Disbond – Fatigue Crack Growth Analysis

EASA
Bonded Structure Workshop

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Introduction

- **leichtwerk**, founded 1996 at research airport Braunschweig
- In direct neighborhood to
    - DLR (Inst. of Aerodynamics and Flow Technology)
    - DNW (3 m laminar wind tunnel)
    - TU Braunschweig (Inst. of Aircraft Design and Structural Mechanics, testlab for coupon and building block tests)
    - LBA (German Aviation Authority)
- **protowerk,** founded 2004 (production of prototypes and test specimen)
- **Leichtwerk AG**, founded 2009, a merger of protowerk and leichtwerk

- Business activities:
    - Lightweight structures
    - EASA DO 21J.332

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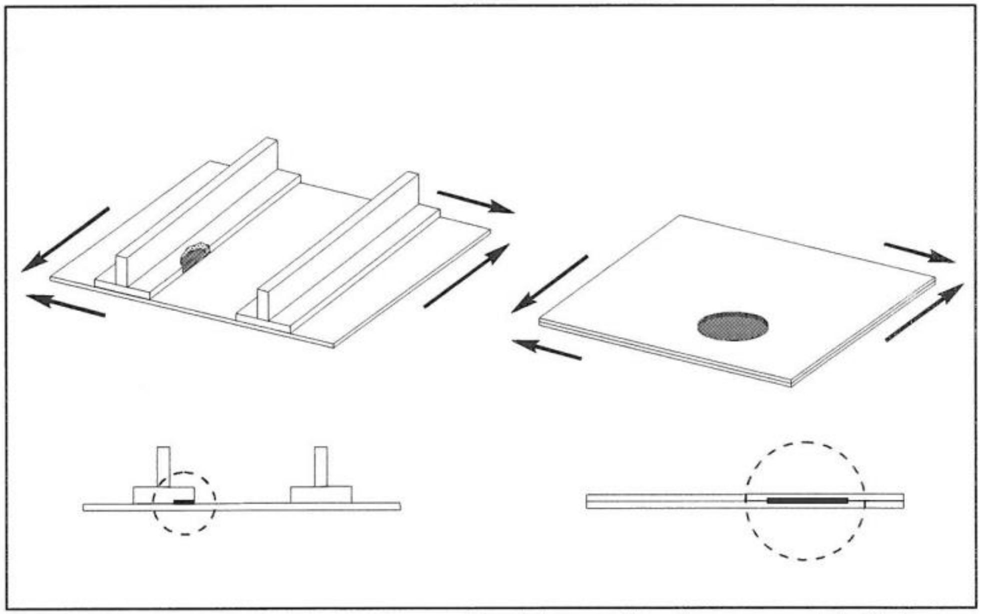
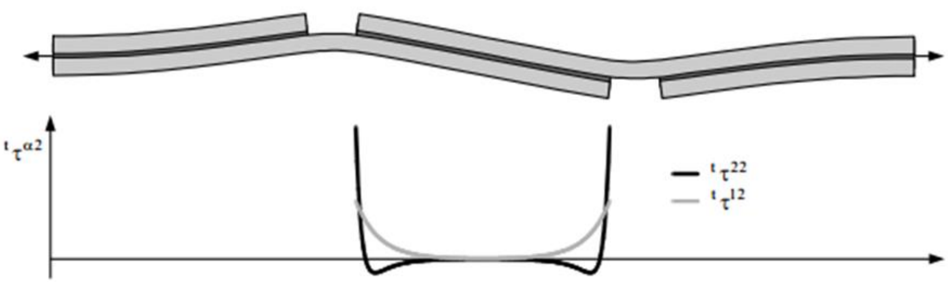
Bonded Structures – the Problem



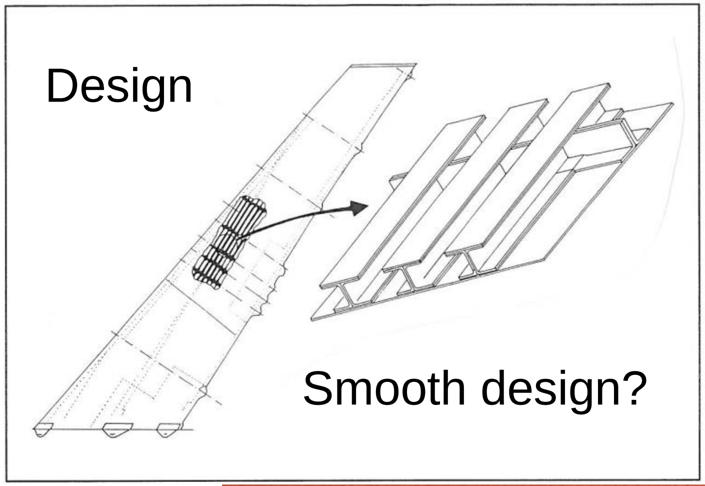
Failure modes of bondings similar to IFF:
Adhesive or cohesive failure

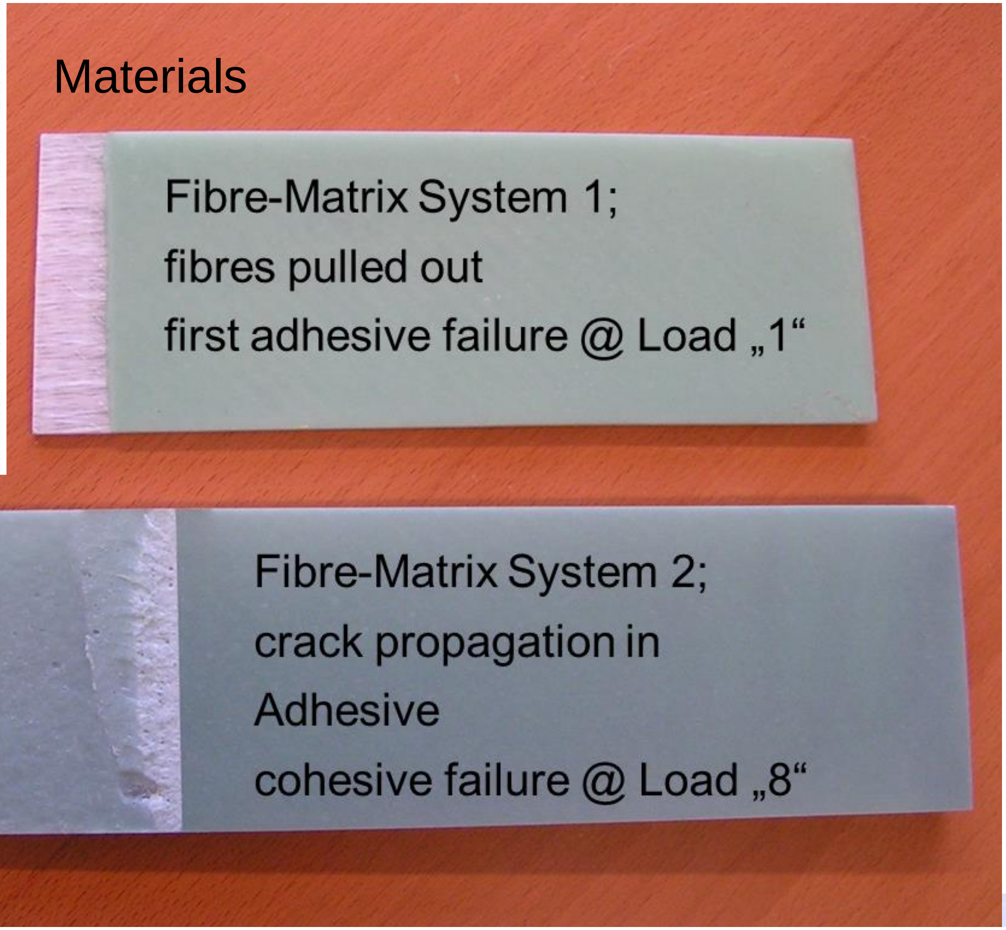
Driven by load spectrum , structural stiffness, properties of the adhesive, fiber matrix interface



