



WIND ASSURING CONFIDENCE THROUGH COMPETENCE

Experimental Fatigue Investigations on Materials and Structures of Rotor Blades

Tobias Mangels, Eric Putnam, Vinzenz Klapper, Florian Sayer, Alexandros Antoniou





Outline

- Fraunhofer IWES
- Introduction
- UD Composite tests: Effect of fiber volume fraction on the UD fatigue life
- Adhesive materials: Fatigue strength of the bond line joint in WTRB
- Summary



Short profile of Fraunhofer IWES North-West

Managing Director:

Prof. Dr.-Ing. Andreas Reuter

Research spectrum:

Wind energy from material development to grid connection

Operational budget 2014:

around 13,2 million €

Staff:

150 employees

Previous investments in the establishment of the institute:

€ 60 million



Strategic Association with ForWind and the German Aerospace Center (DLR)



Where to find us:



- Main site of the institute
- Department
- Working group



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Wind Turbine Rotor Blades

LM 73,5m



Source.
<http://www.windrowerengineering.com>

Siemens 75m



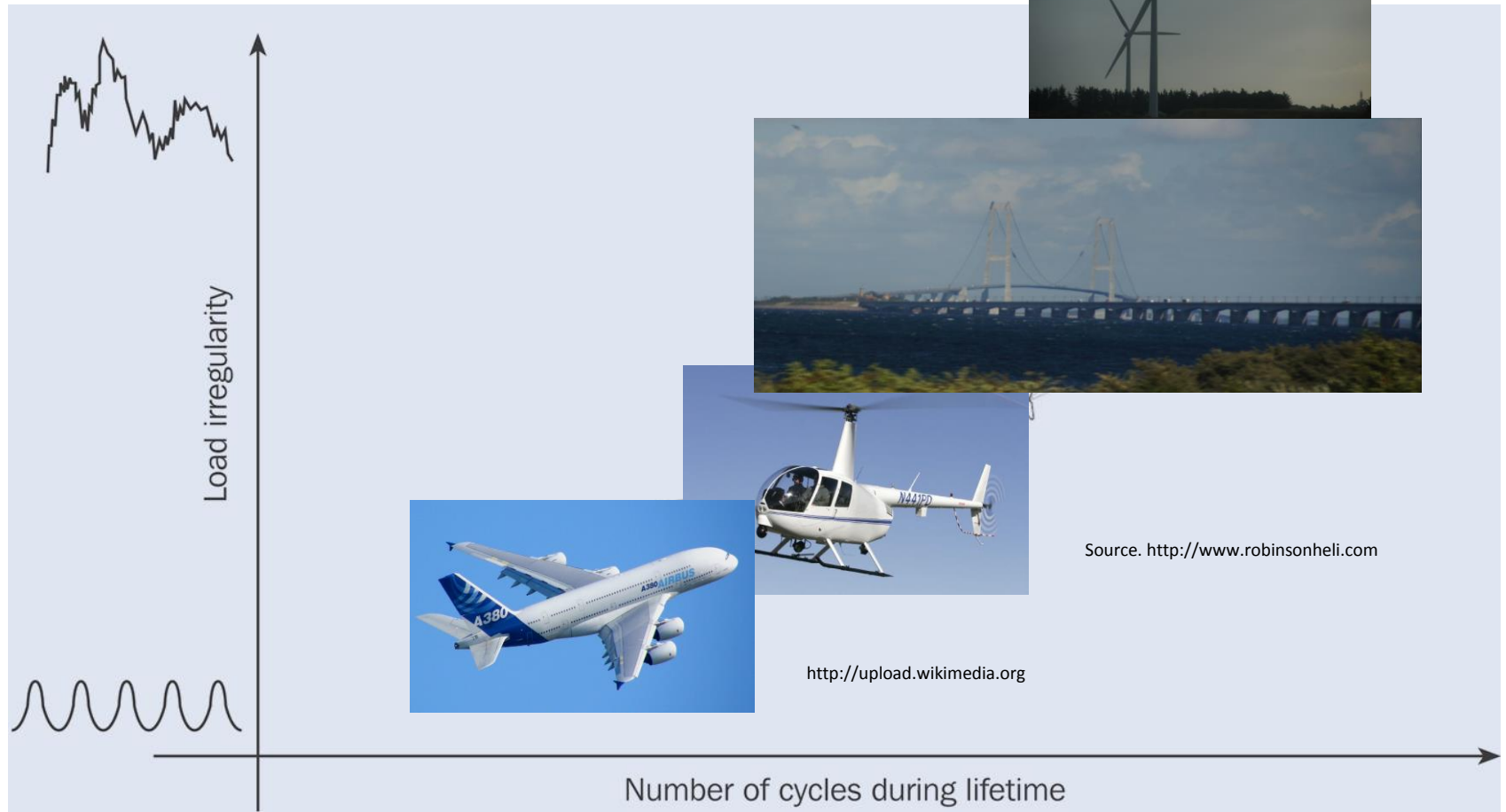
Source. <http://www.siemens.com>

Mitsubishi 81,5m



Source. <http://www.windpowermonthly.com>

Wind Turbine Loads

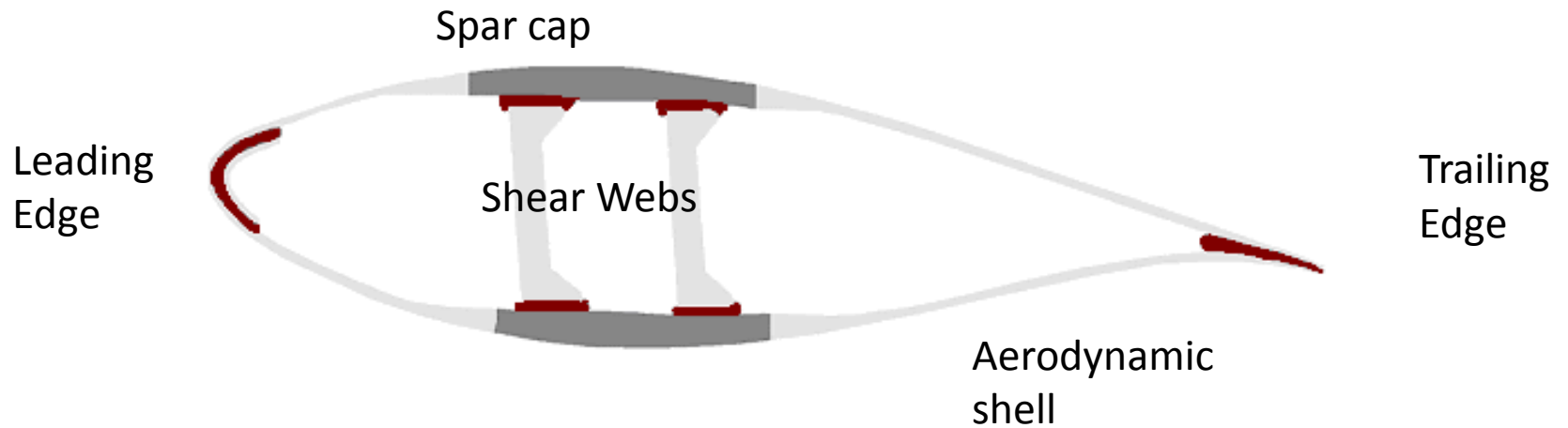


Wind Turbine Rotor Blades

- ↘ Highly loaded structures
 - ↘ High performance materials are required
 - ↘ Fatigue properties are design drivers
-
- ↘ Parameters affecting the material and structural fatigue performance are investigated experimentally

Wind Turbine Rotor Blades

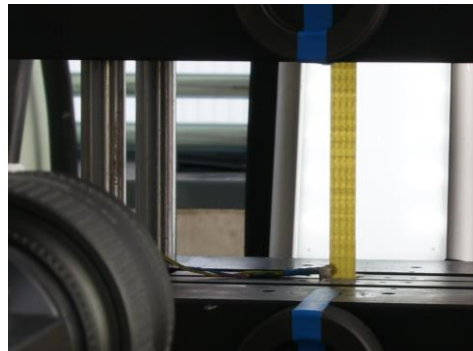
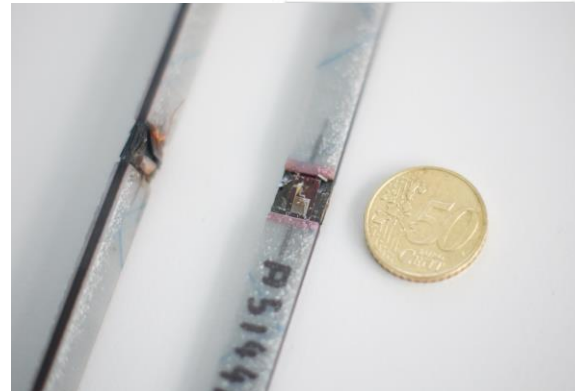
✦ Blade structure: terminology



