testing
- Material research
- Software Development



# Blade Test 1984

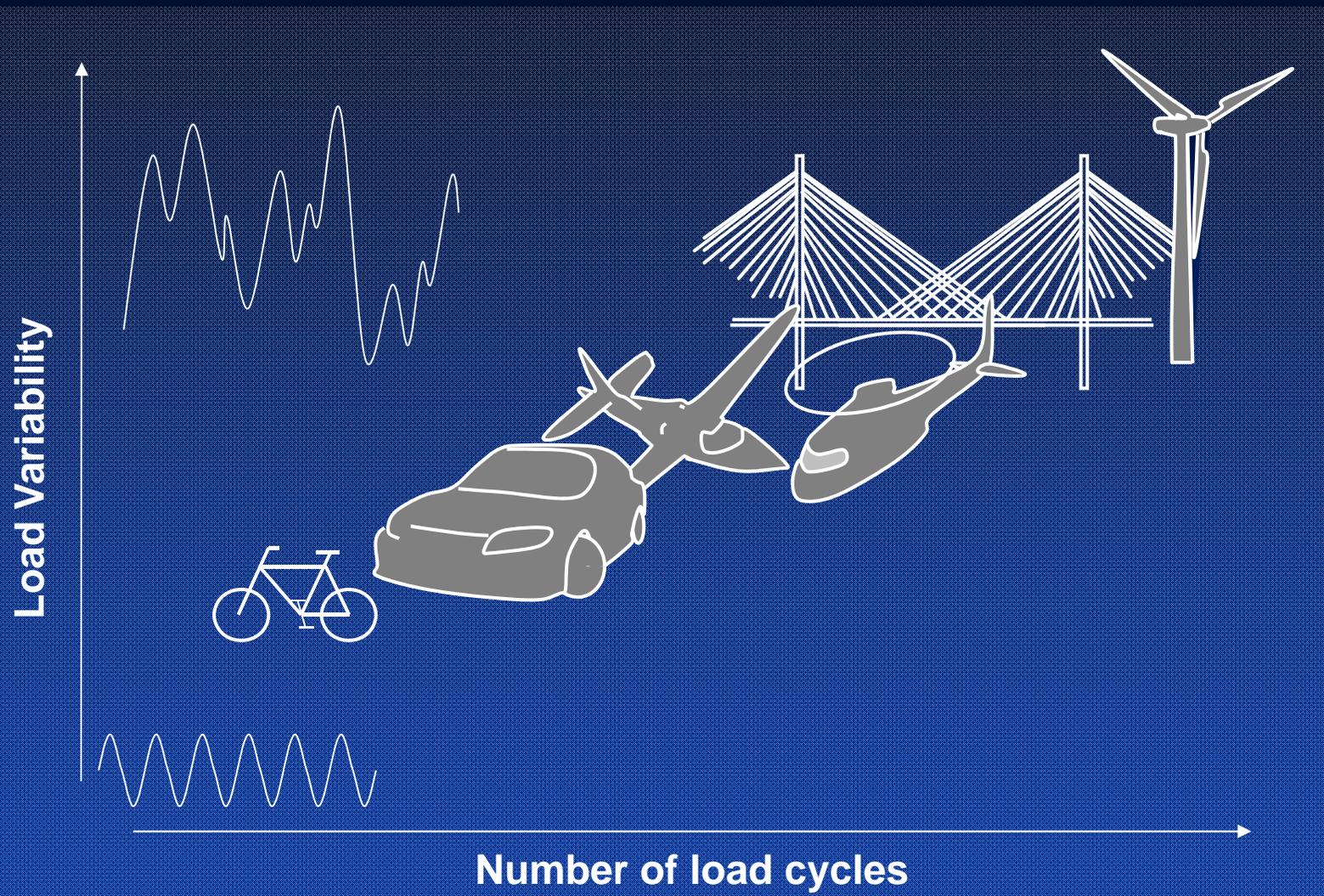


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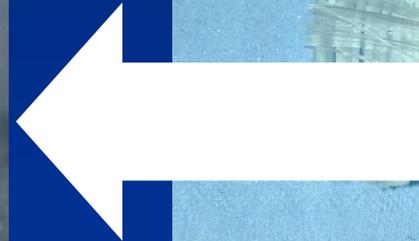
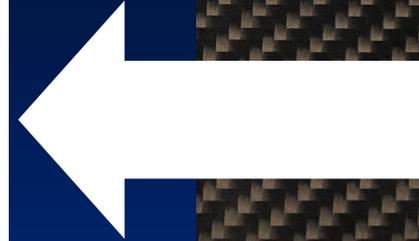
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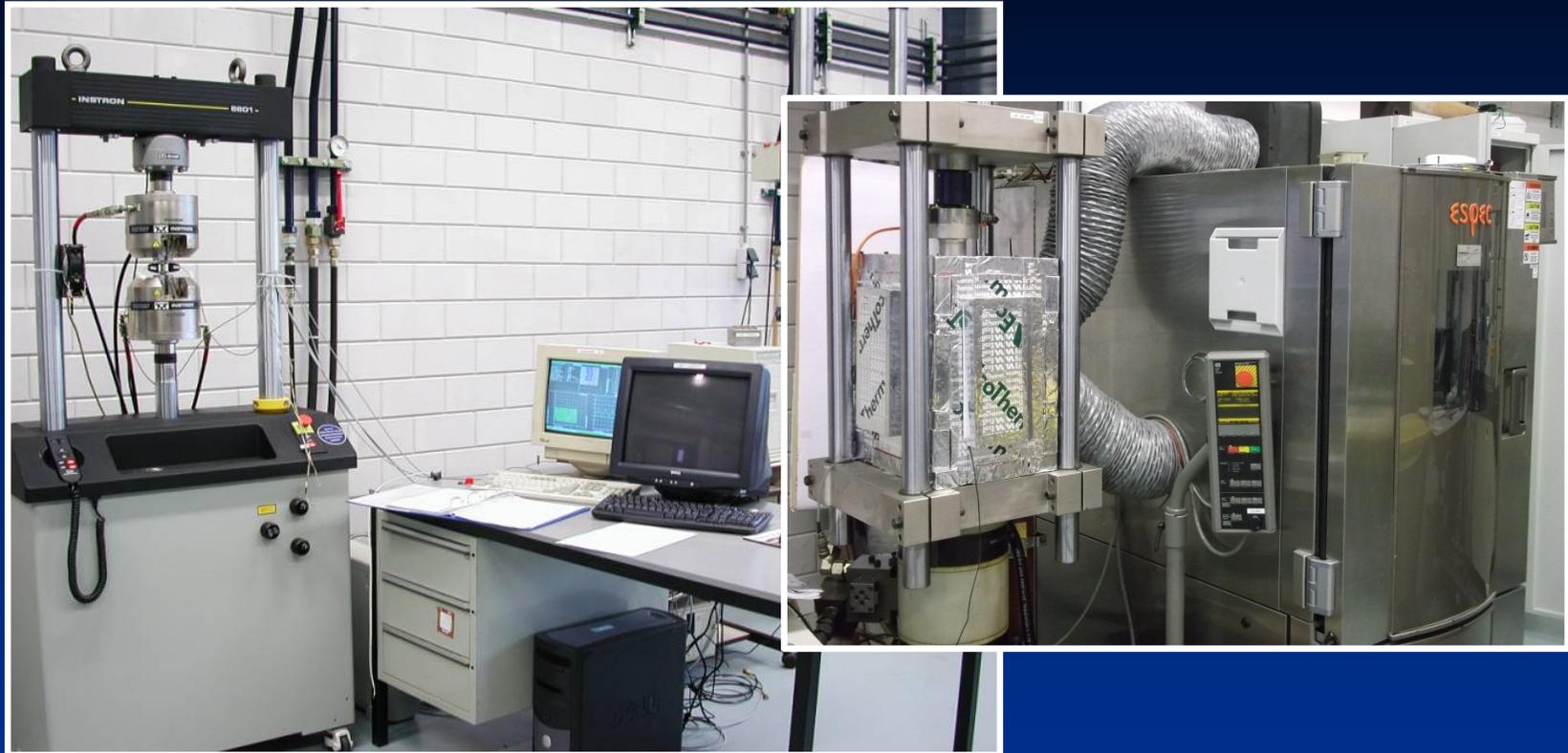
# Fatigue in wind turbine rotor blades



# Rotor Blade Composites



# Test Machines for Material Research and Component Testing



- 20 servo-hydraulic test frames for fibres, coupons, and subcomponents (static, fatigue, creep)
- Maximum capacity between 1 N to 3.5 MN
- Climate chamber
- Glass transition temp measurement, viscosity