Distribution of
peeling stress (black)
and shear stress (grey)

General Loop: Design - Materials – Manufacturing - Properties – Analysis





Adhesive or cohesive failure?

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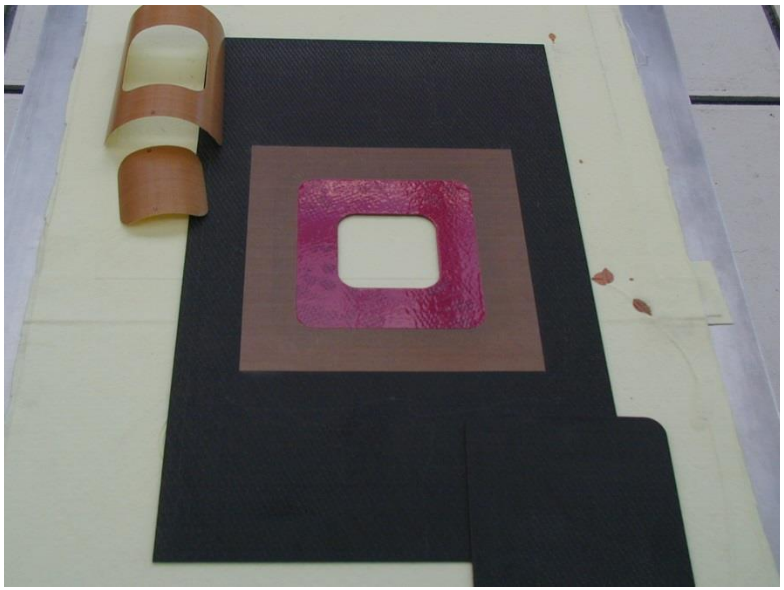
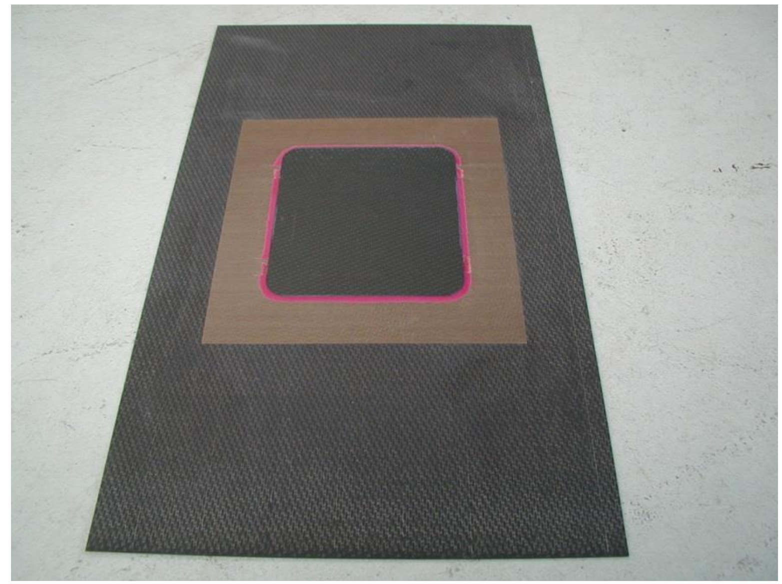
General Loop: Design - Materials – Manufacturing - Properties – Analysis

Manufacturing





CFRP Panel with cutout and AF 163 / 2K secondary bonded repair patch

Secondary bonded or co-cured?

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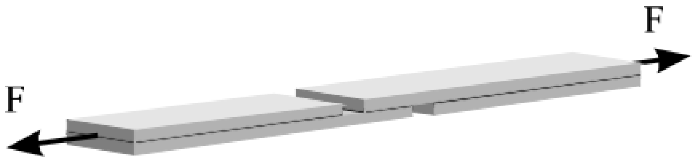
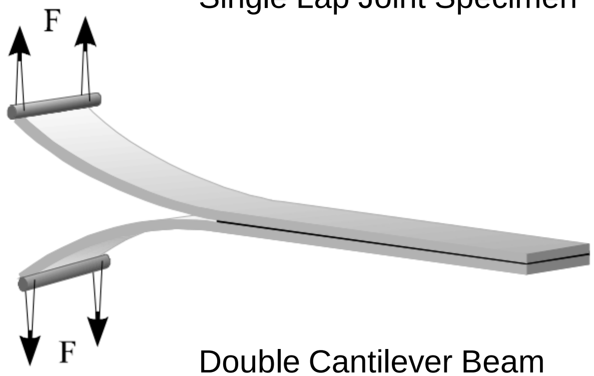
General Loop: Design - Materials – Manufacturing - Properties – Analysis

Properties



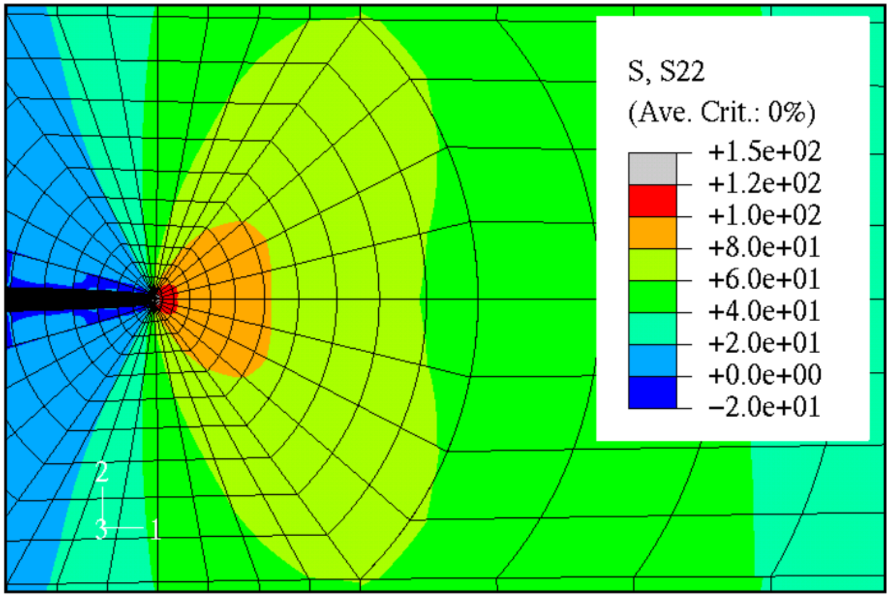
Single Lap Joint Specimen



Double Cantilever Beam

Continuums or fracture mechanic?