Material Testing

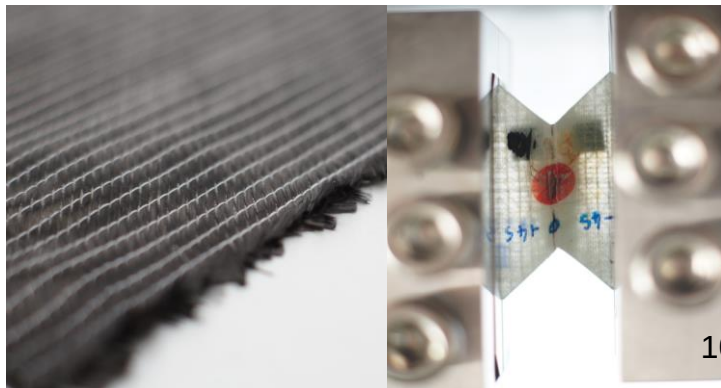
Unidirectional Fabric

- Static
- Fatigue
- Tension, compression



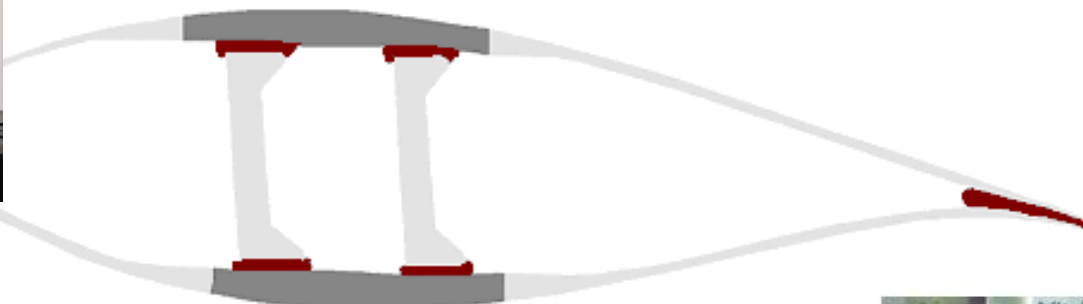
Biaxial Fabric

- Static
- Fatigue



Sandwich, e.g.

- 3 Point bending
- 4 point bending
- "Lap-Shear"
- Skin bonding



Coupon Machines

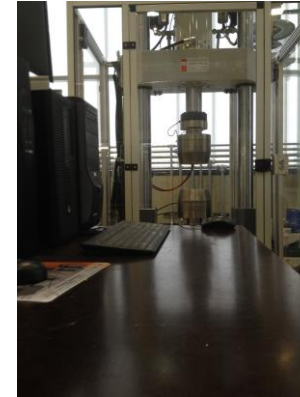
100kN Climate Chamber 40°+130°



250kN



100kN/2000Nm



50kN



1MN



2,5MN



25kN



 **Fraunhofer**

IWES

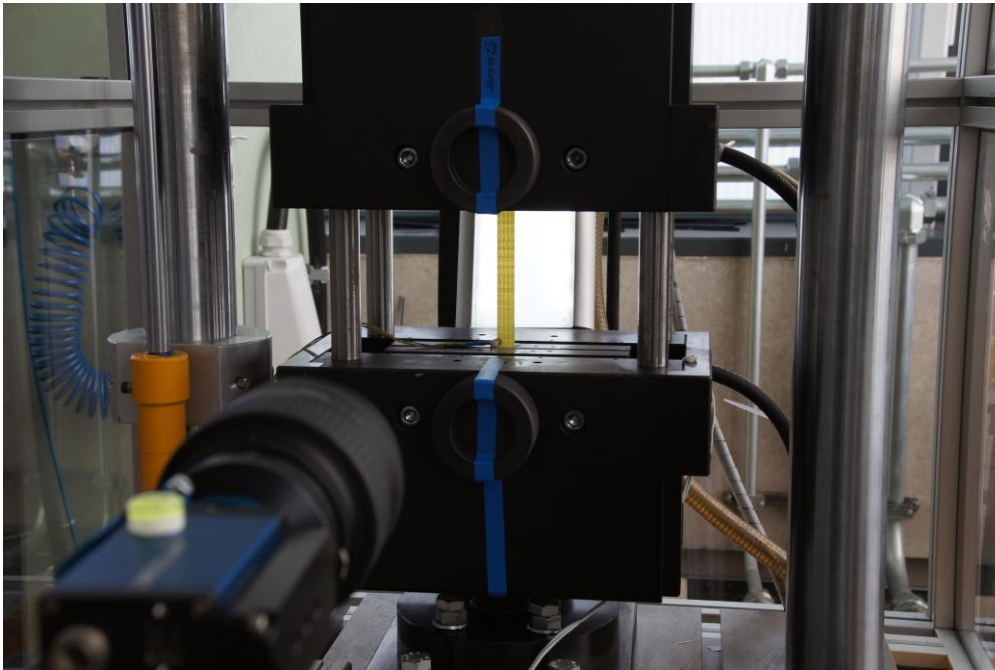


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Effect of FVF on the UD composite fatigue life

- ↘ The Fiber Volume distribution is varying from blade to blade structure
- ↘ The Fiber Volume Fraction effect was investigated
- ↘ Glass/Epoxy systems (UD) were tested in $R=0.1$ @ a 100kN machine
- ↘ Two coupon series with different Fiber Volume Fractions (55% and 58%) were manufactured
- ↘ The manufacturing sequence was the same for both laminates (VARTM, post treatment)



