Introduction to scaling issues of damage and fracture in wind turbine blades

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Wind turbines - big structures... composite blades

Blades are designed against deflection and fatigue.
Composites are damage tolerant materials.
Main blade structures
- manufacturing of wind turbine rotor blades

Shear webs

Main laminate
Joining of blade structures
- assemblage and joining

Adhesive bond (leading edge)

Bondlines (webs)

Adhesive bond (trailing edge)
Blade design
- common blade designs

Load-carrying laminate flapwise: compression-compression
Web
Load-carrying laminate edgewise: tension-compression
Adhesive joint

Load-carrying laminate edgewise: tension-compression
Sandwich
Adhesive joint

Load carrying laminate flapwise: tension-tension

Box type

Adhesive joint
Box girder

Adhesive joint
Sandwich
Adhesive joint

Web type
Failure modes
- failure of a wind turbine rotor blade tested to failure

25 m wind turbine blade (Vestas V52)

[Risø-R-1390(EN), 2004, "Improved design of large wind turbine blade of fibre composites based on studies of scale effects (Phase 1) - Summary Report"]
Failure modes
- a wind turbine blade

Progressive failure:
- multiple damage types
- most are weak interfaces

[Risø-R-1390(EN), 2004]
Case 1: Cracks in gel-coat

Channelling cracking in elastic layer:

\[ G_{1}^{ch} = f(D_\alpha, D_\beta) \frac{\sigma^2 h_1}{E_1} \]

Case 1: Cracks in gel-coat

Model application: Find maximum gel-coat thickness, $h_1$ for $\varepsilon_c = 0.3\%$

$G_{lc} = 100$ J/m$^2$

$E_1 = 4$ GPa, $E_2 = 40$ GPa $\Rightarrow D_\alpha = -0.80$

$\Rightarrow f(D_\alpha, D_\beta) \approx 1.5$

$\Rightarrow h_1 = 0.00185$ m $= 1.9$ mm
Thick laminate (root section)

Thin laminate (tip section)

Case 2: Delamination from a ply-drop

\[ J_{\text{ext}} = \frac{E_1 h_1}{2(2E_1 h_1 + E_2 h_2)} \frac{\bar{\sigma}^2 h_2}{E_2} \]
**Model application:** Find maximum ply-thickness, $h_1$ for $\varepsilon_c = 0.3\%$

**Data:** [Sørensen and Jacobsen, 2009]

$J_0(\psi=45^\circ) = 300 \text{ J/m}^2$

$E_1 = 40 \text{ GPa} \Rightarrow \sigma = 120 \text{ MPa}$

Say: $h_2 = 50 \text{ mm}$

$\Rightarrow h_1 = 1.7 \text{ mm}$
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**Accounting for fibre bridging:**

**Data:** [Sørensen and Jacobsen, 2009]

\[ J_{ss} \approx 2000 \text{ J/m}^2 \]

\[ \Rightarrow h_1 \approx 20 \text{ mm} \]
Case 3: Cracks in bondlines

Generic bondlines:
Case 3. Cracks in bondlines – surface treatments

Untreated adhesive/glass fibre laminate interface

[Defect image showing crack propagation with AE sensor and labels for Adhesive Layer, Laminate, and Crack Tip]

FRACTURE RESISTANCE, $J_R (J/m^2)$

End-Opening, $\delta^*$ (m)

- No crack growth
- Onset of cracking
- Cracking propagation

BMA05-01
BMA05-02
BMA05-03
BMA05-04
BMA05-05
BMA05-06

$\psi_{nom} = 0^\circ$

Case 3. Cracks in bondlines – plasma treatment of surface to be bonded

Gliding arc set-up

[10 mm]

Case 3. Cracks in bondlines – plasma treatment of surface to be bonded

Gliding arc set-up

Resulting fracture mechanics properties:
A significant increasing fracture resistance due to crack bridging in laminate

Scaling issues…
- consequences of manufacturing of large blades

Future design rules should incorporate design rules for various damage modes and account for scaling issues.

Materials research can provide improvements in material properties (more damage tolerant materials).
Thanks for your attention!

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Any questions?