COHERENCE OF THE ACTIVITIES IN THE WORK PACKAGE

In Figure 5 the relation between the different analytical and experimental activities in the WP is schematically shown.

RESULTS AND EXPECTATIONS

After 18 months the project generated the following results:

- Adaptation of the material database OptiDat. The database is now suited for more material data aspects and LCA data. The interactive capabilities have been extended; the LCA data can be directly coupled to the design tools;
- Selection of the test specimen geometry for the material characterization;
- A selection process for the blade detail test specimen has started and a preliminary design has been selected for detailed analyses en pre-testing;
- Numerical investigations of the damage evolution in glass fibre reinforced polymer matrix composites are used to analyse the interplay of damage mechanisms (fibre, matrix, interface cracking) and the effect of local properties on the microscopic damage mechanisms;

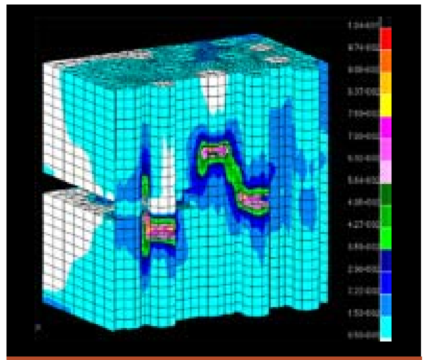

Figure 6: Interaction between fibres and matrix. Maximum shear strain after fibre failure with a cracked matrix.

- An anisotropic non-linear material constitutive model is developed along with a thick shell element implementing progressive damage concepts to predict the load bearing capacity and life of composite structures;
- An analytical approximation, namely the Edgeworth Expansion Technique, was presented for the estimation of the failure probability of a laminated composite plate under general in-plane loading, considering the material mechanical properties as being stochastic. Results were compared with the advanced first order second moment method and Monte Carlo simulation data and were found in good agreement for most of the cases.

It is expected that after five years the results set as targets for this work package will be achieved.

More specifically:

- The OptiDat database will include the material data for the UpWind reference material and one or two alternative materials, including the LCA data for these materials;
- The database can be linked to design tools;
- Material testing procedures will be established and design recommendations will be drafted;
- Empirical and fundamental material models will be available which are based on the material data collected within the WP. The models will be partly embedded in FEM tools;
- Methods to perform probabilistic strength analyses will be available;
- Several measurement techniques will be developed or evaluated. Amongst them non destructive and fibre-optic techniques;
- Blade substructure models will be developed including test methods and design recommendations.

UpWind

SIXTH FRAMEWORK PROGRAMME

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Photography: DIAMANTAKIS George-EWEA - Vestas

Rotor structures and Materials

THE CHALLENGE

For larger wind turbines, the potential power yields scales with the square of the rotor diameter, but the blade mass scales to the third power of rotor diameter (square-cube law). With the gravity load induced by the dead weight of the blades, this increase of blade mass can even prevent successful and economical employment of larger wind turbines. In order to meet this challenge and allow for the next generation of larger wind turbines, higher demands are placed on materials and structures. This requires more thorough knowledge of materials and safety factors, as well as further investigation into new materials.

Furthermore, a change in the whole concept of structural safety of the blade might be required.

The specific objectives of this work package (WP) include:

- Improvement of both empirical and fundamental understanding of materials and extension of material database;
- Study on effective blade details;
- Establishment of tolerant design concepts and probabilistic strength analysis;
- Establishment of a material testing procedure and design recommendations.

WP1A1
WP1A2
WP1A3
WP1B1
WP1B2
WP1B3
WP1B4
WP2
WP3
WP4
WP5
WP6
WP7
WP8
WP9

UpWind

THE RESEARCH ACTIVITIES

The activities in the work package are divided into three major tasks.

1. APPLIED (PHENOMENOLOGICAL) MATERIAL MODEL

In order to serve as a basis for advanced material models, the existing OPTIDAT database is extended with new materials. The results of this task will enable checking the models derived in task 2 as well as input data for a number of integration work packages. Together with the work carried out in 2, this will result in an integrated material model, based on both tests and micro-mechanics, for which design recommendations and material test recommendations will be established.

The data and test methods for static compression, fatigue and residual strength will be refined where needed. Following the main route in implementation of carbon fibre- and/or glass-carbon fibre hybrid thermoplastic composites, a number of material combinations and reinforcement architectures can be investigated. Due to the increase in both number and size of wind turbines, life cycle analysis of the turbines, particularly of the fibre-reinforced blades will become more prominent. Life cycle analysis data of materials will be collected and a methodology will be introduced to enable instant LCA of the rotor structures, to facilitate direct evaluation of various concepts.

In collaboration with WP 7 research will be carried out on the applicability of fibre optical strain measurement techniques. Especially the possibilities of embedded strain gauges will be subject of strength and fatigue experiments.

A structure, representing a structural blade detail, e.g. shear web/spar cap construction will be selected, analysed and tested, assisted with NDT methods, to come up with improved understanding of the structural behaviour of this detail.