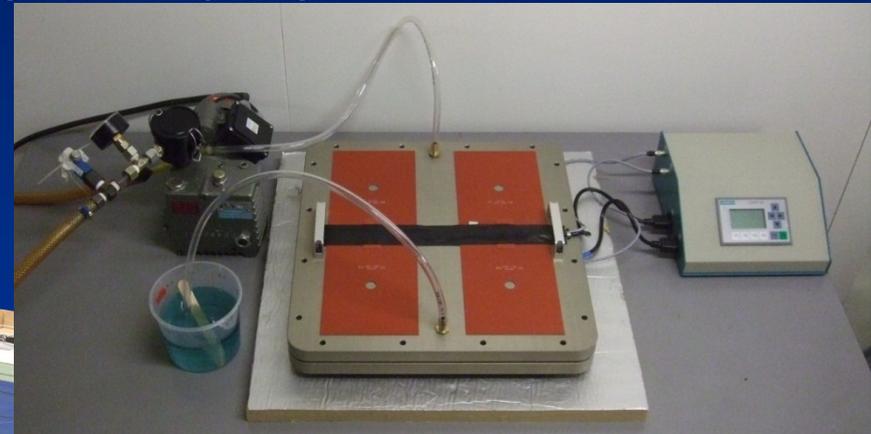
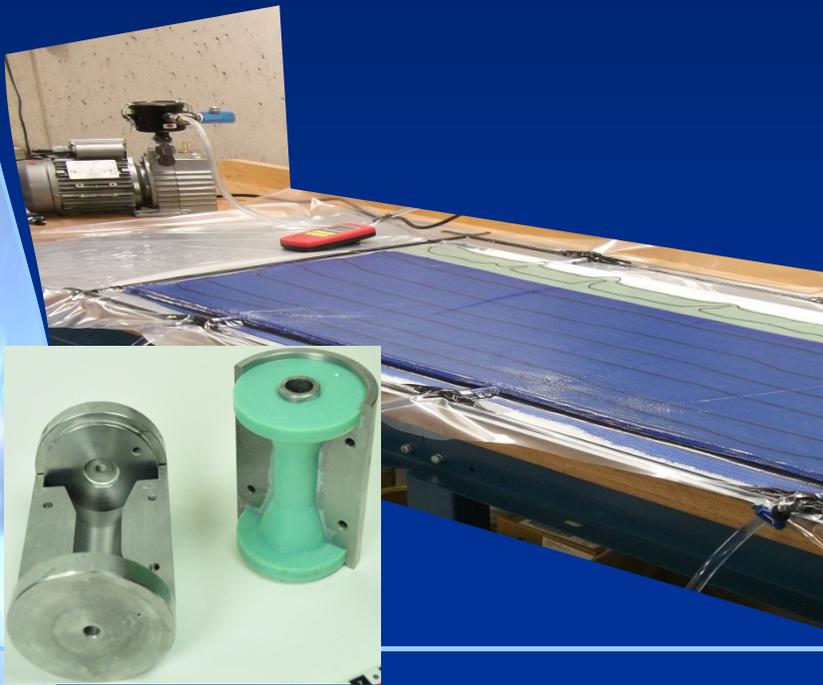
# 3000/2500kN Test Machine for Material Research and Component Testing

- 30MN test frame currently under design



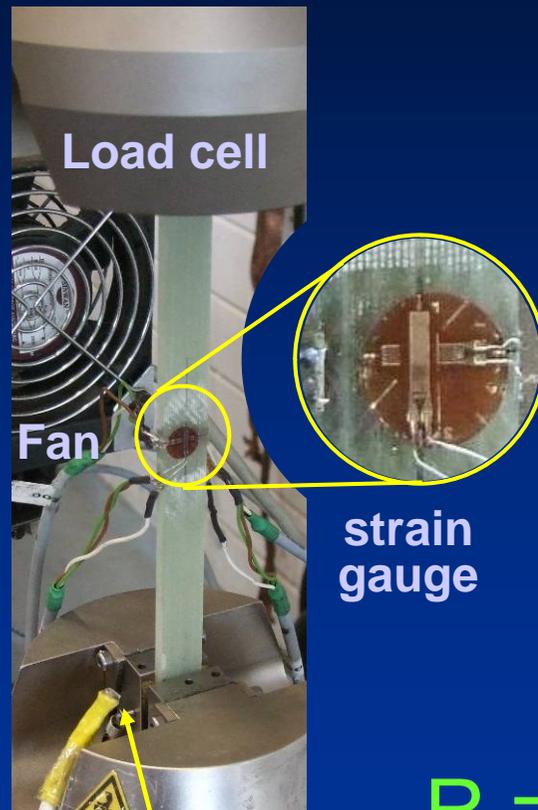
# In-house plate/specimen production

- Variations on test matrix can be implemented quickly
- Full control/documentation of product
- Fibre content determination



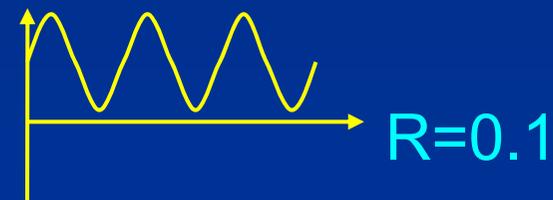
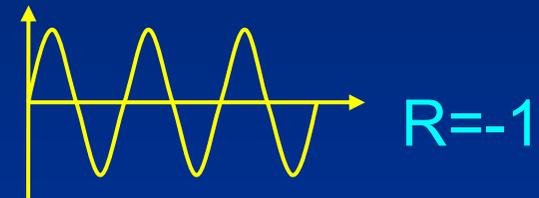
# Material characterization