Effect of FVF on the UD composite fatigue life

✦ Failure modes

FVF 55%



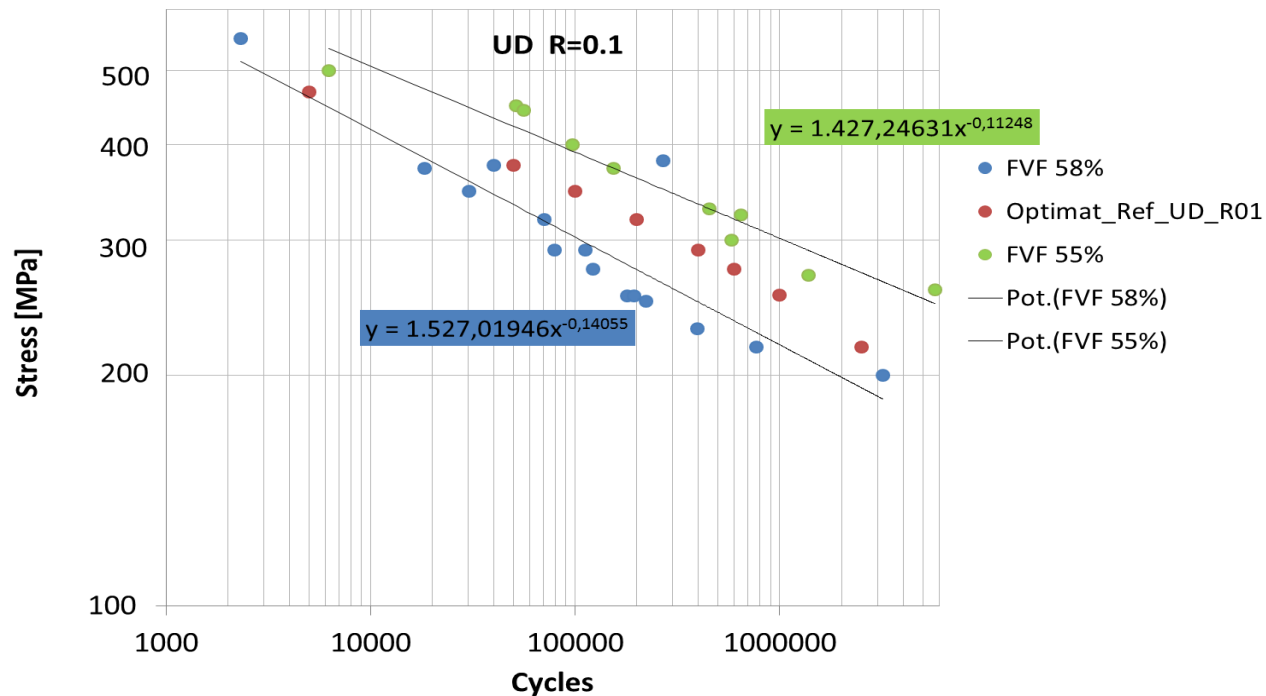
FVF 58%



Effect of FVF on the UD composite fatigue life

✈ The Fiber Volume Fraction effect

UD Glass (1200gr/m²)/Epoxy

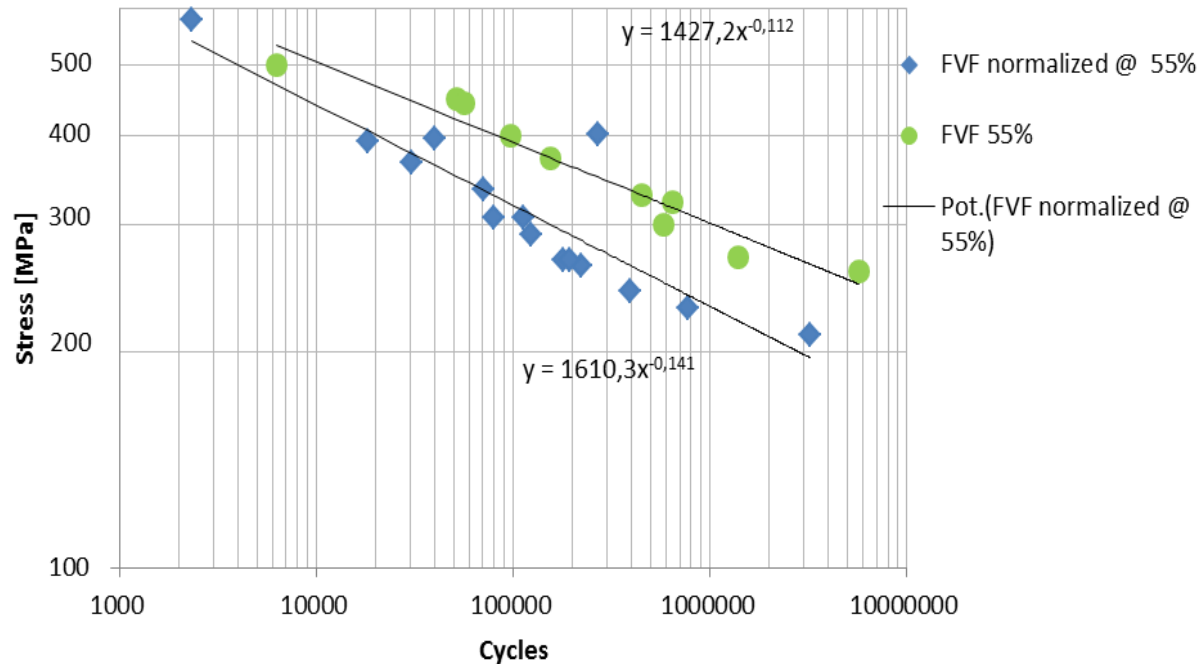


UD ply	Original S/N estimat.
FVF 55%	$\sigma = 1427N^{-0.112}$
FVF 58%	$\sigma = 1527N^{-0.141}$

Effect of FVF on the UD composite fatigue life

✈ The Fiber Volume Fraction effect

58% FVF normalisation to 55% FVF



UD ply	Original S/N estimat.	Normalised to 55%
FVF 55%	$\sigma = 1427N^{-0,112}$	-
FVF 58%	$\sigma = 1527N^{-0,141}$	$\sigma = 1610N^{-0,141}$

✈ FVF diff. is 3% (GL allows $\pm 2,5\%$) but the S/N curves have 20% difference in slope

Effect of FVF on the UD composite fatigue life

✧ The Fiber Volume Fraction effect

Quasi-UD glass fibre NCF composites for wind energy applications: a review of requirements and existing fatigue data for blade materials

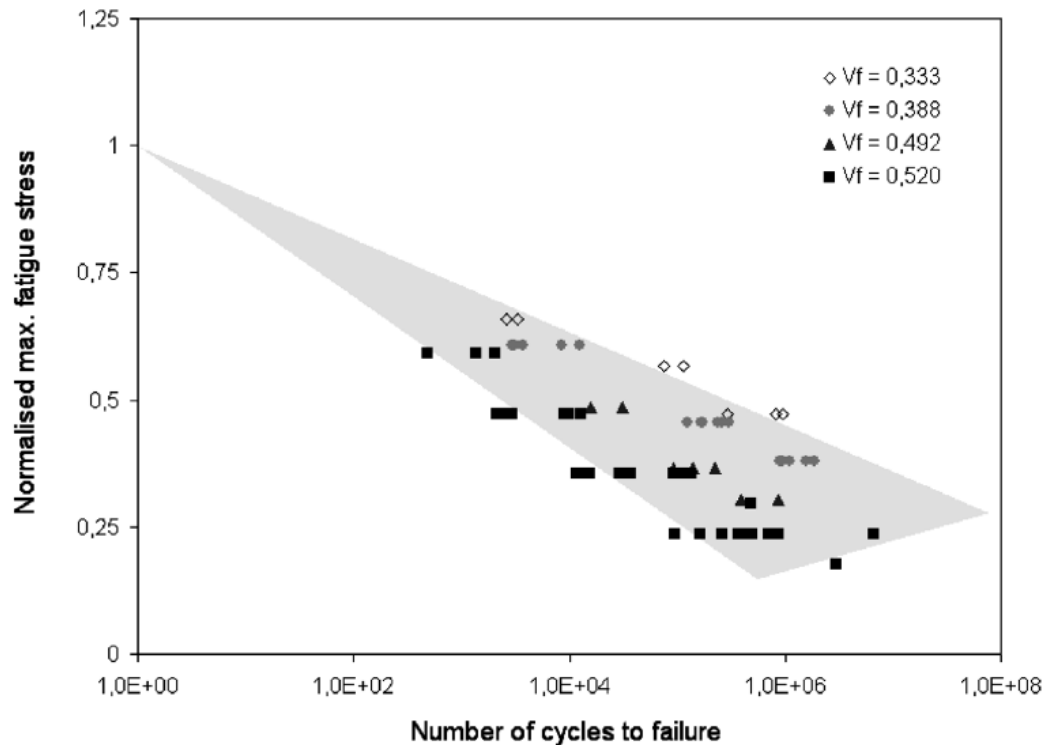
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AND IGNAAS VERPOEST¹

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www.mechanics-industry.org



✧ Similar effect of the FVF on the S/N slope with the IWES test

Summary UD fatigue life

- The FVF has to be taken under consideration for the calculation of fiber dominated properties
 - The FVF seems to affect the slope of the fatigue performance, deteriorating significantly the strength
 - The same slope deterioration has been identified in the literature