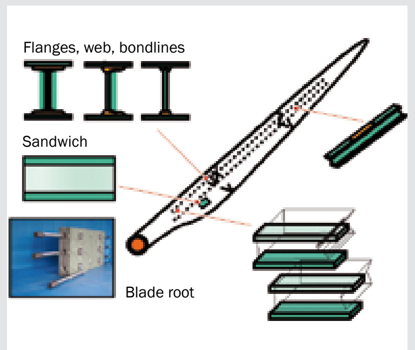

Figure 2: Blade details under consideration.

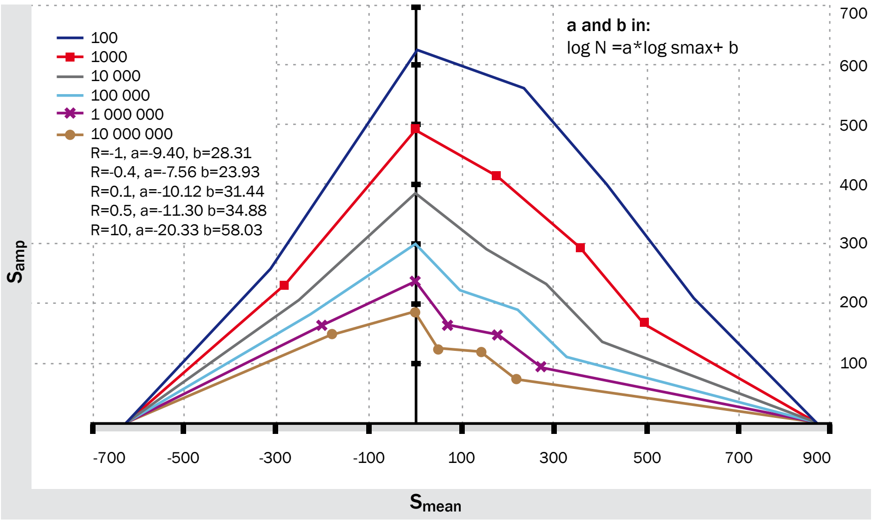

Figure 1: Constant Life Diagram for MD material.

2. MICRO-MECHANICS-BASED MATERIAL MODEL

In addition to empirical tests, a more fundamental understanding of materials will be necessary in the long run. The success of this task depends on several factors:

- The gained knowledge and understanding regarding the basic mechanisms governing the composite material performance in compression and in fatigue;
- The efficient implementation of the knowledge in easy-to-use predictive/design tools;
- The ability to produce on the laboratory and/or industrial scale the material combinations, surface treatments etc. required to utilize the whole potential of the optimised composites;
- The identification and optimisation of the most important processing/manufacturing parameters affecting the composite quality/performance (initial defect state related to voids, bad impregnation etc.).

The existing models available in literature will be examined with respect to damage mechanisms and micromechanics that are identified and characterized within Task 1. The Interface/matrix materials influence and Fibre fracture/kink-band formation are considered as most significant mechanisms, and will be systematically investigated to greater details. They will be looked upon as part of Micromechanics/Damage mechanics models, and results will be incorporated as particular damage mechanisms described in model. Strength predictions can be compared with the results of Task 2.1 or used as input to macroscopic/phenomenological models. Both, macroscopic phenomenological analysis and model composites will be used in this study.

The work will be concentrated around the following items:

- Non-linear constitutive modelling;
- Interface/matrix materials influence on compression strength;
- Fibre fracture/kink-band formation in compression.

The work of this task is supported by the UpWind.TTC project. In this project three partners will carry out research on:

- Experimental analysis of micro-mechanisms of fatigue damage;
- Micro-mechanical analysis of damage under cyclic loading;
- Computational modelling of damage evolution and interaction under fatigue loading.

3. DAMAGE TOLERANT DESIGN CONCEPT

The effect of fatigue on static strength and stiffness, as well as the effect of post first ply failure strength are studied and included in the material models, composed of the following aspects:

- Nonlinear stress analysis, especially for the highly nonlinear in-plane shear response and the usually weak non-linearity observed under transverse compression of a FRP UD layer;
- Failure prediction under static loads. Several failure criteria sets, e.g. Puck, will be implemented in a commercial finite element code, to provide designers with more effective design options;
- Failure prediction under cyclic loads and rules for strength and stiffness degradation. Implementation of appropriate residual strength and stiffness theories into a commercial FEM code so as to formulate life prediction procedures for the blade under cyclic loading;
- Macroscopic blade failure. The synthesis of modules already discussed above, once implemented in FE codes, will provide at any desired load configuration, static or cyclic, the residual strength, stiffness and remaining life of the blade.

Numerical procedures will be developed for determining strength of a composite laminate, using various failure criteria, by taking into account the stochastic nature of anisotropic material properties. This will lead to the quantification of blade design reliability.

Development of appropriate software in the form of pre- and post-processors that can be used along with current aero-elastic codes is foreseen.