- Given 'S' (e.g. cyclic load)
- Find 'N' (life)
- Relationship in S-N curve



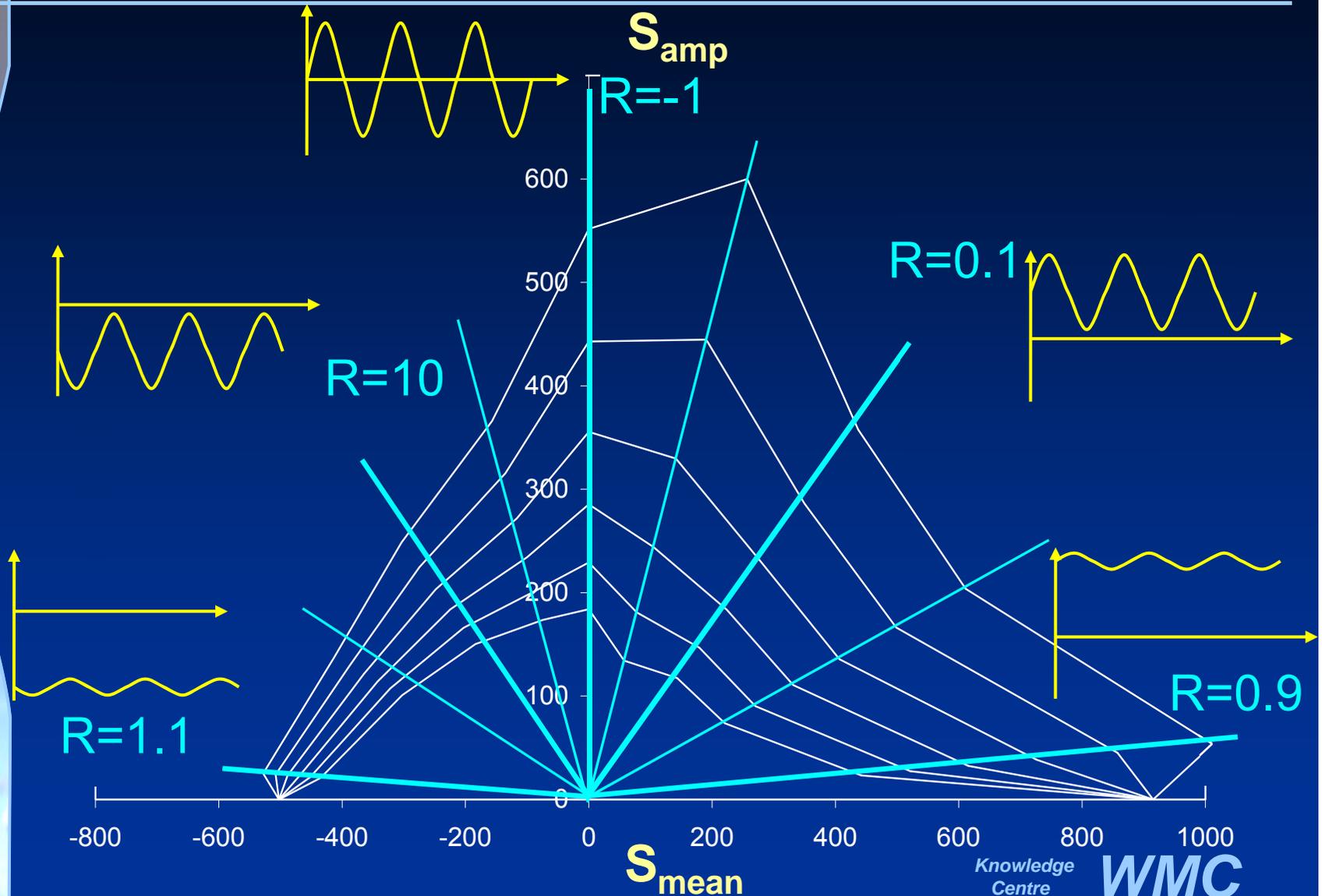
Temperature sensor

$$R = \frac{\sigma_{\min}}{\sigma_{\max}}$$

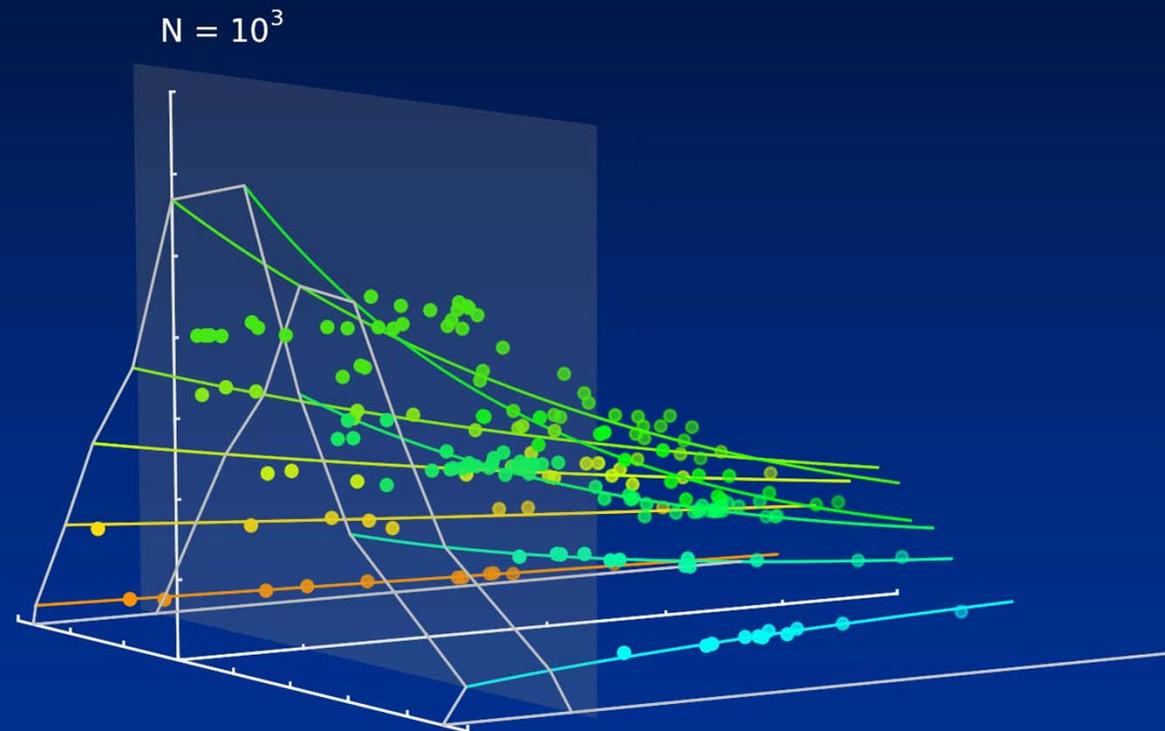




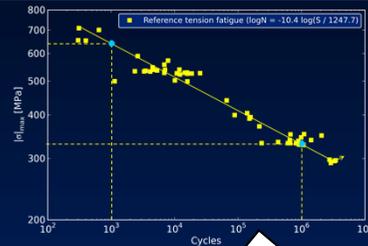
# Fatigue behaviour of reference



# Constant life diagram

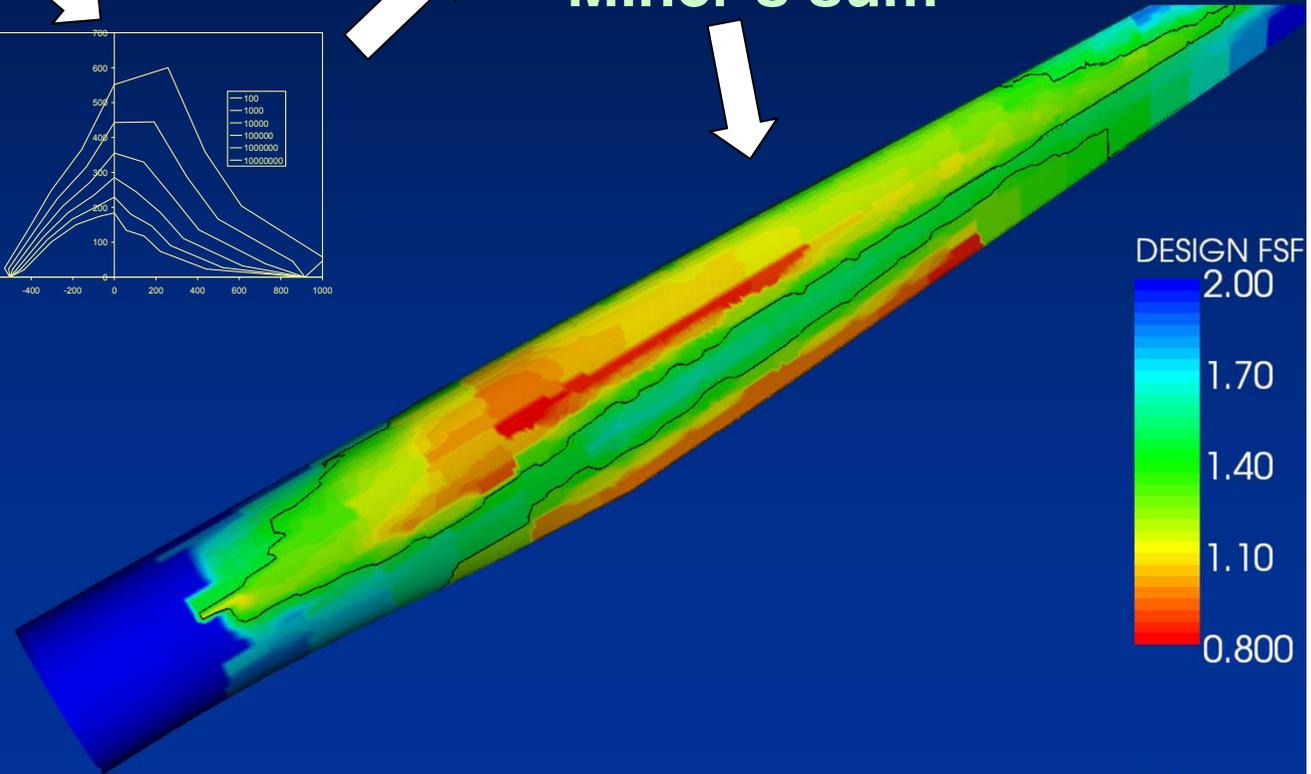
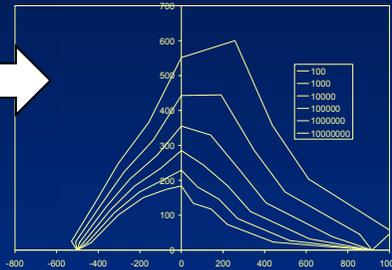


# Fatigue calculation



$$D = \sum_i^k \frac{n_i}{N_i} = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \dots \leq 1$$

Miner's sum



# Micromechanical Analysis

## Multi-scale approach

Composite constituent properties



Unit cell fatigue simulations



Meso model fatigue simulations

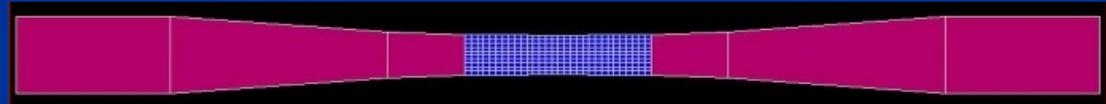
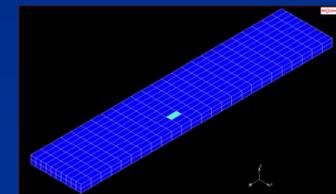
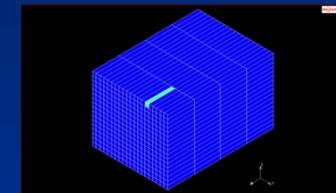
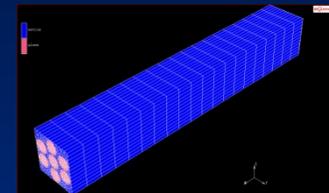