Outline

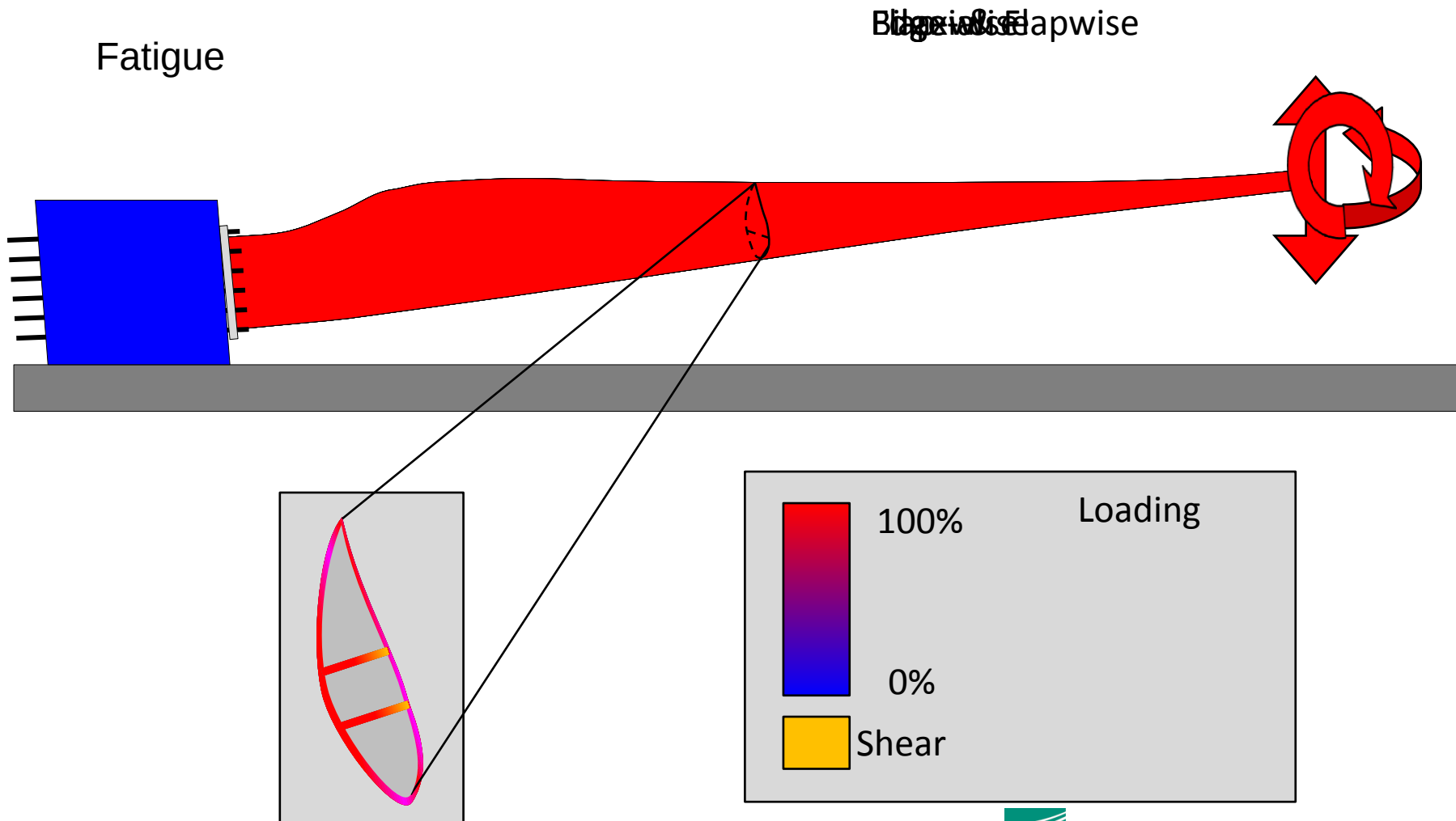
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Full Scale Rotor Blade Testing

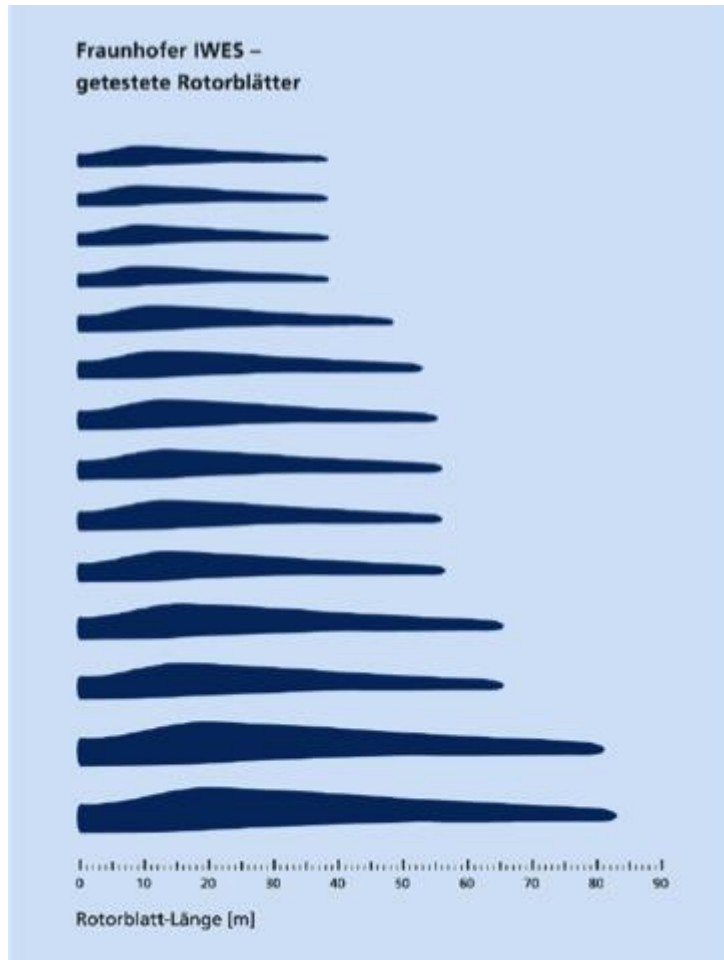
- Two of the world largest test rigs
 - 70m test rig
 - 90m test rig with tilt function
- Static and fatigue testing
 - Servo-hydraulic actuators
 - Excellent control of tests
- Non-destructive testing and proven shut down strategies in case of failure
- Experience in logistics for large blades (>80m)



Full Scale Blade Test: Current Practices

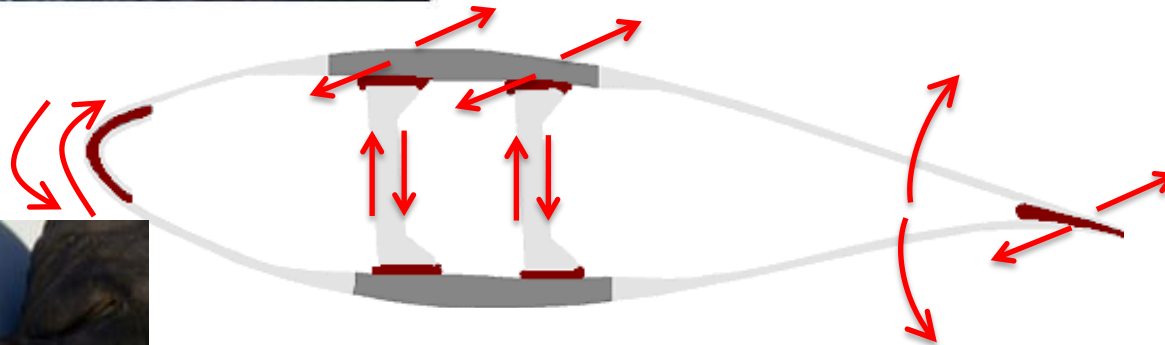
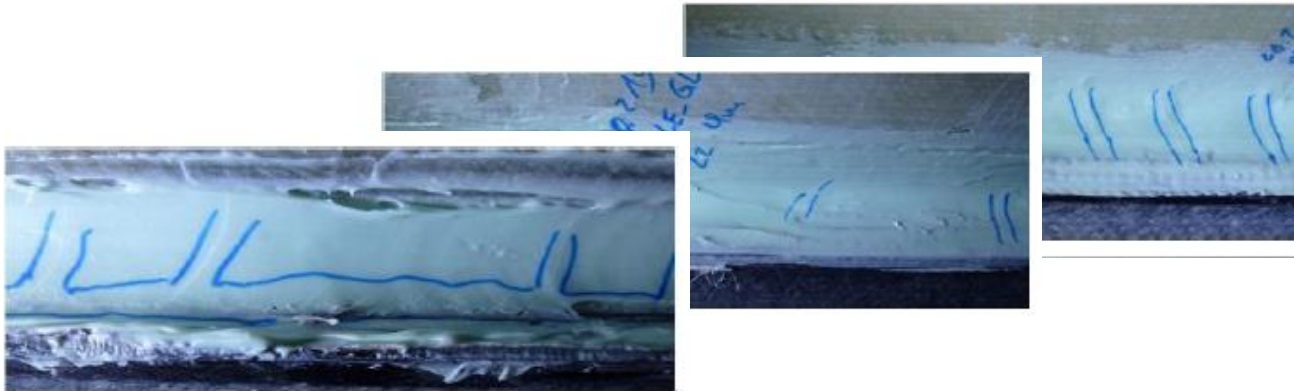