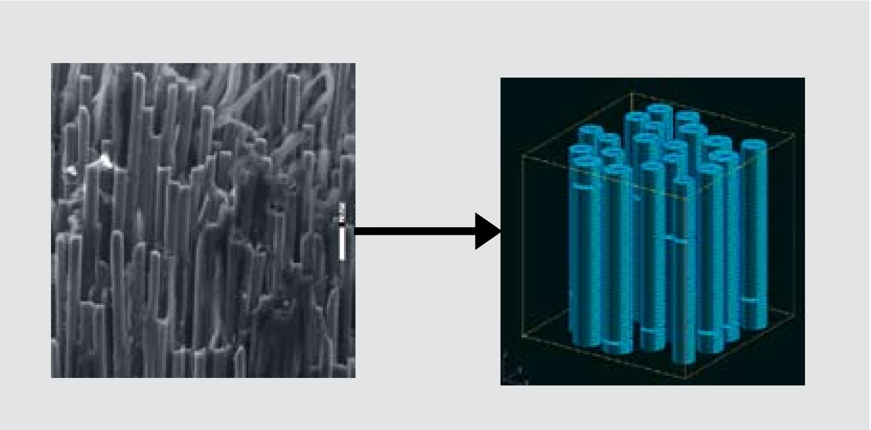

Figure 3: Modelling fibre matrix interaction.

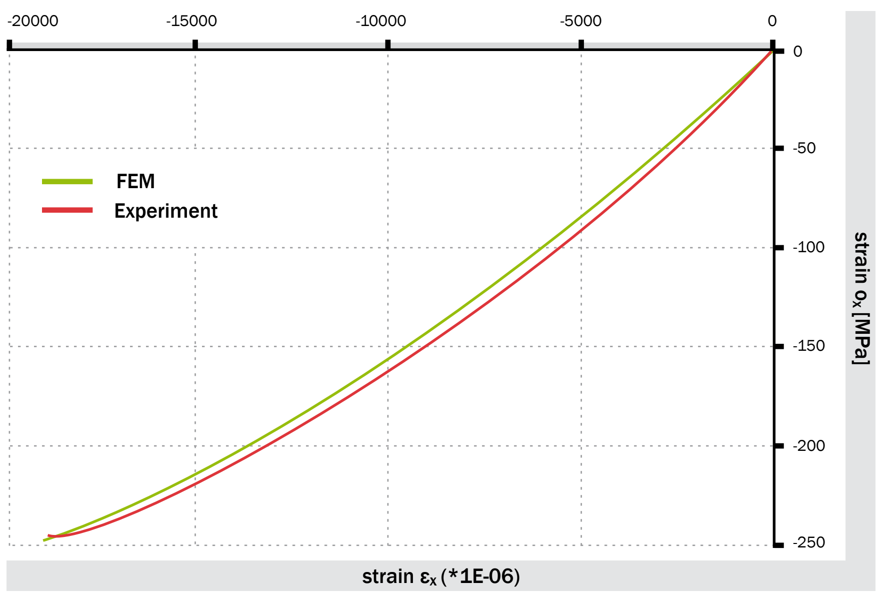

Figure 4: Failure load for a 60° off-axis compressed OB MD coupon. Comparison of test results and FEM simulation predictions.

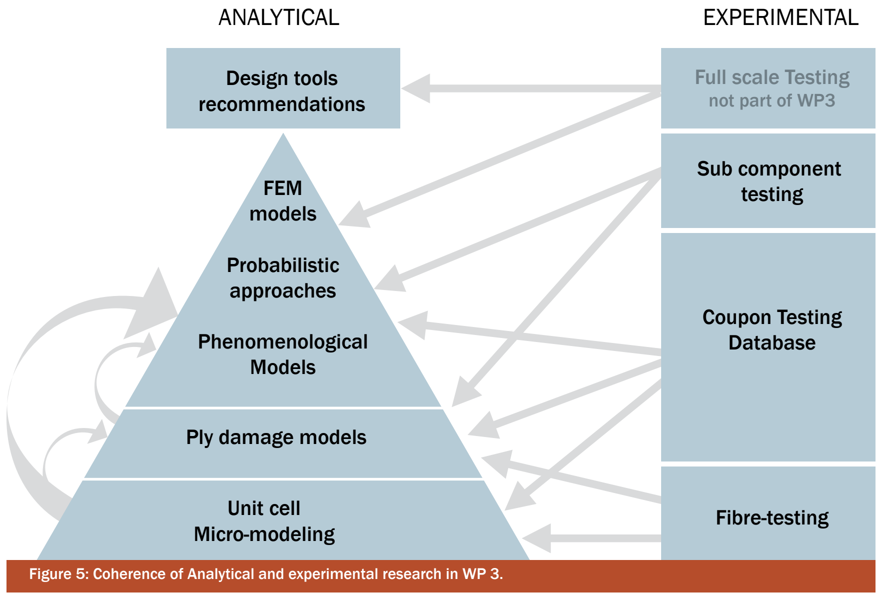

Figure 5: Coherence of Analytical and experimental research in WP 3.