UD coupon fatigue simulations

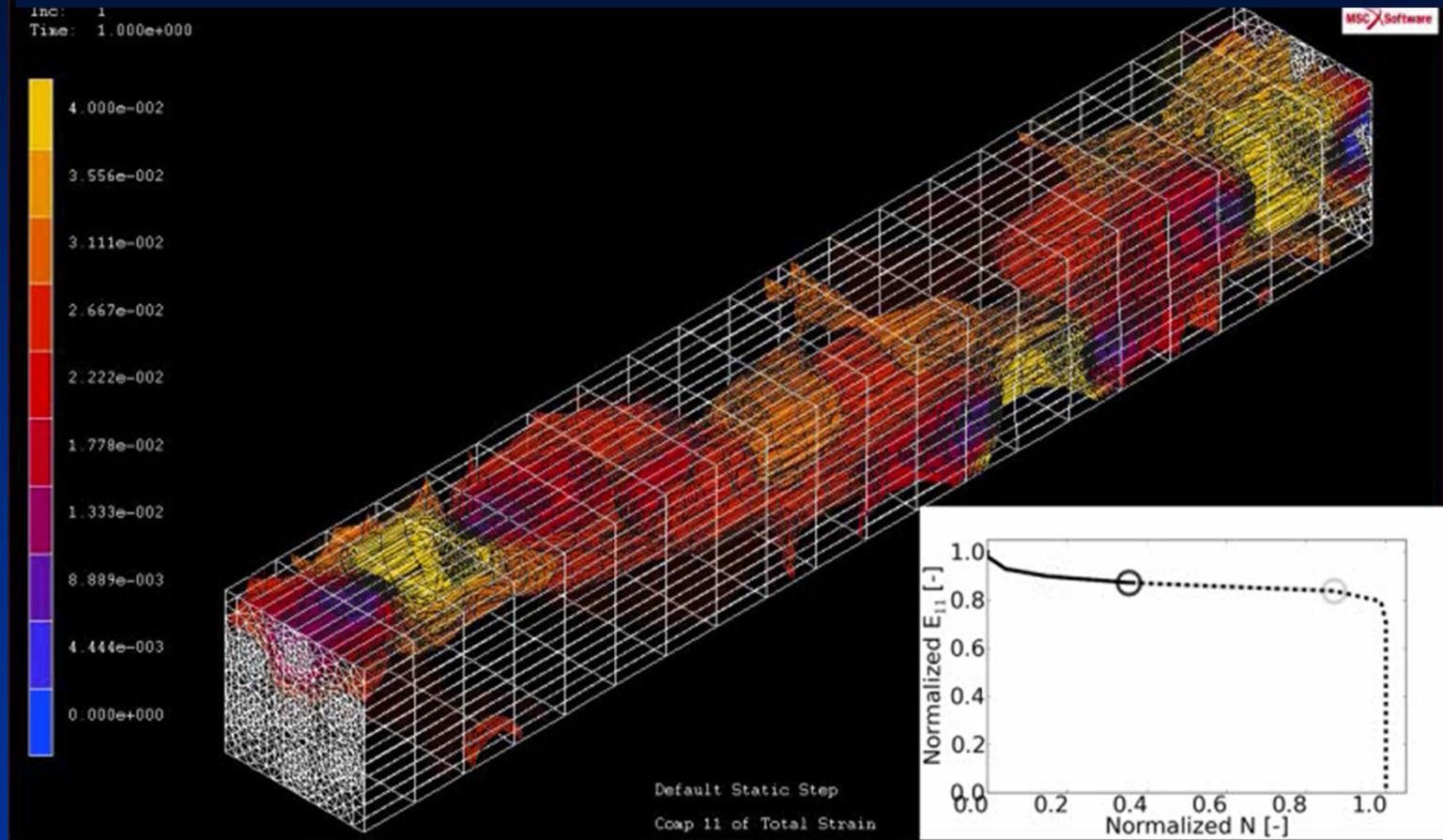
1<sup>st</sup> geometrical up-scaling

2<sup>nd</sup> geometrical up-scaling

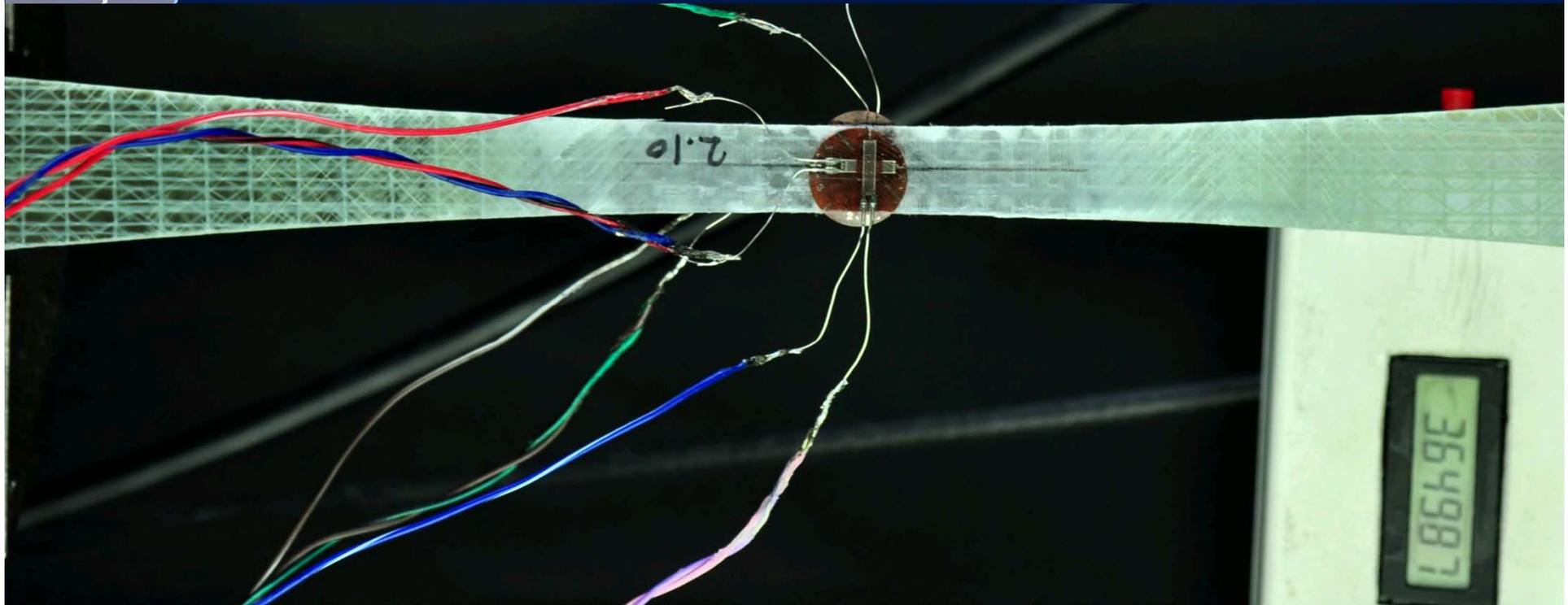
3<sup>rd</sup> geometrical up-scaling



# Micromechanical Analysis

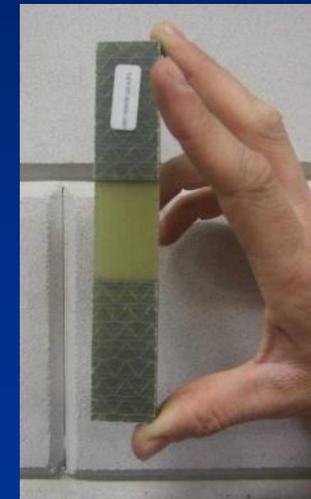
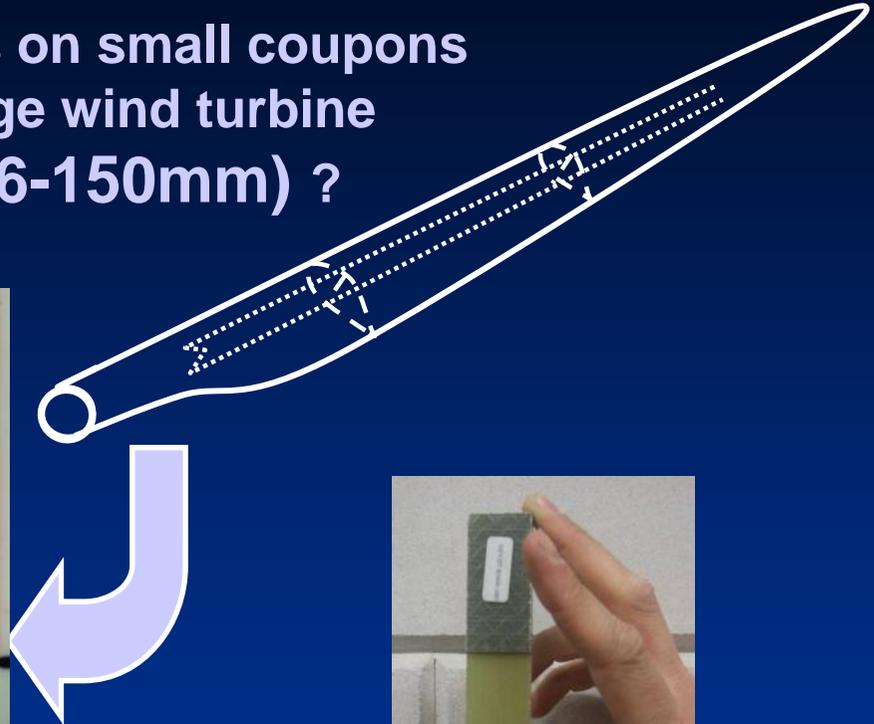
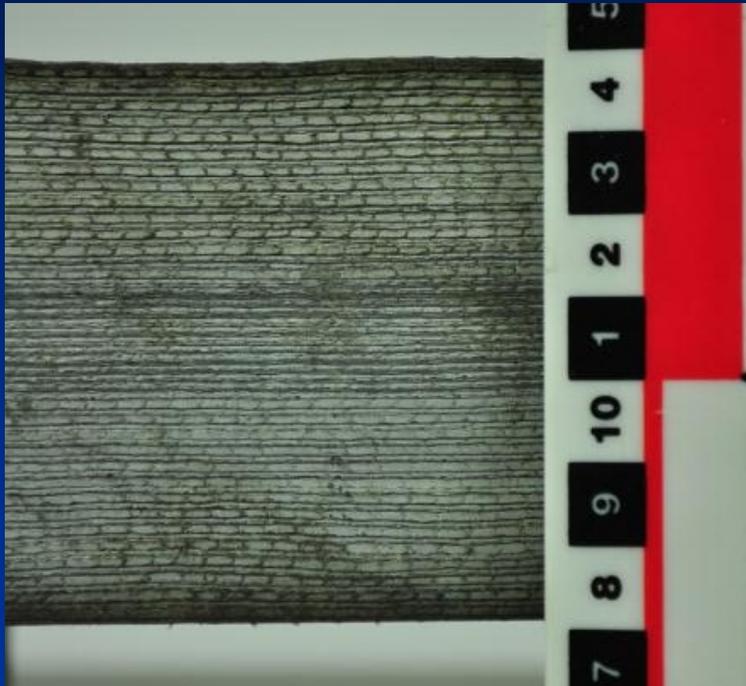


