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TG 2

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DETAILED REPORT FOR TASK GROUP 2

In the following, detailed information can be found regarding the activities for Task Group 2: 'Investigation of blade material behavior under complex stress states ' (WP6 and WP7).

Specific objectives for this period

The main objective of TG2, is to investigate the effect of complex stress states, e.g. plane stress conditions, on failure prediction both under static or cyclic loading. The combined action of all three in-plane stress tensor components will be taken into account in defining failure in contrast to one-dimensional approaches where only a normal and shear stress components are considered separately. To meet the objective, extensive testing for material characterization of basic UD ply is foreseen accompanied by uni- and multi-axial tests on MD laminates of various stacking sequences. Test results will be used to implement validated failure theories in conventional and FE large blade models and derive, in cooperation with certifying organizations, design guidelines for large rotor blades. In addition, basic characterization test results from UD material are a prerequisite for other task groups as TG1, TG4 and especially TG5.

Specific objectives for this first year were:
- generate the Detailed Plan of Action (DPA), describing tests to be performed along with geometry and lay-up of specimens, FE analyses plan and time schedule
- producing and start testing OPTIMAT coupons and special specimens for multi-axial loading (static and fatigue loading)
- Build FE and conventional blade models for theoretical analysis and assessment of complex stress state effect

Overview of technical achievements

DPA of WP6

After a considerable amount of discussion, especially in TC meetings, preliminary testing and analyses, the DPA has been drafted in accordance with the choices made regarding various specimen geometry for the whole project. The DPA has been approved by the Steering Committee (DLR, Stuttgart, December 16).

Preliminary tests

Preliminary tests were conducted in the frame of TC by all TLs. The scope of the tests was to determine the optimal coupon geometry, suitable for all kinds of tests, i.e. static, fatigue, residual strength, both in tension and compression that are foreseen in the various DPA's of OPTIMAT Task Groups. Test results were included in a technical report [1], uploaded at the OPTIMAT site. In addition, preliminary biaxial tests were performed on cruciform specimens to investigate candidate geometries of reduced stress concentration, which in combination with the available test frame at VUB should produce acceptable failure modes. In the frame of TG2, multi-axial tests are also foreseen, consisting of combined torsion and tension/ compression applied to tubular specimens (to be performed mainly at DLR) besides to the tensile tests on cruciform specimens (to be performed mainly at VUB). Although in the former case the experimental setup and specimen geometry are well defined and previous experience is already available, this is not the case for the cruciform specimens subjected to tensile loads. Therefore, a detailed FE analysis was performed by ECN and TUDT [2], in which a large number of biaxial test specimen geometries was modelled

to investigate the influence of variations in shape, thickness and material properties. The aim was to derive a set-up where the highest stresses would occur in the central area, so as to cause failure also there. Furthermore, this area should also have a relatively homogeneous stress distribution, irrespective of material properties and loading, see Figs 1 and 2 for cruciform specimens made of UD plies.

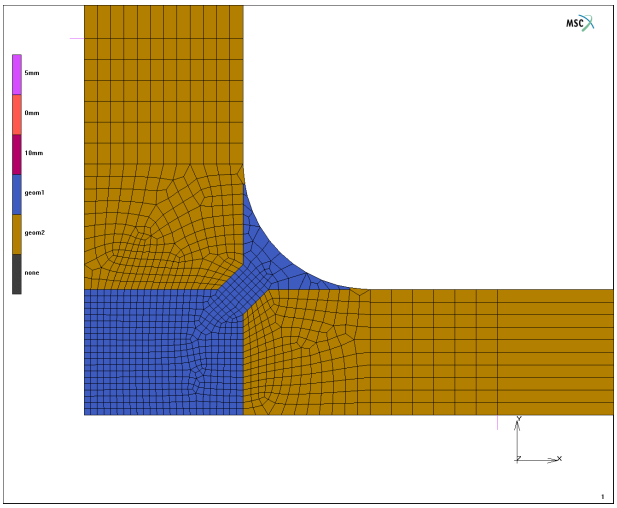

Figure 1 FE model of cruciform test specimen

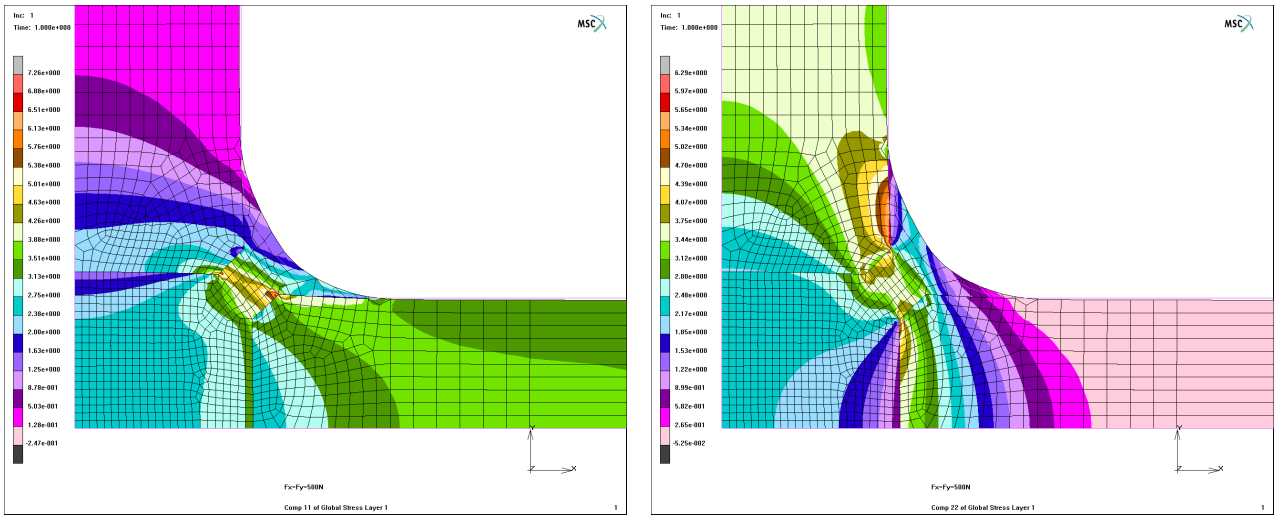

Figure 2 Deformation and stress, in x- and y-directions respectively. Fx= Fy =500 N.