Analysis Method



Global or local analysis?

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Classical Numerical Methods

1. As simple as:

Shear force / bonding area = average shear stress

2. Local continuums mechanic FE-analysis:

The more elements – the higher the shear stress

3. Local fracture analysis:

Limited to local problems – no global design

4. Global fracture analysis:

That‘s what we want to do: getting local fracture mechanic results from analysis of global structure

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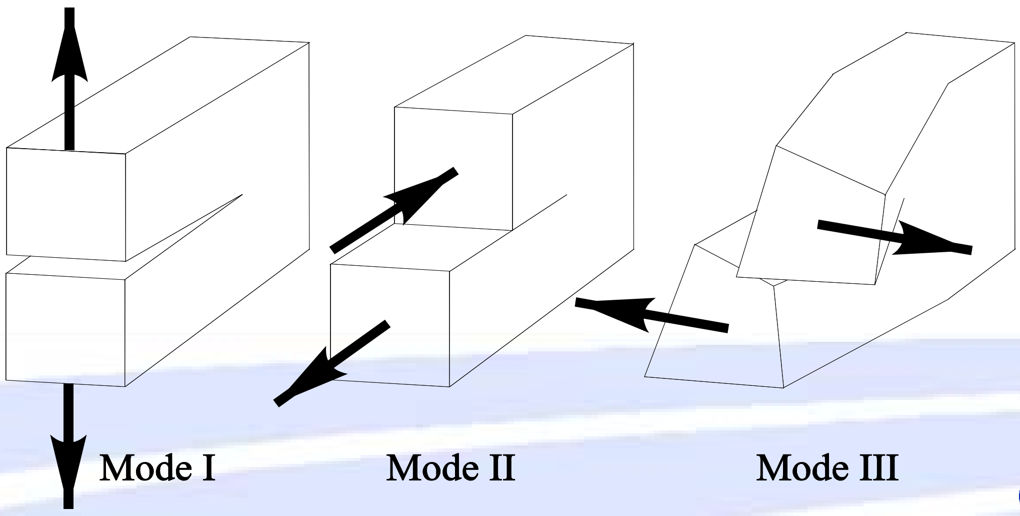
Leichtwerk‘s Approach

Consider a Bonding as Pre-Cracked

- Voids
- Non-Bonded Areas
- Delaminations from External Forces
- Edge Effects

Establish Fracture Mechanical Properties:



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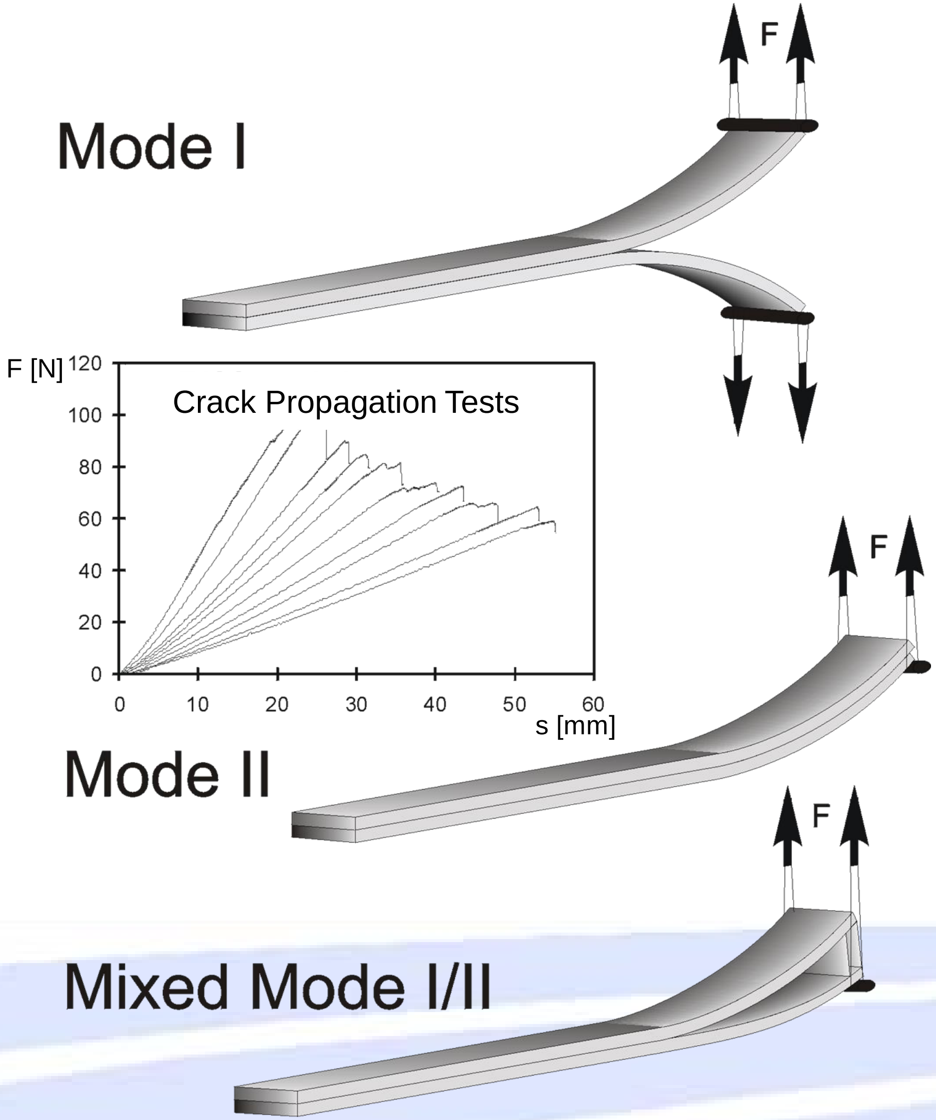
Leichtwerk's Approach
Coupon Tests