# Fatigue of UD Glass/epoxy

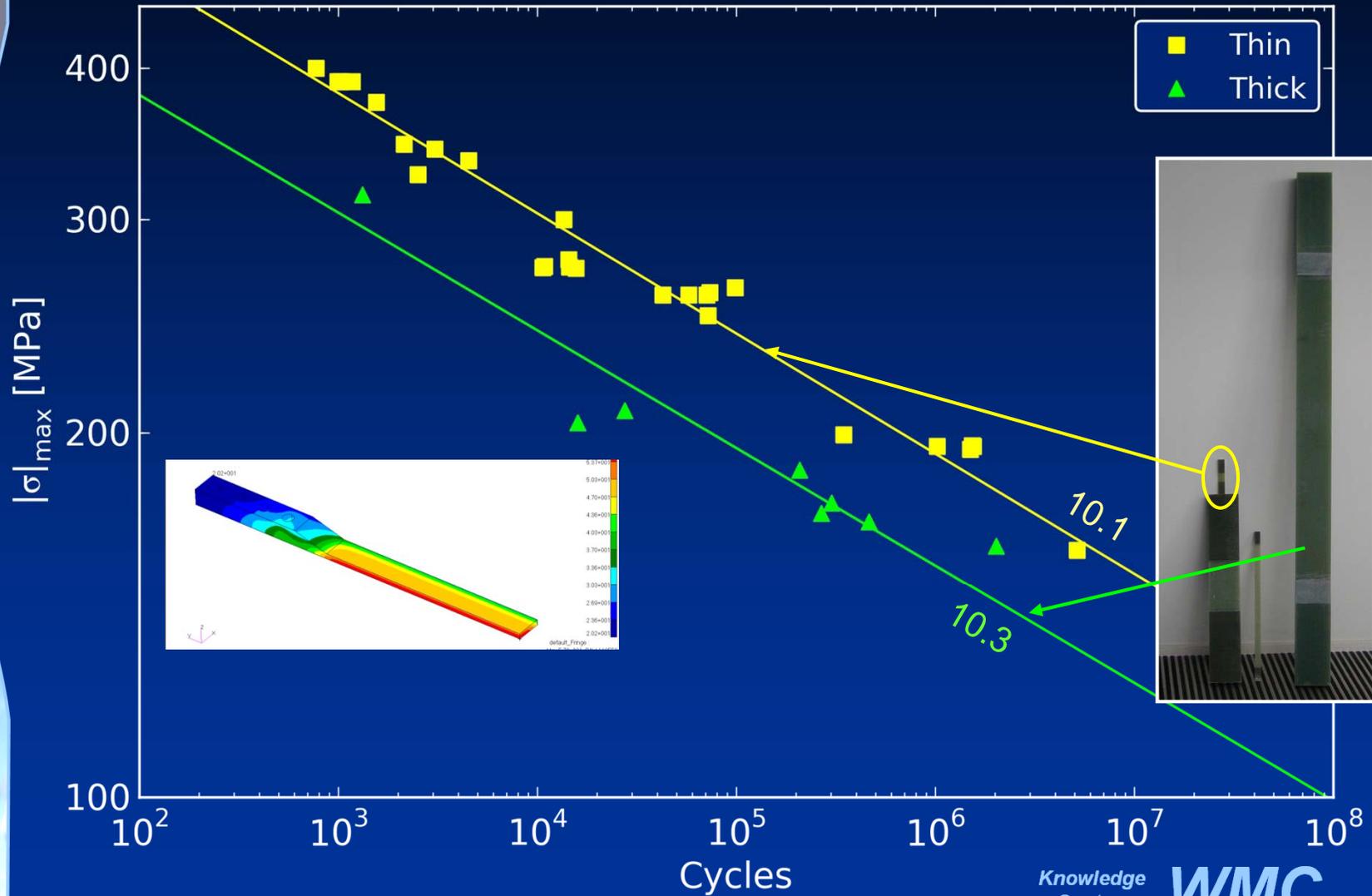


# Thick laminates

How representative are tests on small coupons (thickness is 1-8 mm) for large wind turbine composites (thickness is 6-150mm) ?



# Thick vs. Thin – R = 0.1

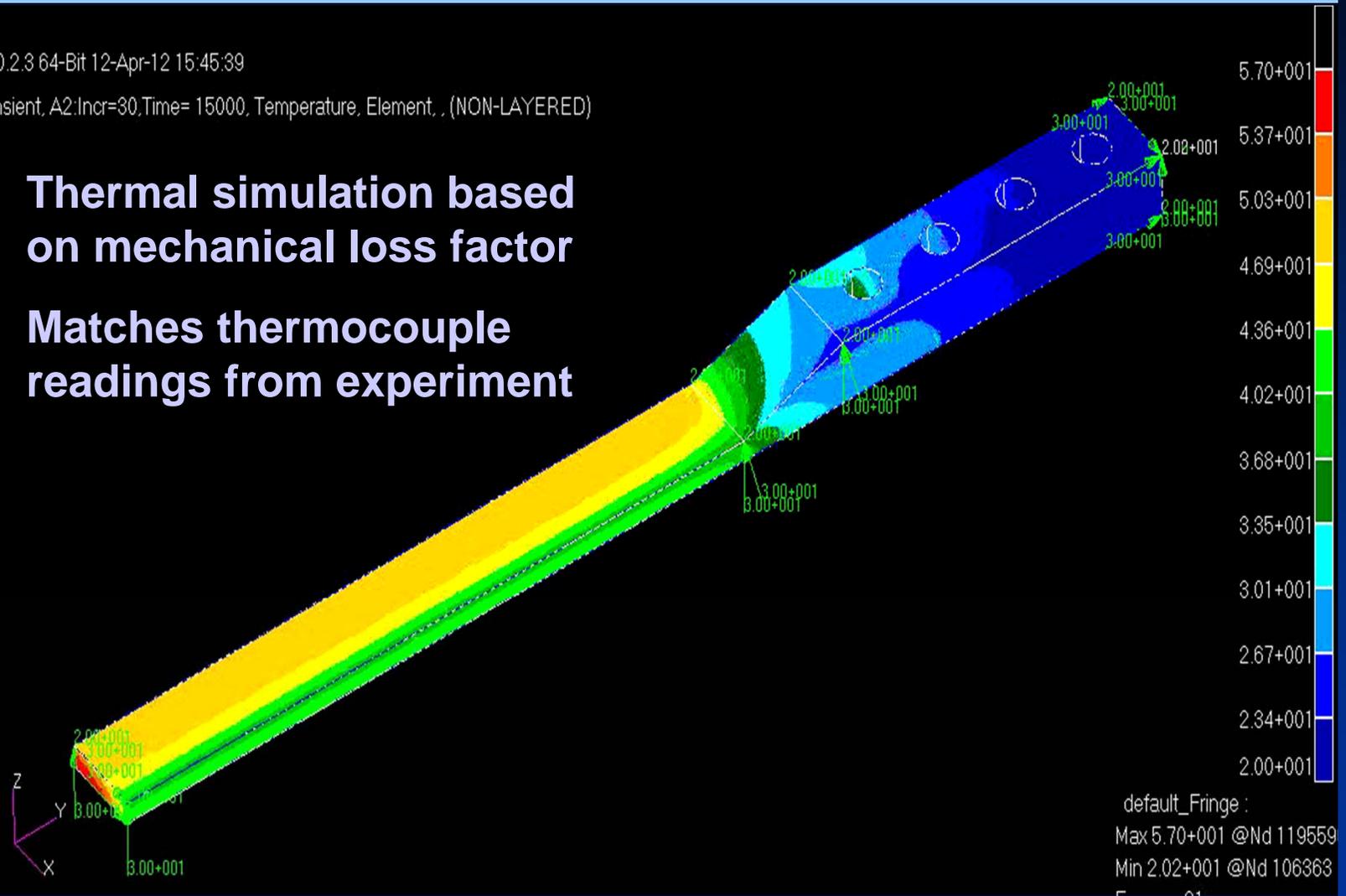


# Thick laminates

Patran 2010.2.3 64-Bit 12-Apr-12 15:45:39

Fringe: Transient, A2:Incr=30,Time= 15000, Temperature, Element, (NON-LAYERED)

- Thermal simulation based on mechanical loss factor
- Matches thermocouple readings from experiment



# Temperature & Frequency

Laminate type	Loading type	Condition	Target N	Frequency
UD	Static	Room Temperature, -40°C, +60°C	1	1 mm/min
	R=0.1	Room Temperature, -40°C, +60°C	10,000	2, 8, 24
		Room Temperature, -40°C, +60°C	1,000,000	6, 8, 24
	R=-1	Room Temperature, -40°C, +60°C	10,000	1, 24
		Room Temperature, -40°C, +60°C	1,000,000	3, 24
<b>Biax ±45°</b>	<b>R=0.1</b>	Room Temperature, -40°C, +60°C	10 <sup>3</sup> – 10 <sup>6</sup>	1, 3