Full Scale Blade Testing

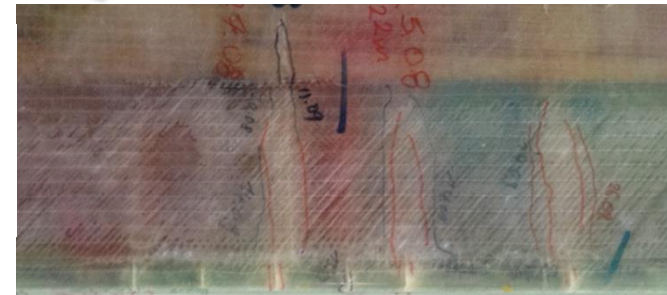


- ↘ IEC 61400-23
- ↘ Summary of the bond line cracks
- ↘ Multiple cracks are excluded in the range of $\pm 20\text{cm}$

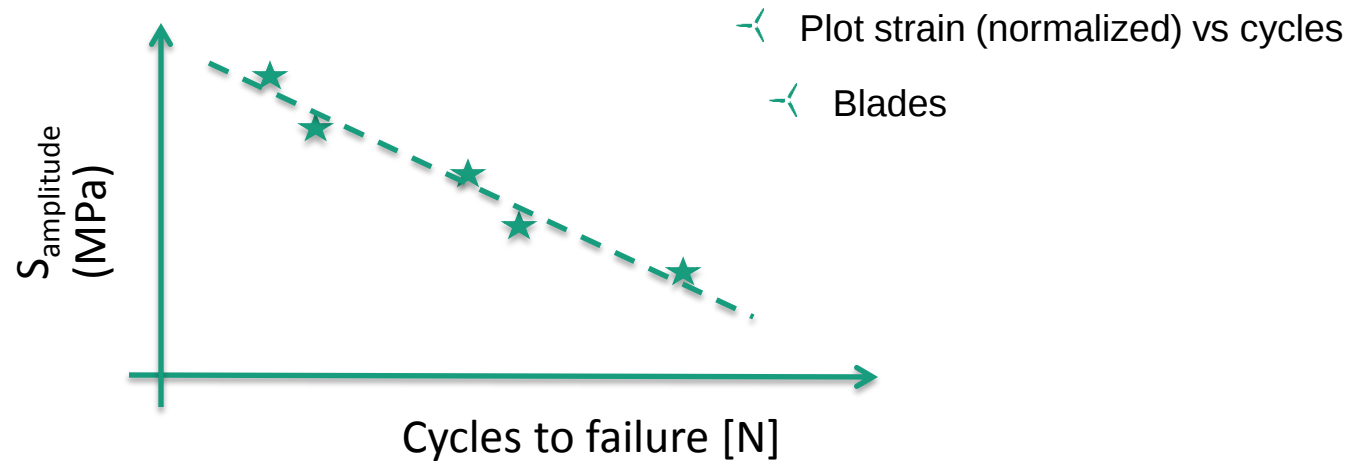
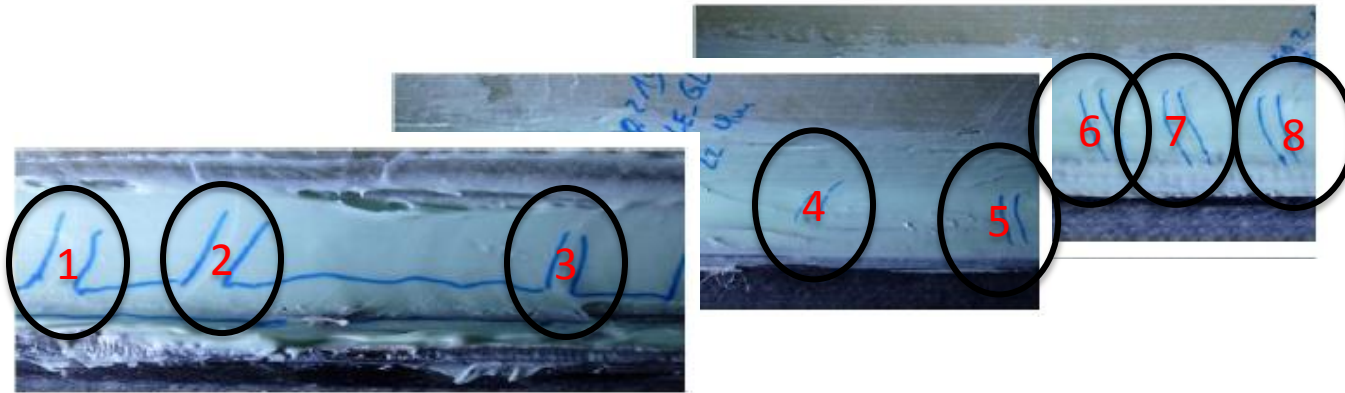
Bond Line Stress States and Strength



Leading edge cracks: occur in field, however usually not observed in full scale testing