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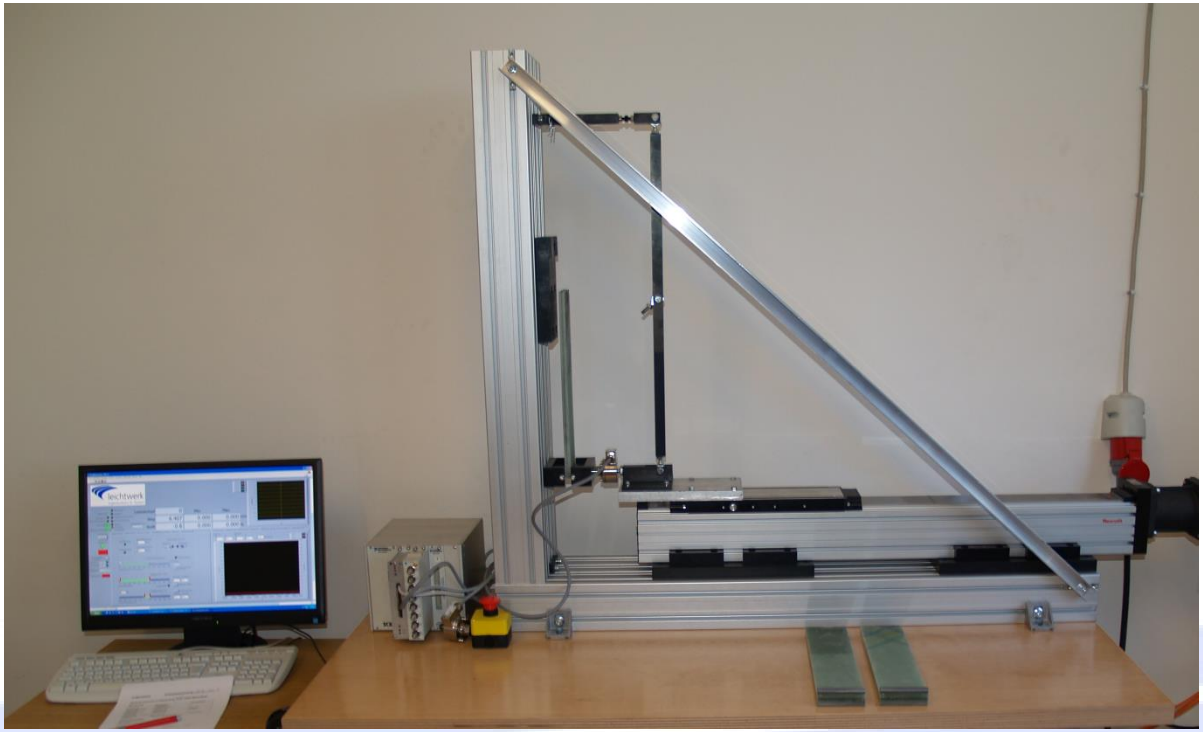
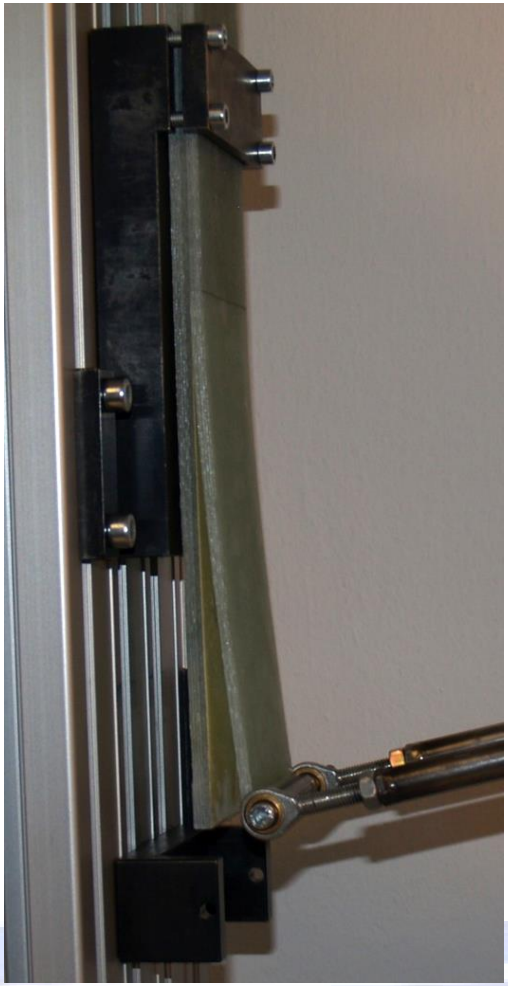
Leichtwerk's Approach
Test Setup

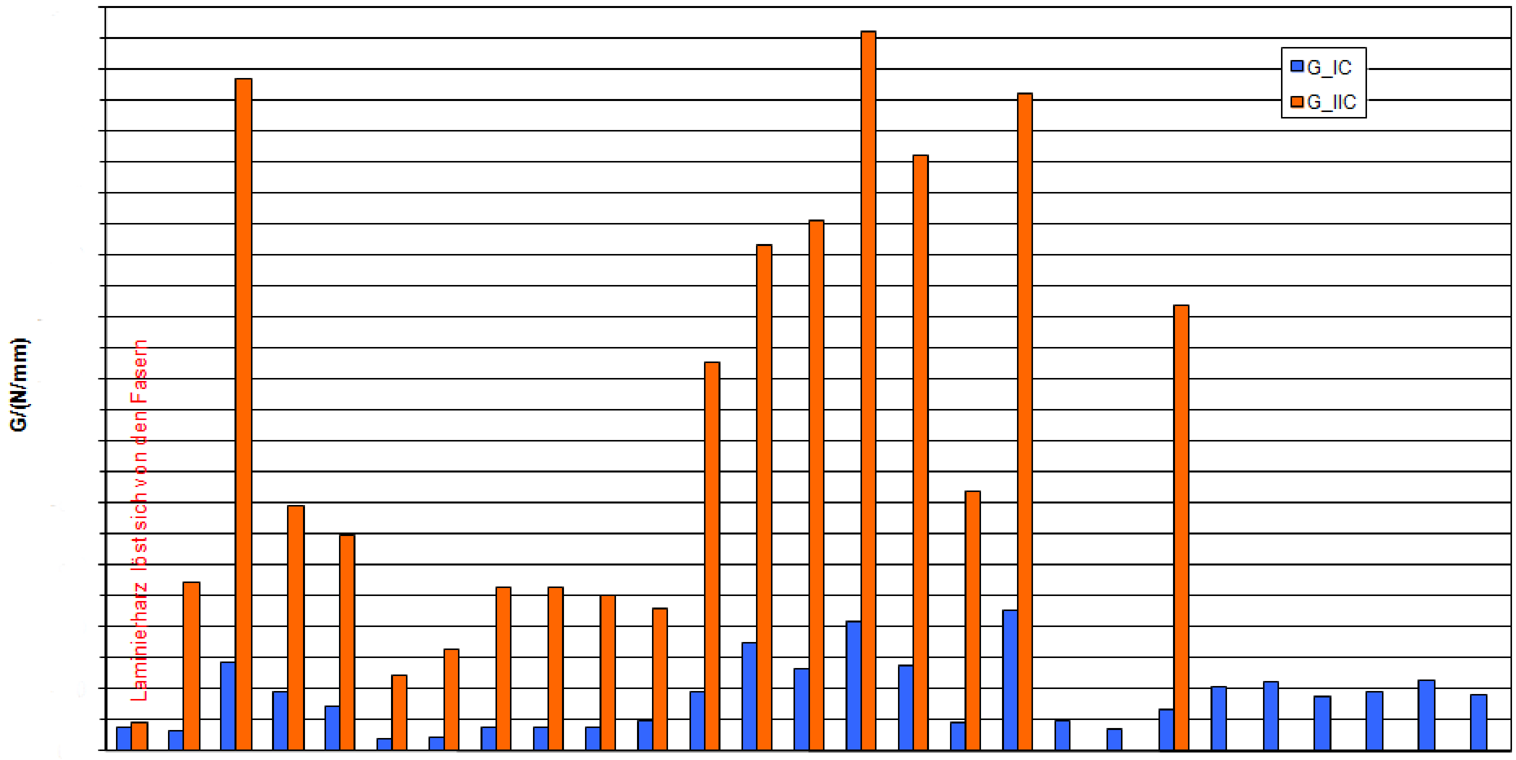
Static and dynamic testing of bonding coupons:

Mode I, Mode II, Mixed Mode





Leichtwerk's Approach
Static Test Results



Windturbine adhesives characterisation

Leichtwerk‘s Approach
Crack Propagation

Per coupon batch:

- Critical Energy Release Rate $G_c = f(\beta)$
- Crack Propagation Rate $da/dN = f(G, \beta)$ -> Paris‘ law

as function of phase angle $\beta = \arctan \sqrt{G_I / G_{II}}$

Evaluation of test results by nonlinear Finite Element Analysis using force and displacements recorded in cupon tests

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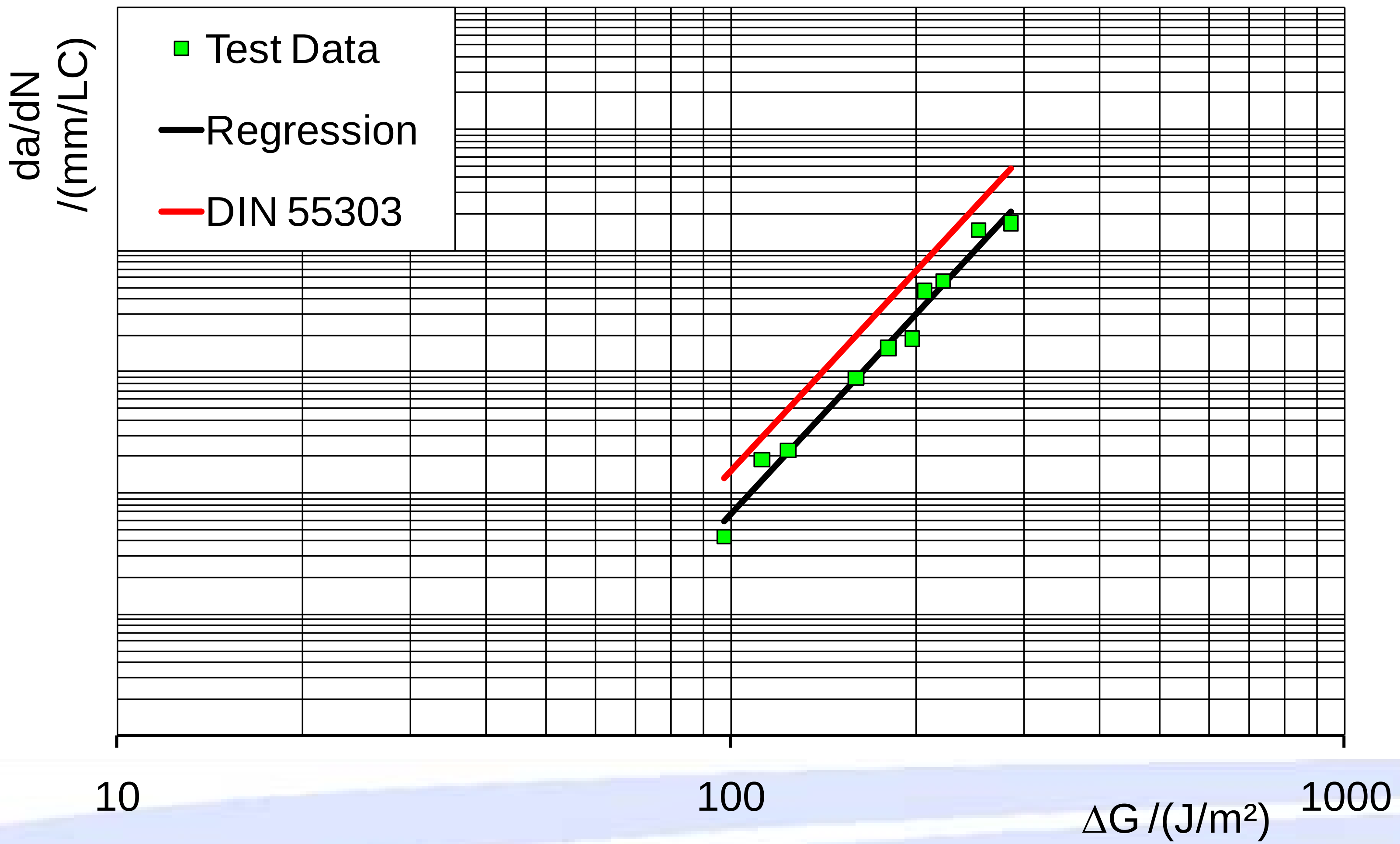
Paris' Law



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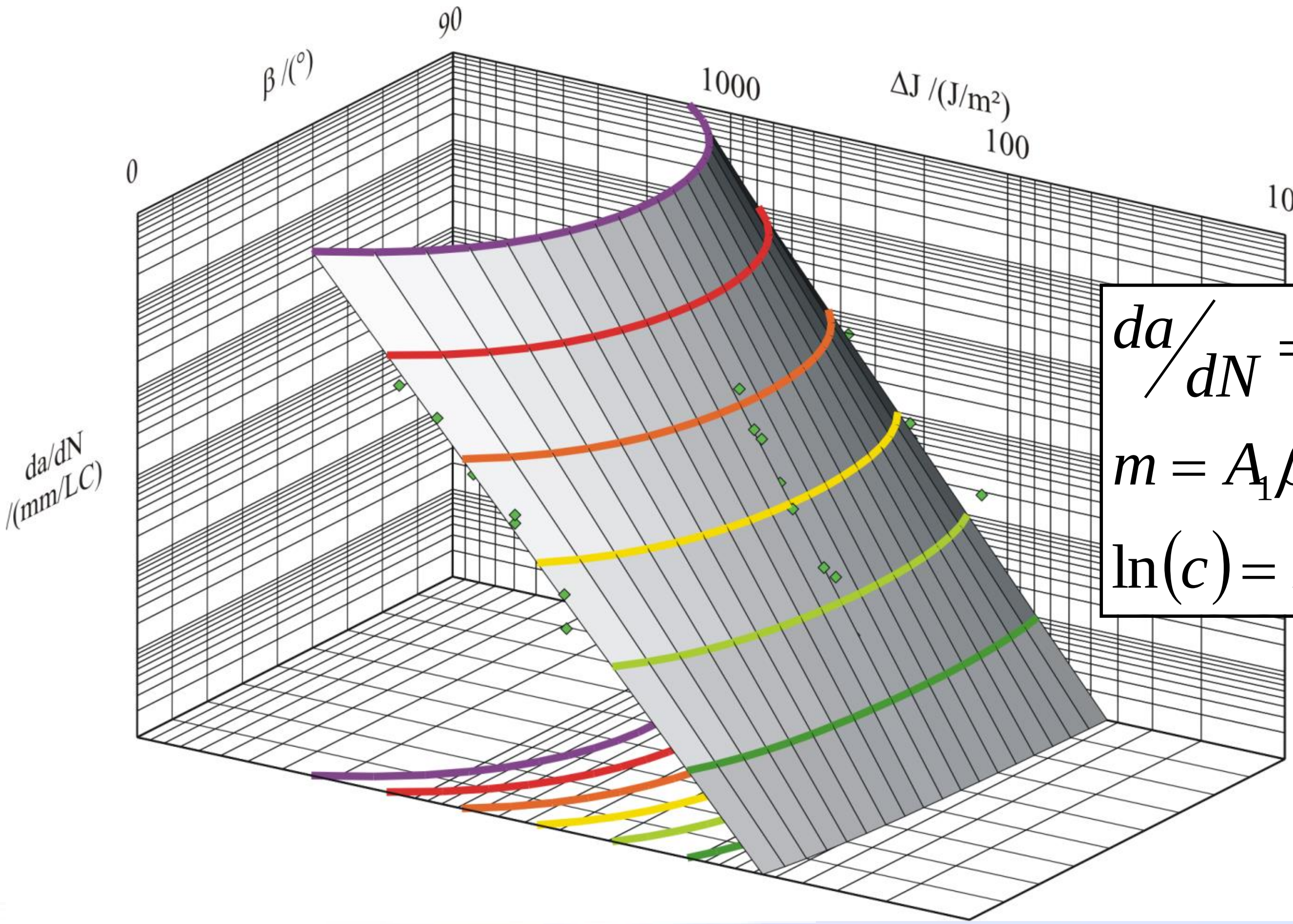
Leichtwerk's Approach
Paris' Surface