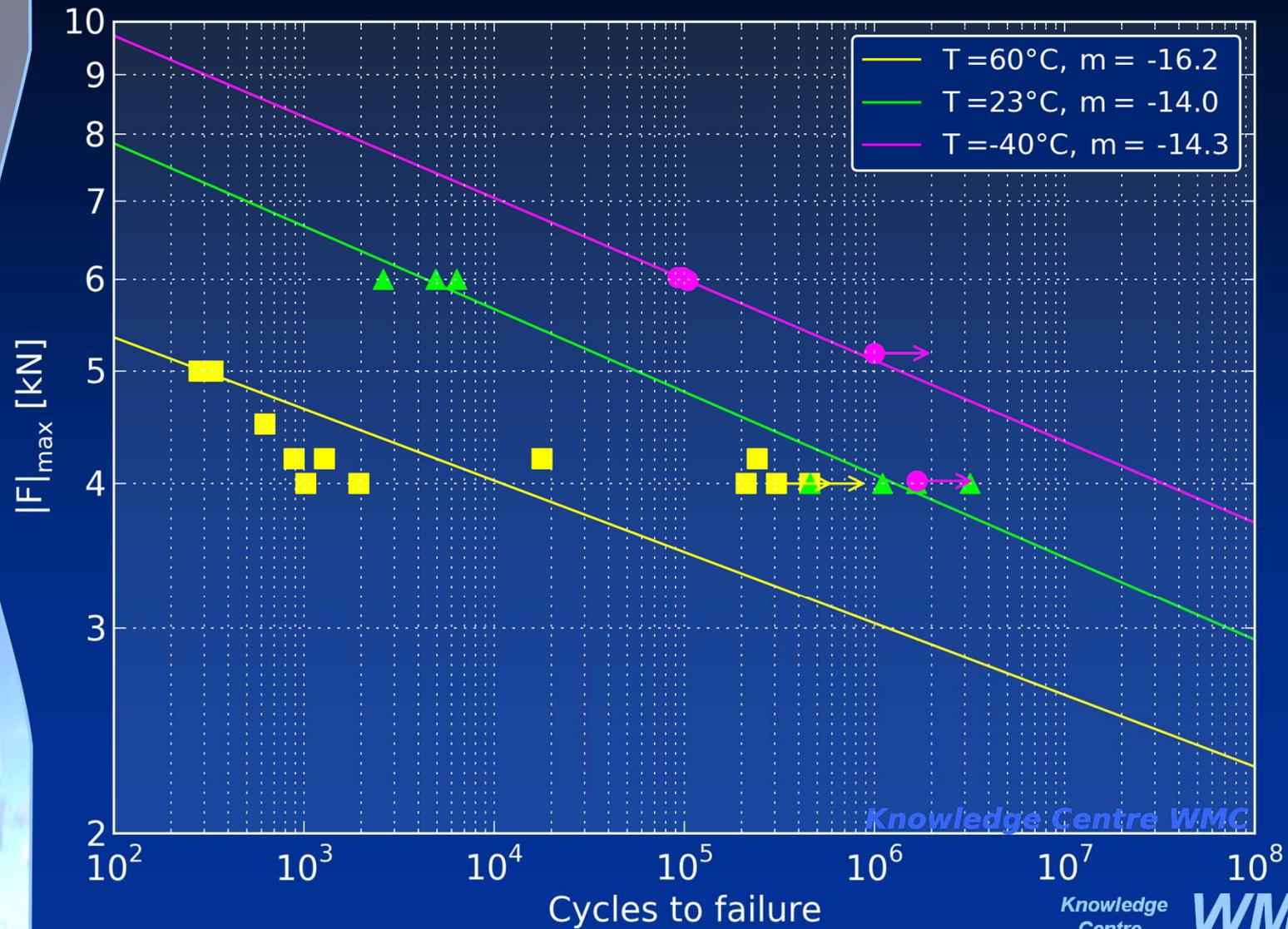


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# $\pm 45^\circ$ - Effect of temperature ( $R = 0.1$ )



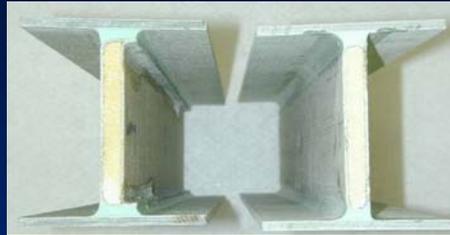
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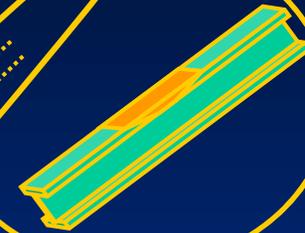
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# Subcomponents

Flanges, web, bondlines



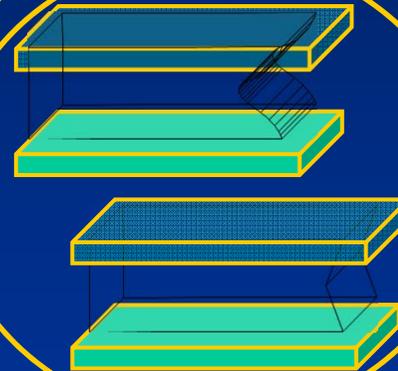
Repairs



Sandwich and foam



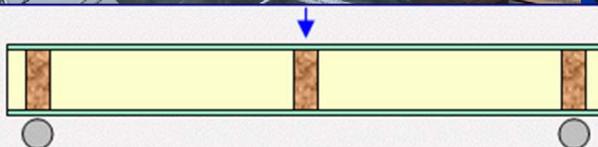
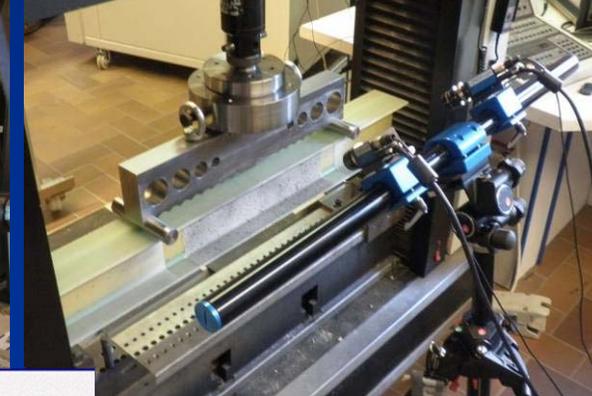
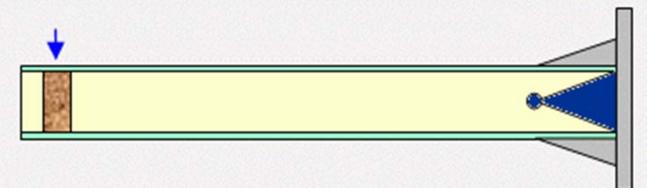
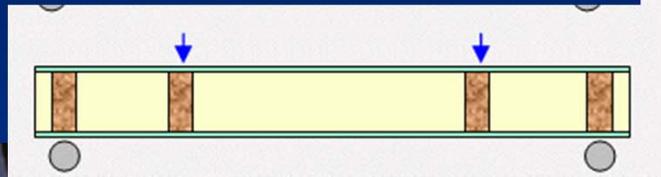
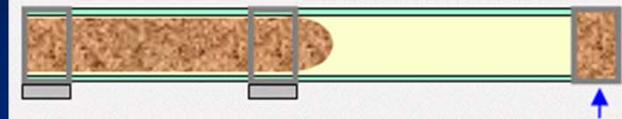
Blade root



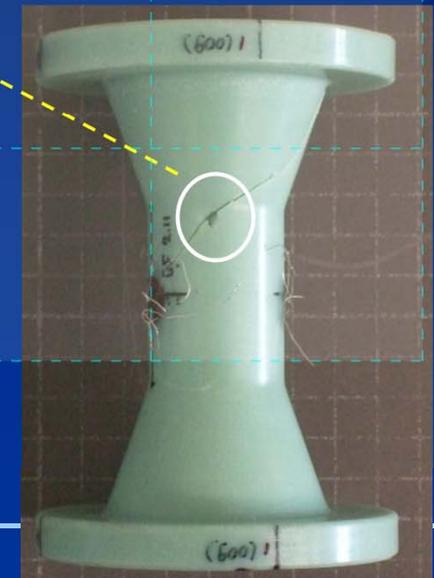
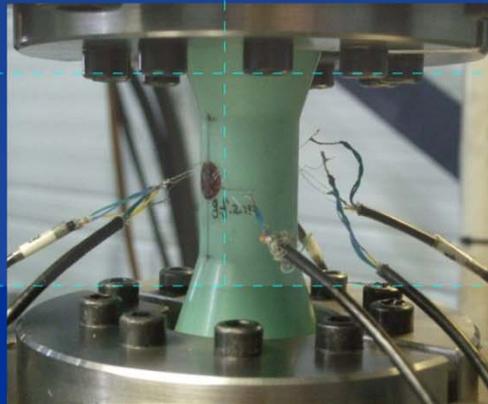
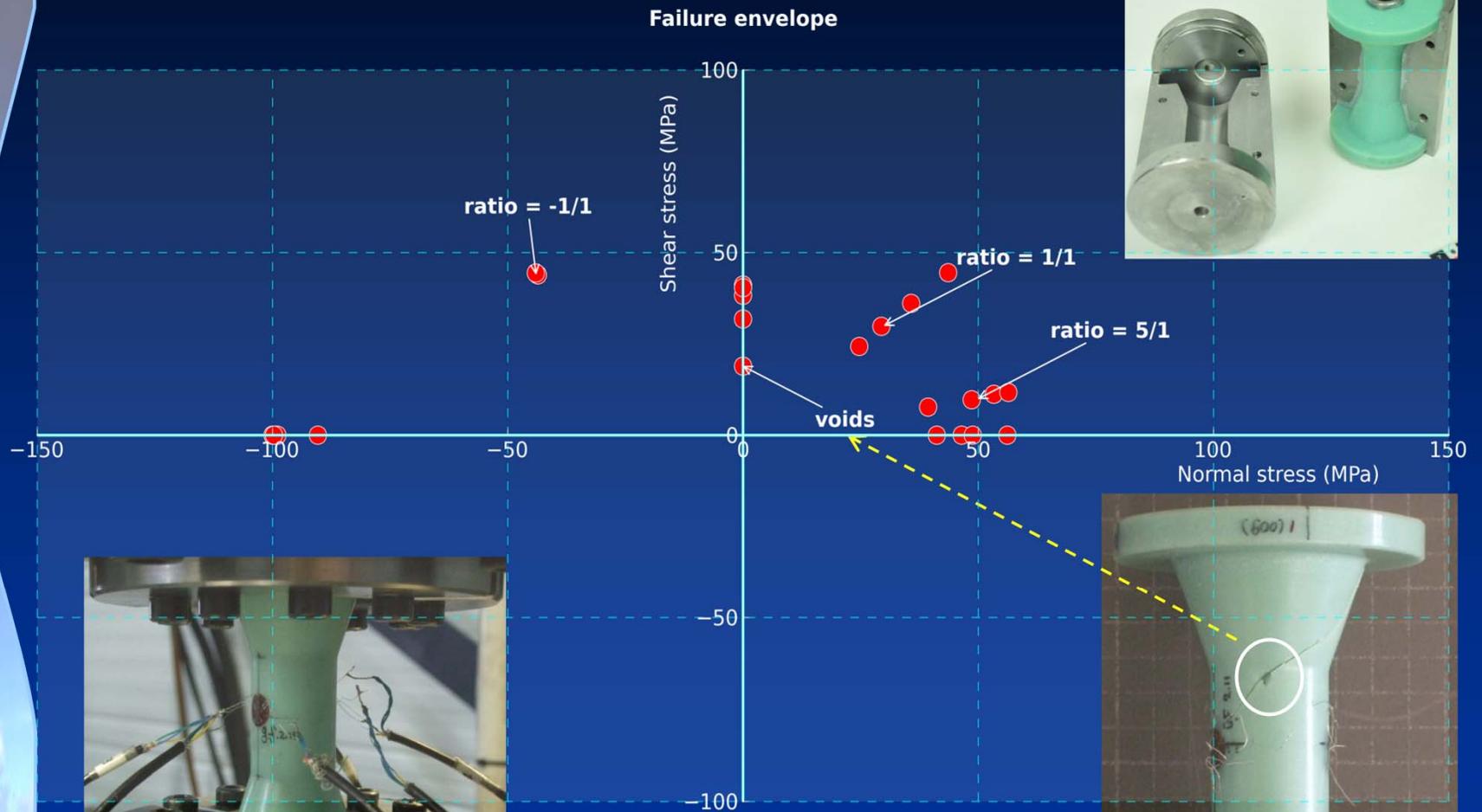
Spar end detail