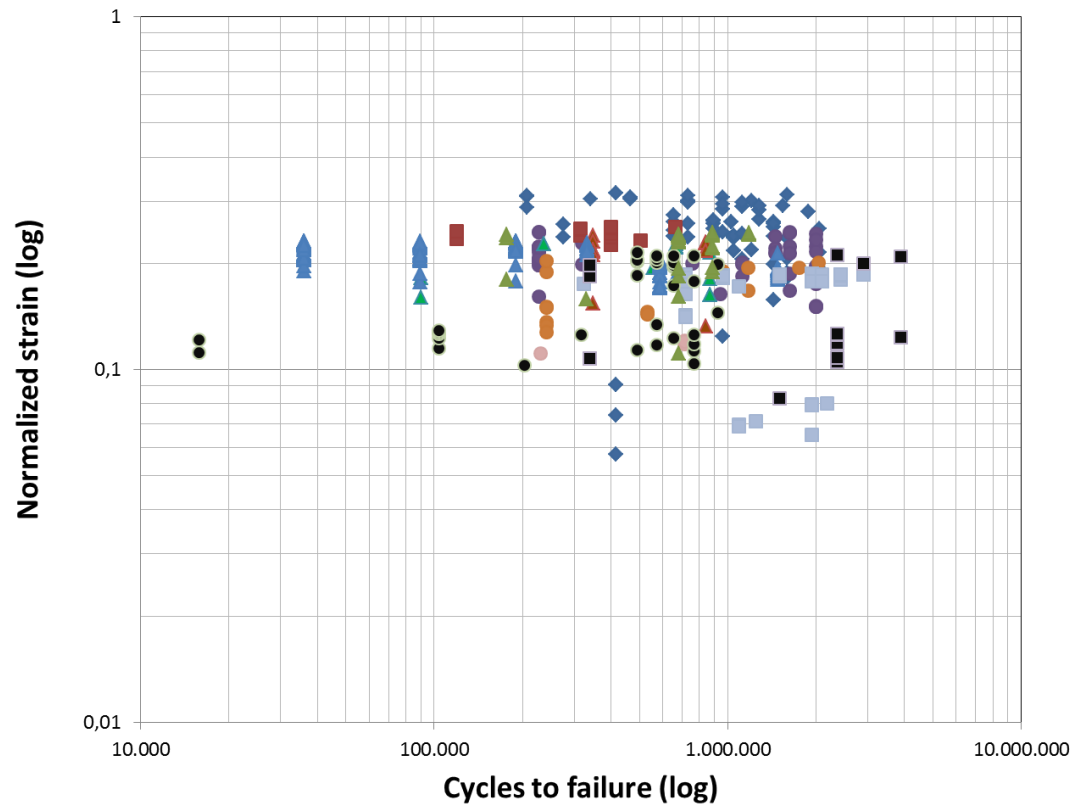


Bond Line Stress States and Strength

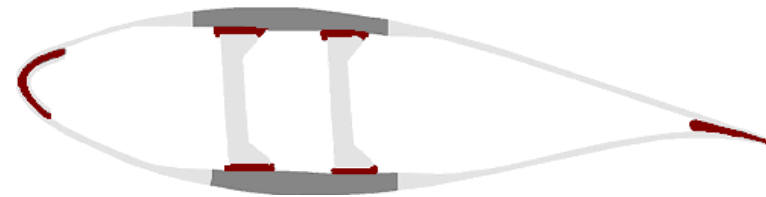


Bond Line Stress States and Strength: All Blades

Strain (normalized) vs cycles



All tests
All bond line cracks



Bond Line Stress States and Strength: All Blades

Strain (normalized) vs cycles

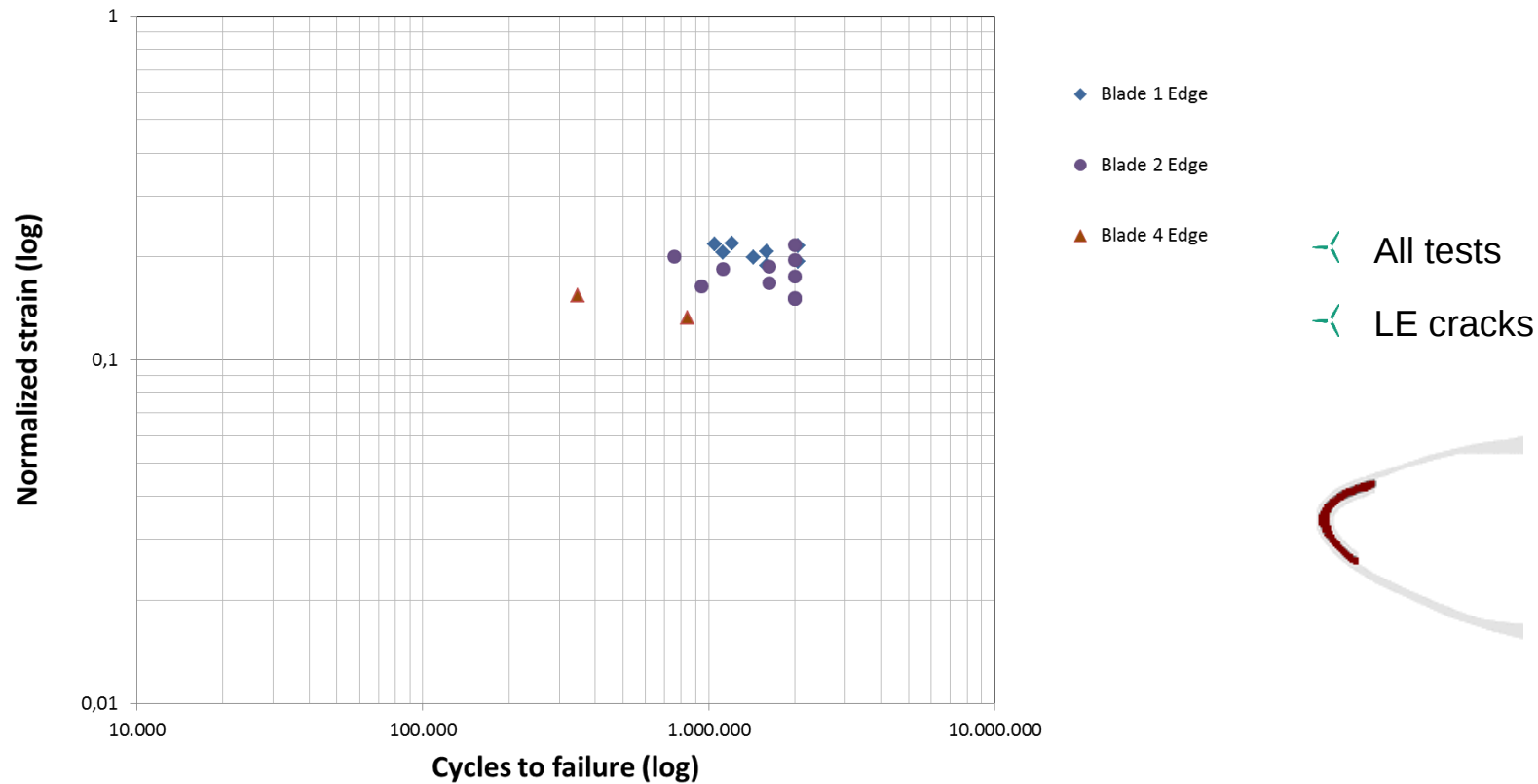


All tests
SW – SC cracks



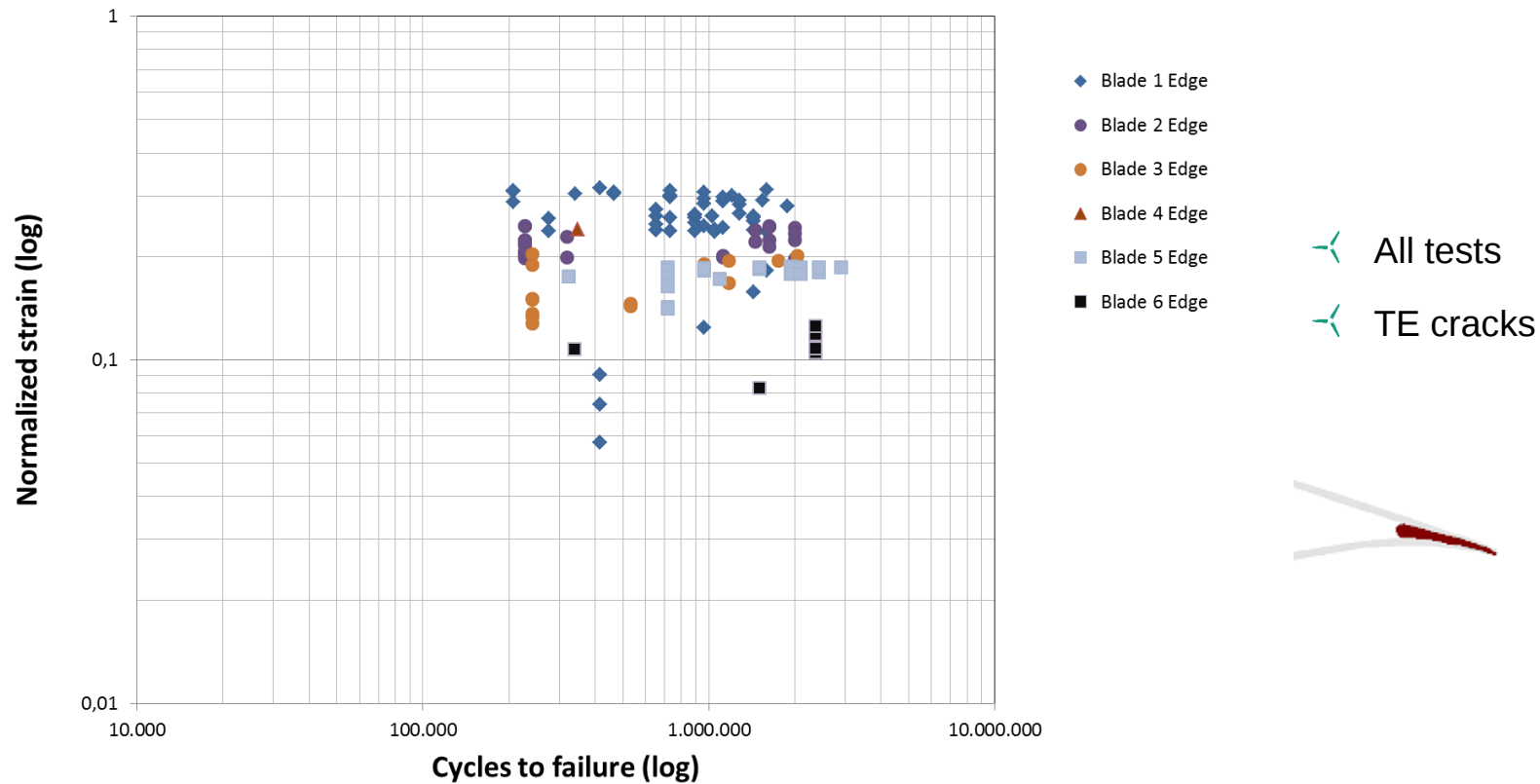
Bond Line Stress States and Strength: All Blades