$$\frac{da}{dN} = c\Delta G^{m}$$

$$m = A_1\beta^2 + A_2\beta + A_3$$

$$\ln(c) = B_1\beta^2 + B_2\beta + B_3$$

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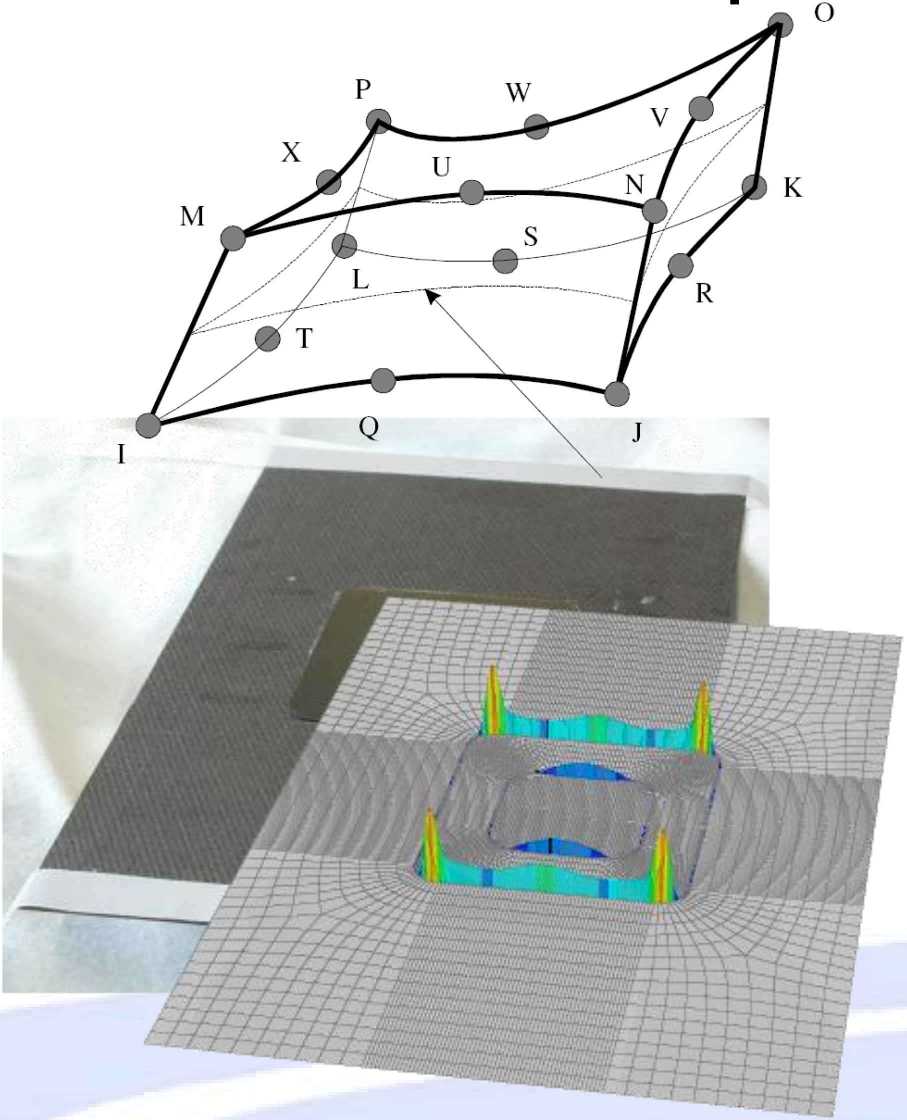
FE-Implementation



User Element:
16 Node adhesive interface element

Additional property input:
regression data provided by coupon testing

Element Output:
- local ERR
- static reserve factor
- local da/dN

at crack front / bonding line

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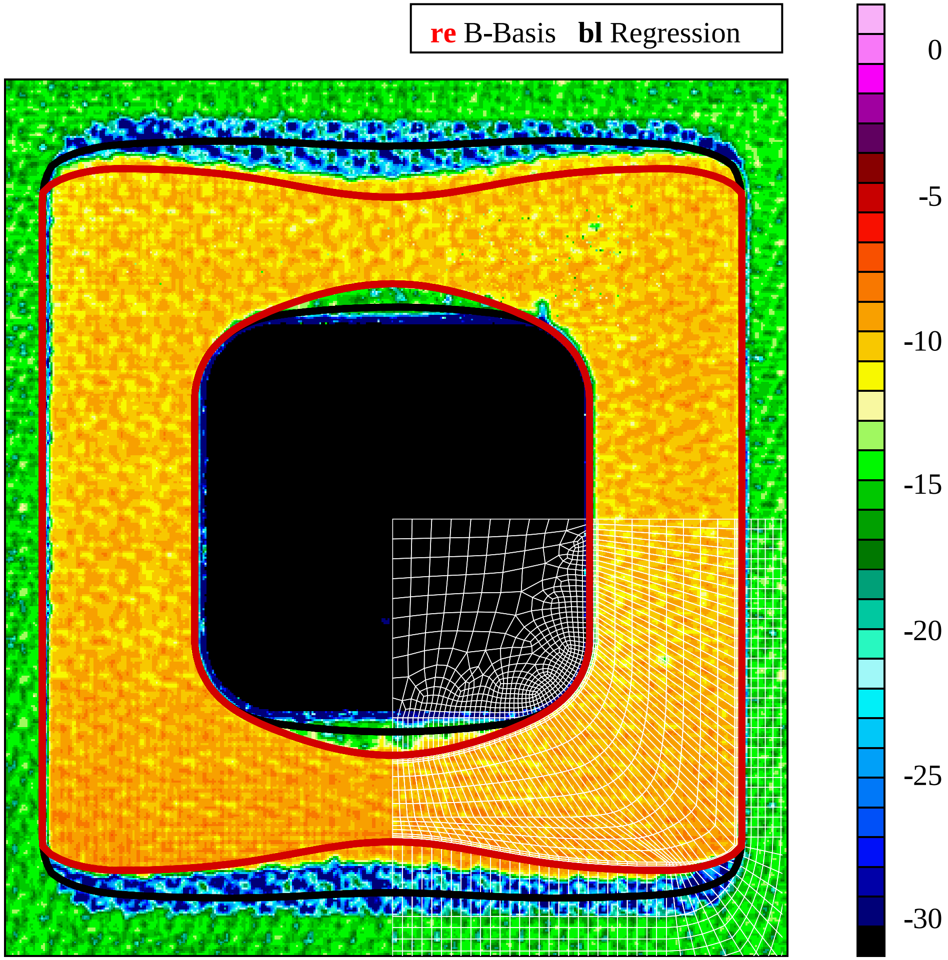
Fatigue Analysis of Co-Bonded Repair Panel