# Subcomponents – Experimental

- CRES
- Fraunhofer – IWES
- STFC-RAL
- VUB
- WMC



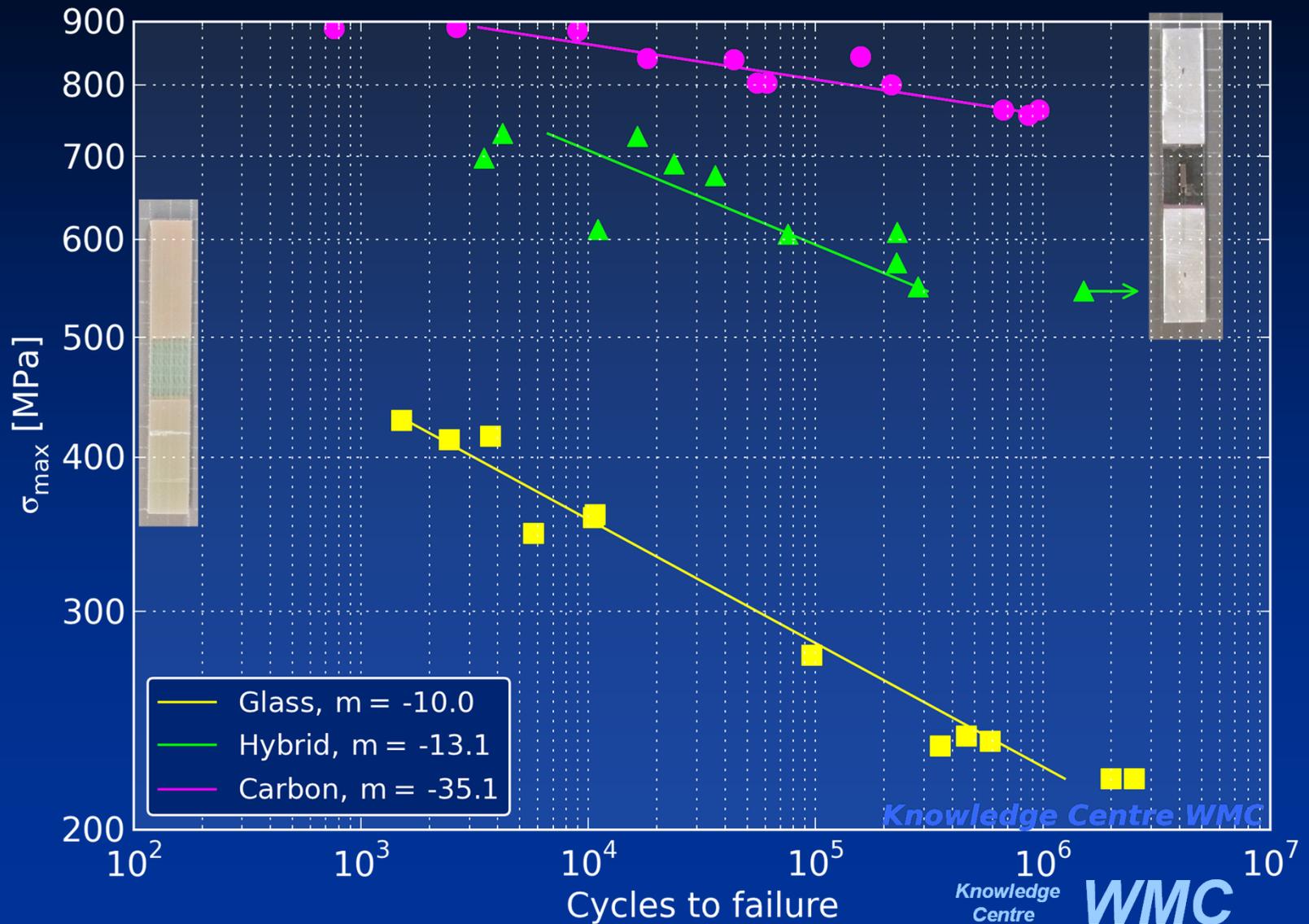
# Failure envelope of adhesive



# Glass/carbon

- **Glass vs carbon reinforcement**
  - stiffness
  - cost, infusability
- **Characterisation of glass and carbon vs hybrids**
- **Blade modelling**

# Glass-carbon hybrids (R=0.1)

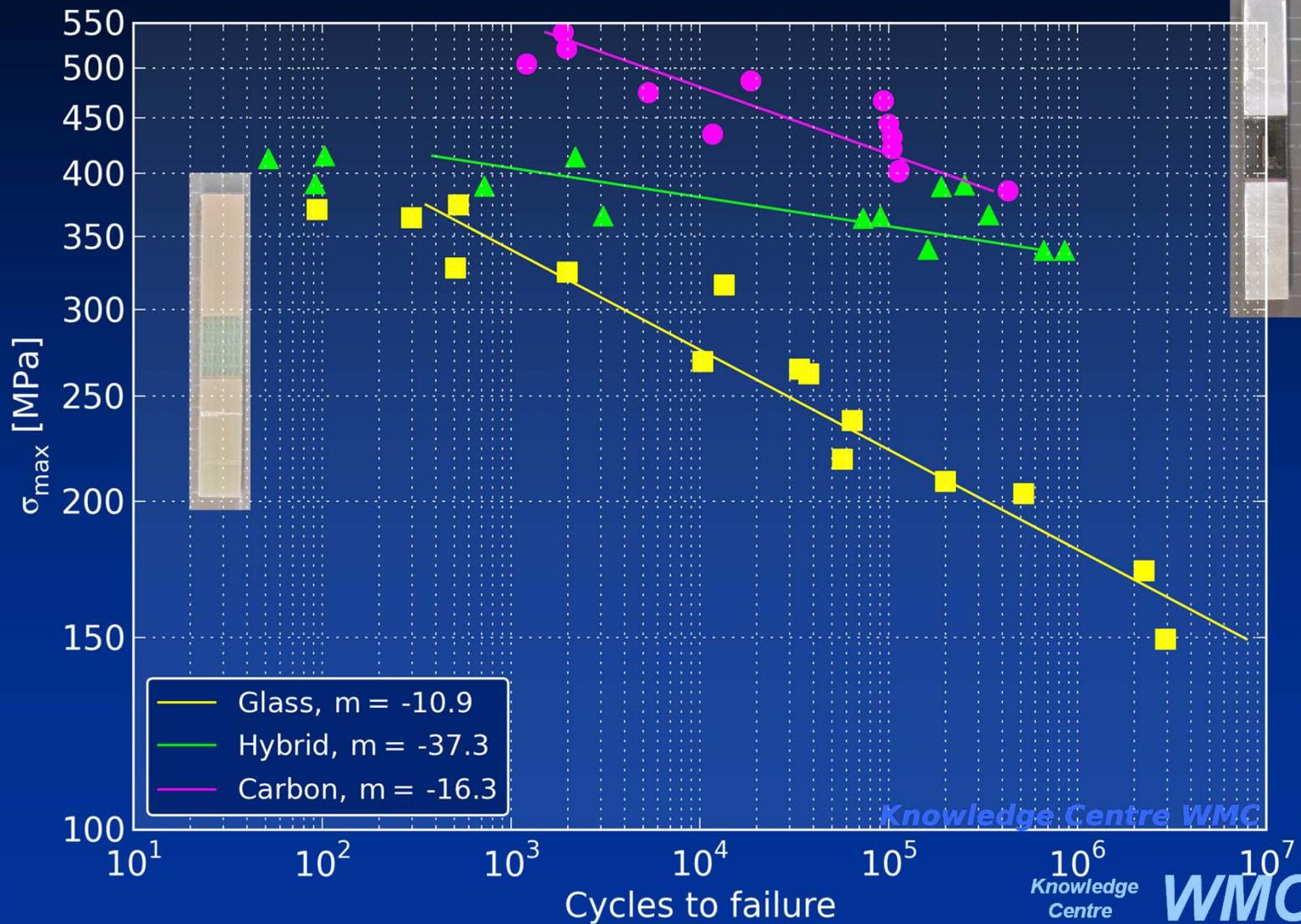


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# Glass-carbon hybrids (R=-1)