Strain (normalized) vs cycles



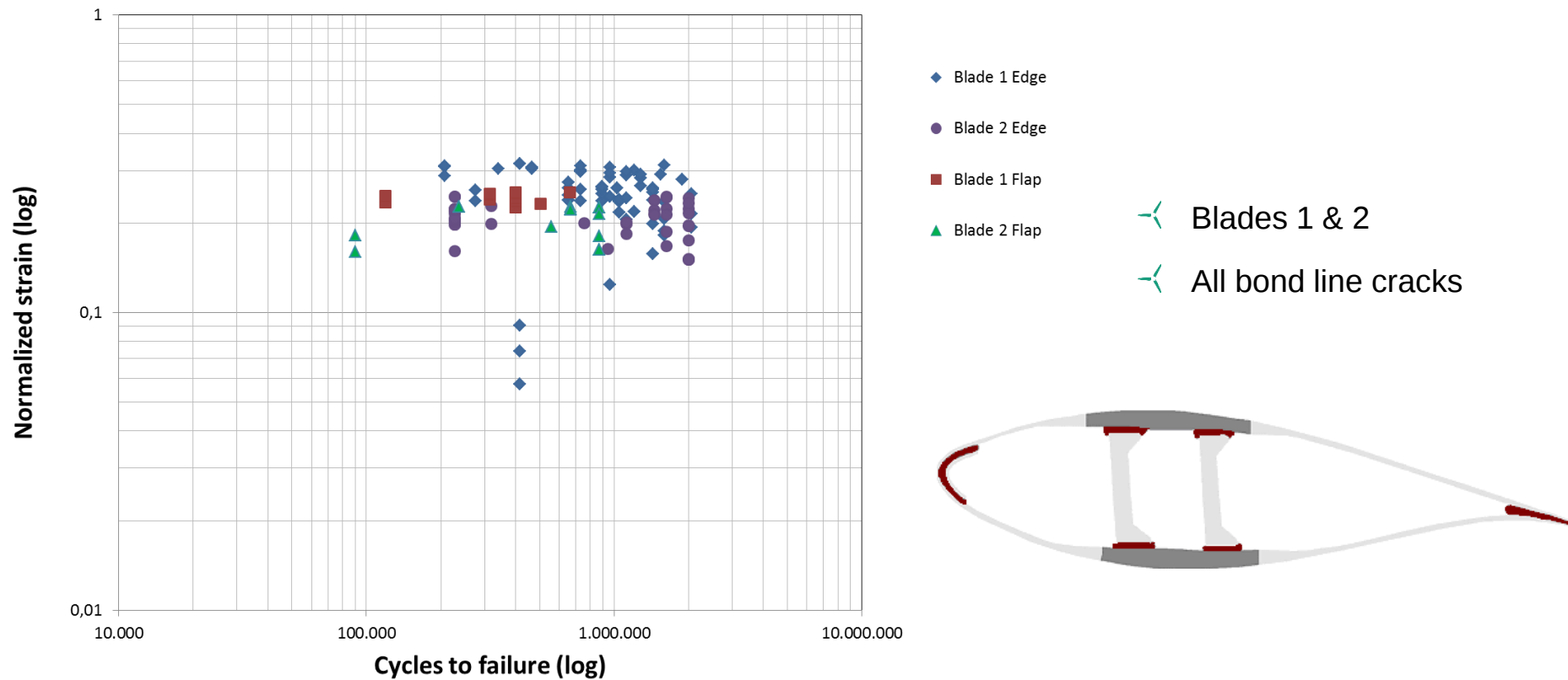
Bond Line Stress States and Strength: All Blades

Strain (normalized) vs cycles



Bond Line Stress States and Strength: Blades 1 & 2

Strain (normalized) vs cycles



Bond Line Stress States and Strength: Blades 1 & 2

Strain (normalized) vs cycles

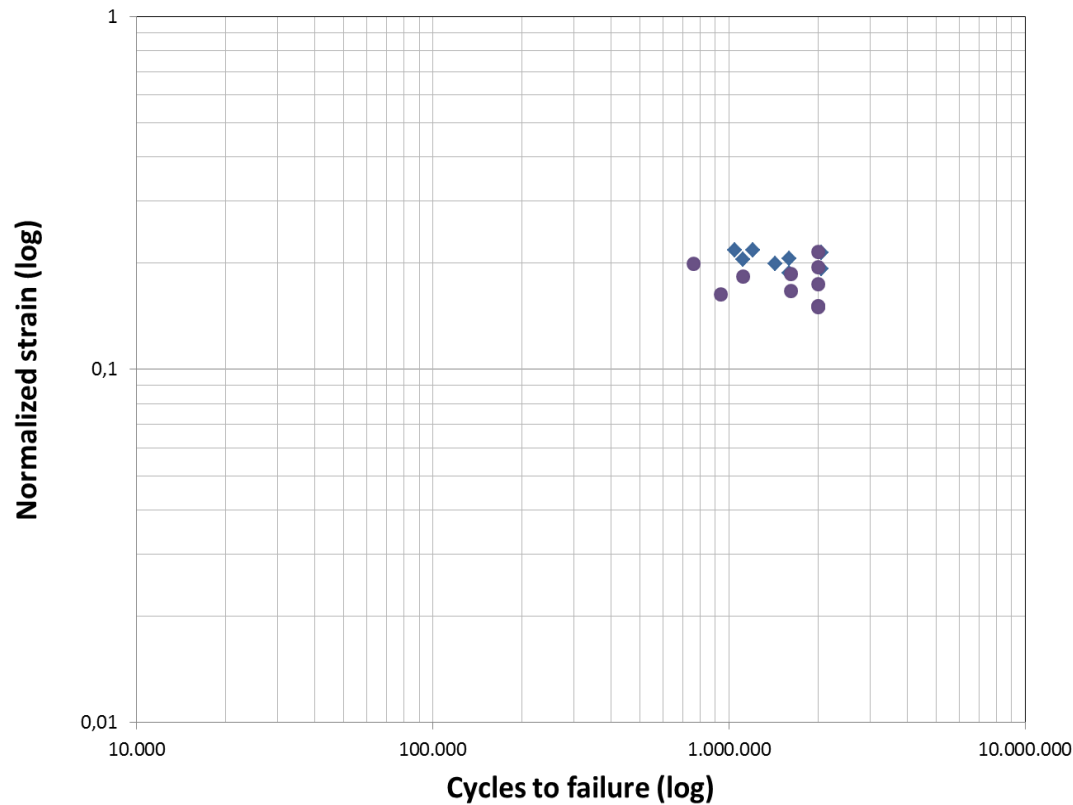


Blades 1 & 2
SW – SC cracks



Bond Line Stress States and Strength: Blades 1 & 2

Strain (normalized) vs cycles

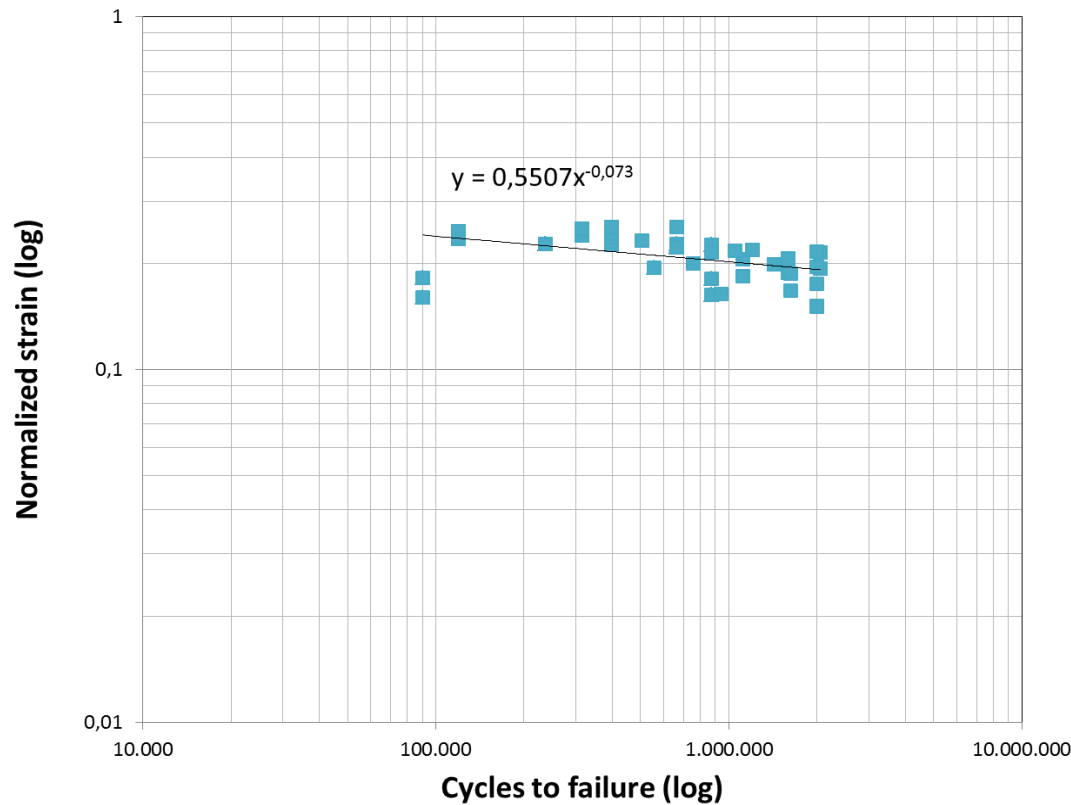


Blades 1 & 2
LE cracks



Bond Line Stress States and Strength: Blades 1 & 2

Strain (normalized) vs cycles (LE & SW-SC)