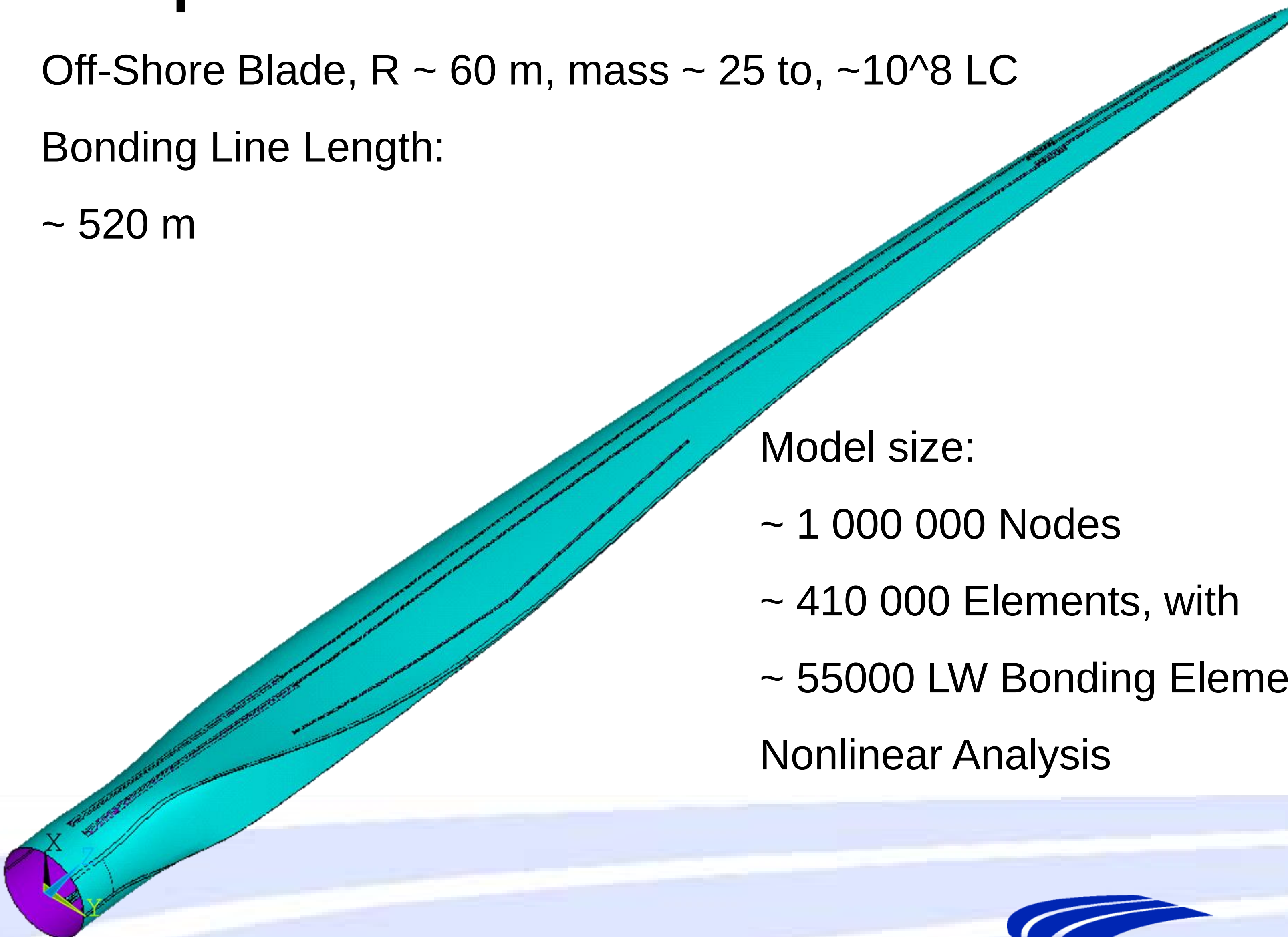


Sample Windturbine Rotorblade

Off-Shore Blade, R ~ 60 m, mass ~ 25 to, ~10^8 LC

Bonding Line Length:

~ 520 m



Model size:

~ 1 000 000 Nodes

~ 410 000 Elements, with

~ 55000 LW Bonding Elements

Nonlinear Analysis

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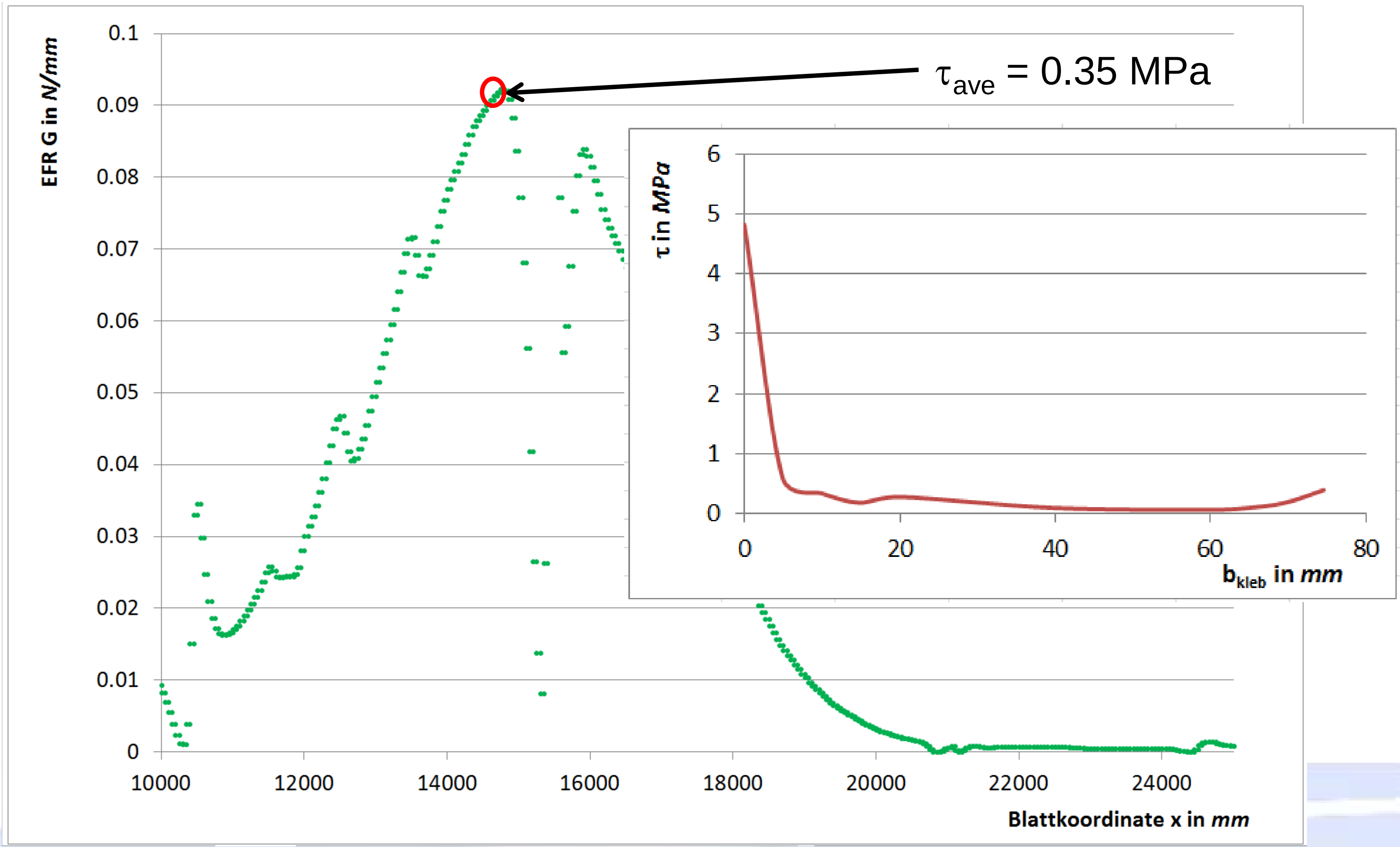
Sample Windturbine Rotorblade

Static Analysis



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Sample Windturbine Rotorblade

Static Analysis

Evaluation:

EFR_max	= 0.09 N/m^2
τ_max	= 4.8 Mpa (is it max?)
τ_ave	= 0.35 Mpa

Material Properties:

EFR_crit	= 0.72 N/m^2 => $j = \sqrt{8} = 2.8$
τ_ave_crit	= 7.0 Mpa => $j = 20$

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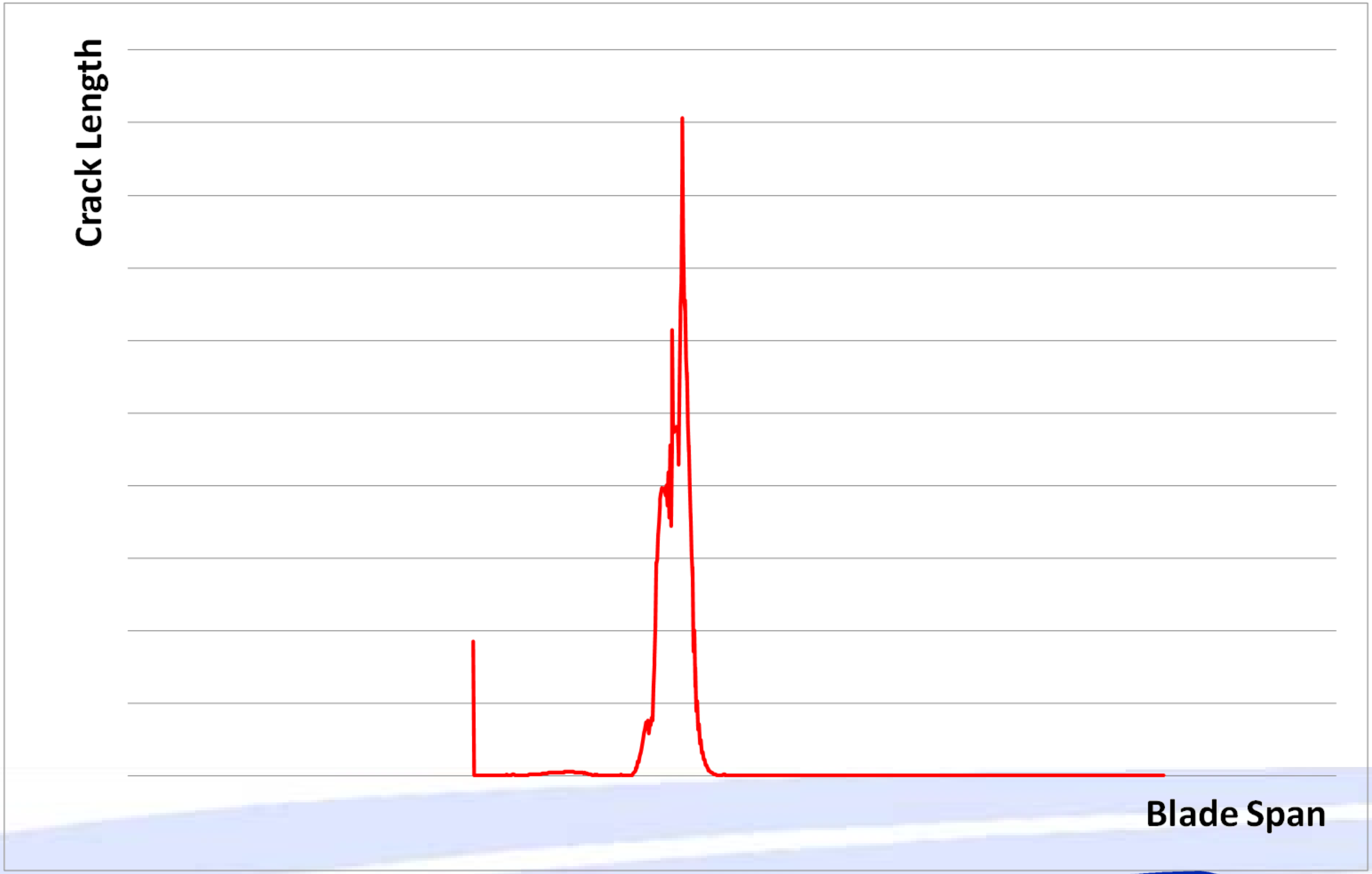
Sample Windturbine Rotorblade

Crack Growth Analysis



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Conclusion

- Fracture Mechanics provide a suitable basis for analysis of bonded structure of complex models
- Efficient static and crack growth analysis with proprietary user bonding element
- The presented study shows our capabilities after 20 years of research effort

Fracture mechanics have been lifted
from local analysis to global design

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