Note on Engineering Details

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Title: **Verification of inter-fibre failure**

Revision 1 editorial

Ref.: GL Wind "Guideline for the Certification of Wind Turbines", Edition 2003 with Supplement 2004.

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This note is intended to give a more detailed description of how to perform the analysis of inter-fibre failure according to section 5.5.3.3 of the a.m. guideline. The content of this memo does neither change the principles of the analysis nor supplement any requirements.

Definitions

Laminate: material composed of successively bonded layers of resin and fibres in one or more directions.
Layer: material composed of resin and fibres in one direction.
Remaining safety: remaining safety after including all partial factors.

Computational Verification of Inter-Fibre Failure

The verification is to be based on an acknowledged failure hypothesis for anisotropic material (IFF-hypothesis), e.g. as per VDI 2014 or Puck (see a.m. guideline) using the material values determined according to section 5.5.4 (1) of the a.m. guideline.

The verification is to be based on the serviceability limit state. Mean values (instead of characteristic values) determined in the relevant material tests can be used for the verification.

For the verification, the required transverse strains ε_q can be determined either by FE-analysis (three dimensional) or by experiment. In case neither transverse strains determined by FE-analysis nor by experiment are available a parameter study is to be performed. Within this parameter study the transverse strains have to be varied from ε_q according to fully restricted deformation in blade transverse direction to ε_q according to unrestricted deformation in blade transverse direction (based on a reasonable Poisson's ratio of the laminate under consideration).

Within the verification of inter-fibre failure the mean values (transverse tensile strength, transverse pressure strength and shear strength) have to be reduced by the factor

$\gamma_{Ma} * C_{IFF}$, where both γ_{Ma} and C_{IFF} are specified in the a.m. guideline. The factor $\gamma_{Ma} * C_{IFF}$ shall not be less than 1.35.

C_{IFF} depends on the failure mode relative to fibre direction and on the force component ΔF to be transferred in the case of a predicted inter-fibre failure. It has to be mentioned that for none of the values for C_{IFF} inter-fibre failure is expected in reality. The specification of C_{IFF} as a function of ΔF as described above is intended to give a criterion which allows for differences in the build-up of the laminate as well as for the criticality regarding inter-fibre failure. In any case for all layers a remaining safety of more than 1.0 regarding inter-fibre failure has to be proven.

Initially the verification has to be performed using the highest values for C_{IFF}. If under this condition the IFF-hypothesis does not predict cracking the requirements regarding inter-fibre failure are fulfilled. No further calculations regarding this verification are needed.

If the calculation predicts cracking for individual layers of the laminate a force component ΔF that hypothetically has to be transferred to other layers shall be determined. In doing so no precise tracing of the stress changes caused by the transfer is required. ΔF is to be determined in longitudinal and transverse direction of the blade. The determination can simplisticly be based simplistic on a comparison of the E-Modulus of the laminate including the layers for which cracking is forecasted with the E-Modulus of the laminate excluding these layers. If ΔF amounts to less than 5 % the verification can be repeated using the lower values for C_{IFF}. If under this condition the IFF-hypothesis does not forecast cracking for any of the layers the requirements regarding inter-fibre failure are fulfilled. If the IFF-hypothesis forecasts cracking more extensive actions might be required, e.g. change of laminate, reduction of loads, precise tracing of the stress changes including influence on fatigue behaviour or experimental verification as described below.

Note:

Example:
Let a laminate consist of 20 layers of UD-material with an E-Modulus of 38000 N/mm² and thickness of 1 mm per layer and 4 layers of +/- 45°-material with an E-Modulus of 12000 N/mm² and a thickness of 0,35 mm per layer. Let the IFF- hypothesis forecast cracking for the -45° layer based on the higher values for C_{IFF}. In the next step the comparison of E-Moduli is performed:
blade lengthwise direction: E-Modulus including all layers: 36300 N/mm²
E-Modulus excluding -45°-layers: 35900 N/mm²
comparison: 36300 / 35900 = 1.01 < 1.05

blade transverse direction: E-Modulus including all layers: 9760 N/mm²
E-Modulus excluding -45°-layers: 9360 N/mm²
comparison: 9760 / 9360 = 1.04 < 1.05

Conclusion:
Since for both longitudinal and transverse directions DF amounts to less than 5 % the verification of inter-fibre failure for the -45°-layers can be performed using the lower values for C_{IFF}. If the IFF-hypothesis under this condition does not forecast cracking the requirements regarding inter-fibre failure are fulfilled. If the IFF- hypothesis still forecasts cracking more extensive actions as described above might be required.

Experimental Verification of Inter-Fibre Failure

Material tests for the relevant material properties regarding inter-fibre failure reveal:

- high differences of results within nominally identical tests
- material values are clearly lower than proposed in relevant literature.

For the tests follows that the transferability of these tested values to the material behaviour in the rotor blade can not sufficiently be assured. In order to account for the a.m. uncertainties in addition to the computational analysis an experimental verification of inter-fibre failure can be performed.

This procedure shall include the following steps:

- inter-fibre failure analysis based on the loads for the static blade tests for determining the critical areas,
- static rotor blade tests as required in IEC WT01, first edition,
- fatigue rotor blade tests as required in IEC WT01, first edition and
- inspection by GL Wind of the areas critical to inter-fibre failure of the rotor blade tested.

If the a.m. inspection does not reveal any damage the requirements regarding inter-fibre failure are considered to be equally fulfilled.

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