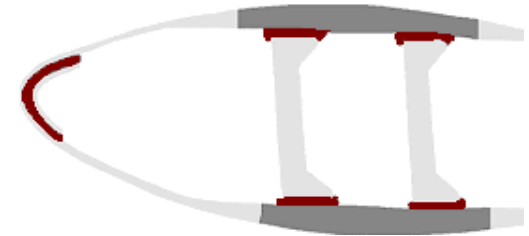
Blade 1 Flap

Blade 2 Flap

Blades 1 & 2

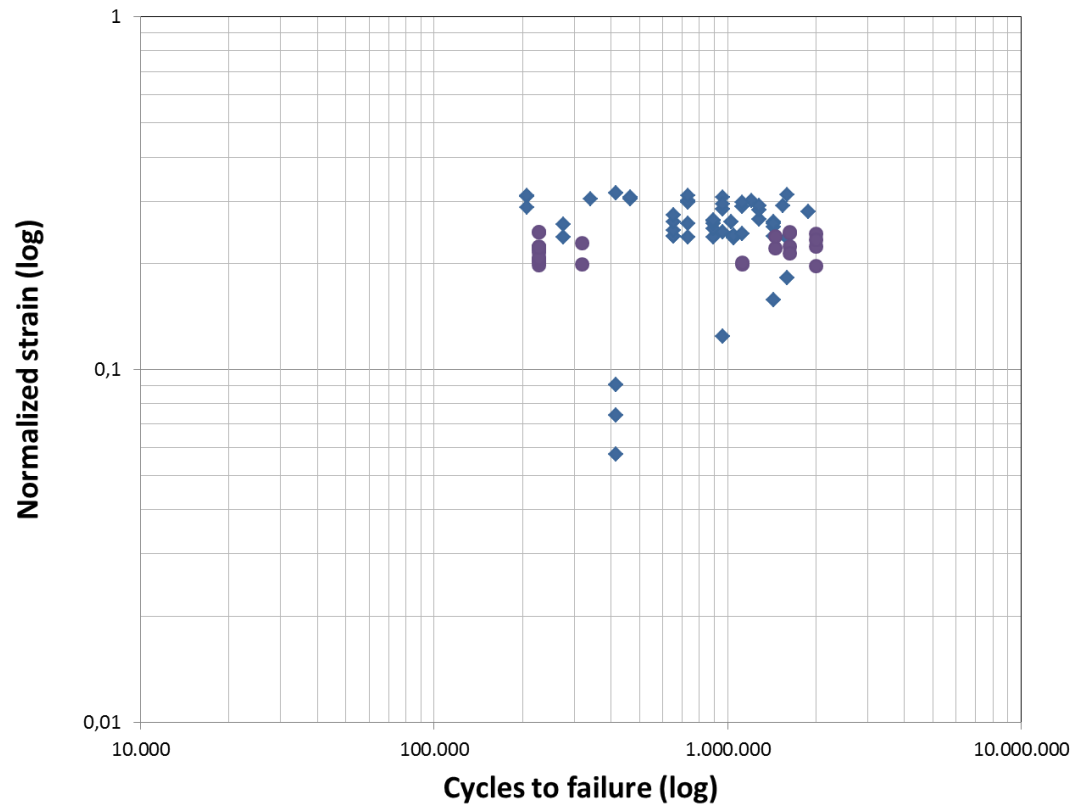
SW – SC cracks

LE Cracks



Bond Line Stress States and Strength: Blades 1 & 2

Strain (normalized) vs cycles



Blades 1 & 2

TE cracks



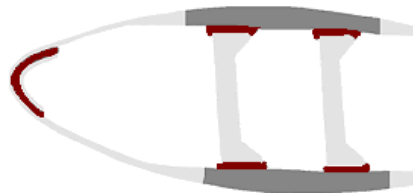
Bond Line Stress States and Strength: Blades 1 & 2

Strain (normalized) vs cycles

Blades 1 & 2

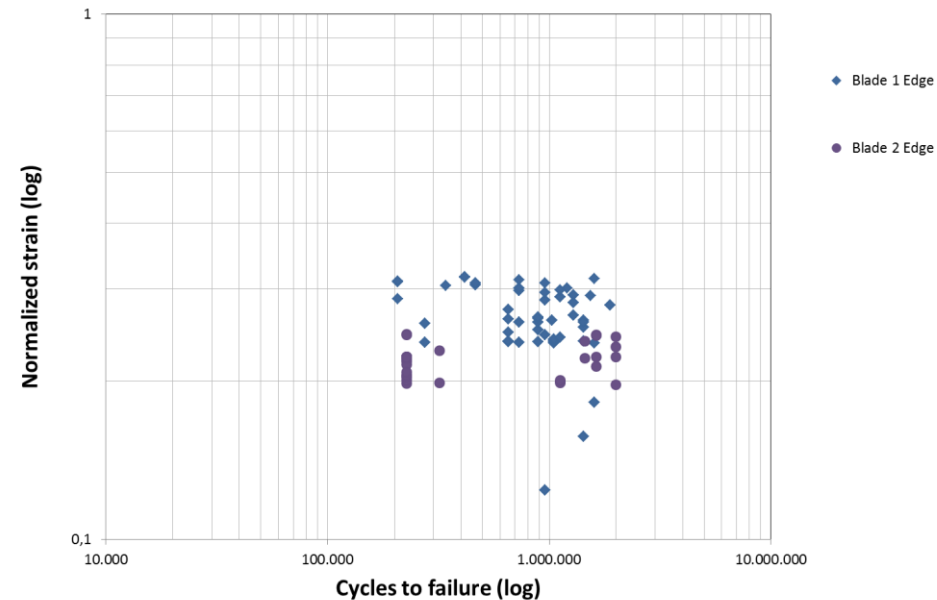
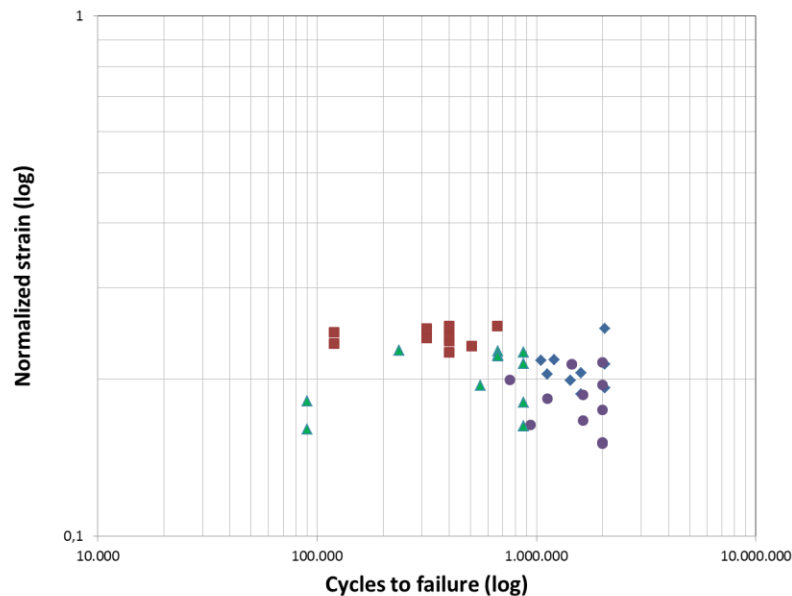
SW – SC cracks

LE Cracks



Blades 1 & 2

TE cracks



Summary on fatigue of adhesive bond joints of WTRBs

- ↘ Adhesive shows one (1) decade scatter in fatigue life in the same strain level both in flap and edge loads for one blade.
- ↘ The scatter increases when more blades are taken under consideration.
- ↘ The adhesive structural performance is dependent on the substrates and the local stress states.
- ↘ Adhesive material fatigue resistance to mode A cracks shows a higher average fatigue strength at trailing edge rather than at leading and shear web to spar cap connection.





THANK YOU FOR YOUR ATTENTION

Questions?

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