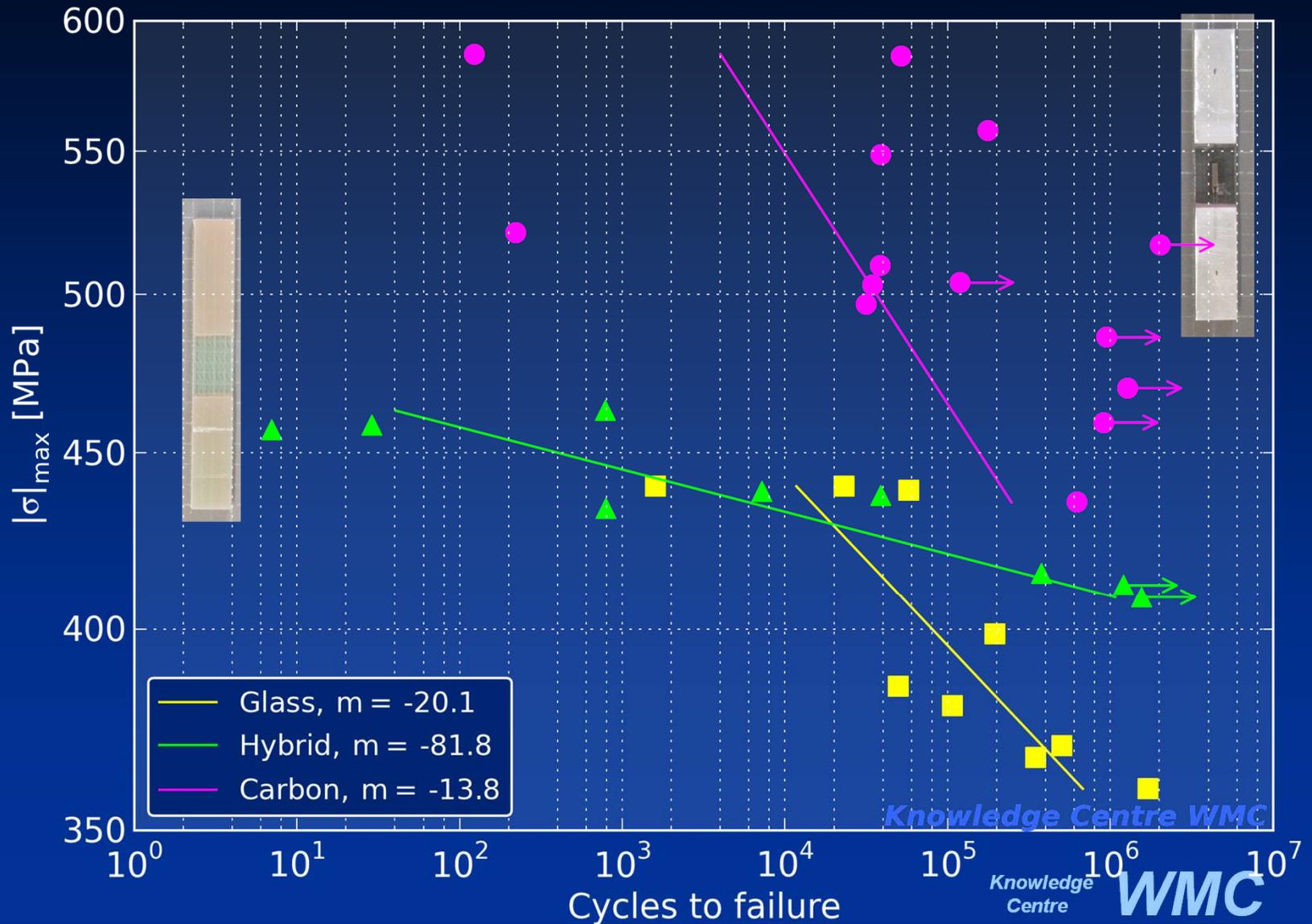


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# Glass-carbon hybrids (R=10)

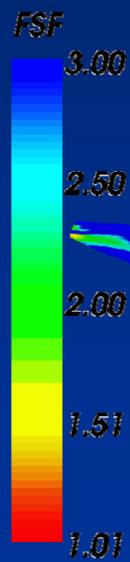
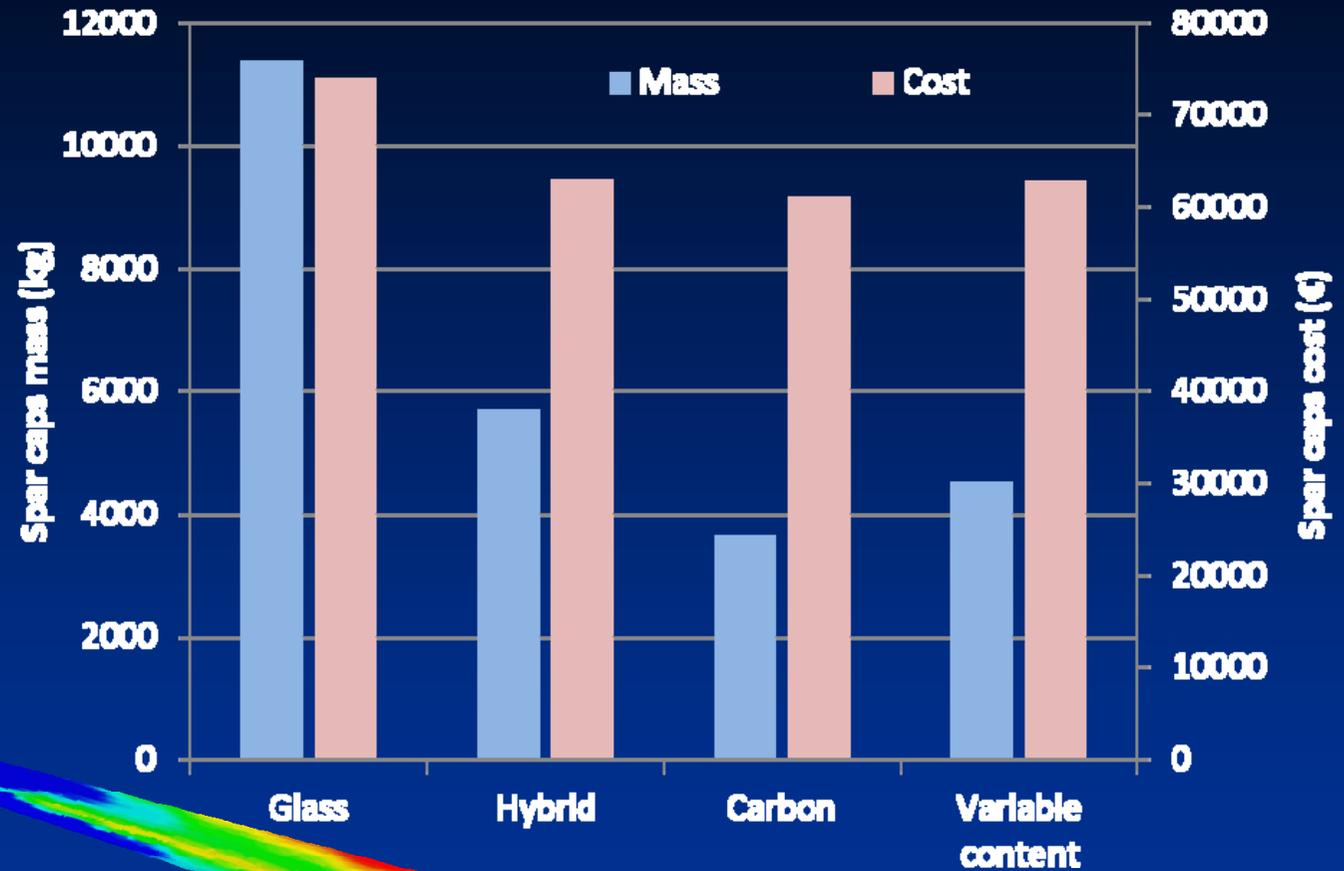


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# Blade modelling – effect of material



# Concluding remarks / Outlook

- Major issues in fatigue characterisation/prediction
  - are being tackled
  - in increasing detail/material variety
  - requiring new methods and models
- Thick laminates
  - Manufacturing and heating
- Micromechanics
- Subcomponents
- Carbon/glass hybrids
  - promising

# Thanks! Questions/comments?

[info@wmc.eu](mailto:info@wmc.eu)