Taking into account the numerical analysis results, a series of preliminary tests was performed at VUB including photo-elastic analyses of transparent cruciform, to study overall stress distribution, see Fig.3, as well as testing of several composite specimens of different geometry, prepared by LM, to study failure modes, see Fig.4. A series of technical reports with test results were written and uploaded to the OPTIMAT site [3]-[5].

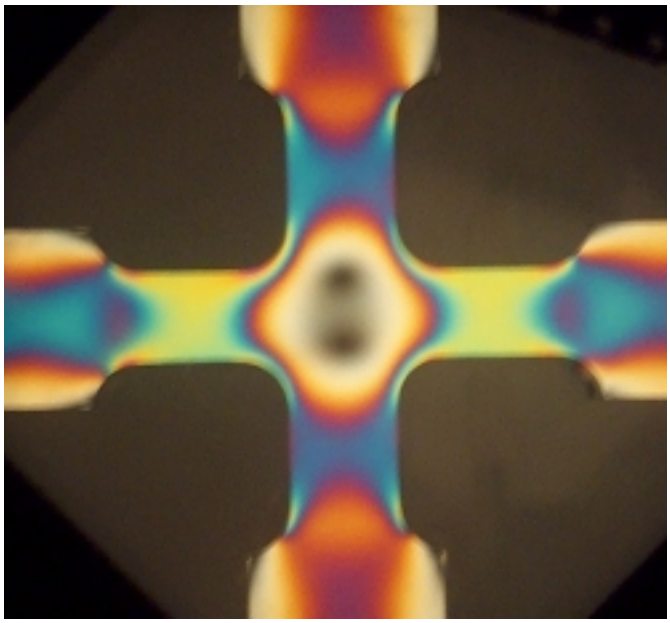

Figure 3: ISOCHROMATICS in a transparent cruciform loaded biaxially. Fx= Fy =300 N

Figure 4: Photos of specimen R 20 E, Loading ratio=2.2/1.

Optimized stress analysis

Existing FE model of relatively large blade, 30 m, was used at UP to identify areas where normal stress in the blade axis was dominant and regions where complex stress states were developing, see Fig.5, for experimental simulation in biaxial tests. Conventional (one-dimensional) and 3D shell-FE models of a Gl/Ep blade of 35 m were developed by TUDT and ECN and calculations for comparison of stress and strain between the two modeling philosophies are under way. Objective of the exercise is to compare failure indices from both analyses and calibrate safety factors for each case so as to reach the same safety margin.

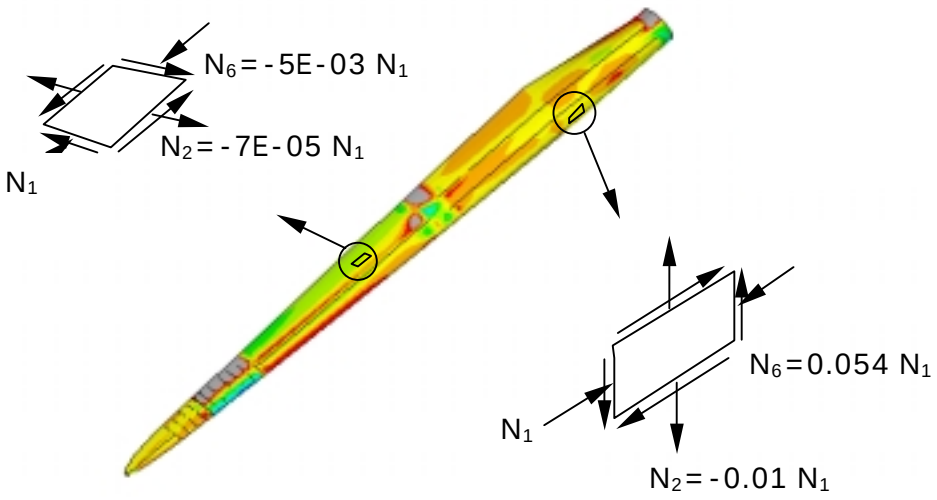

Figure 5: Characteristic states of stress resultants in a rotor blade of 30 m.

Comparison of planned activities to accomplished work

In this first year, a lot of time was needed for the initial phase of defining the standard Optimat specimens through preliminary tests. Drafting of the DPA has taken more time than anticipated, and considerable delay was encountered. To limit the time delay, the initial activities of WP6 have been started before formal approval of the DPA. Furthermore, more test rigs will be used than foreseen by UP. Testing is expected to start the second half of February.

Planned activities for the next period

The time schedule has been up-dated (it is included in the uploaded new version of the DPA at the OPTIMAT site) in view of the delay. This will be also reported on elsewhere in this document. Selection of optimum cruciform specimen geometry is not yet concluded and a series of tests will be performed by VUB by the end of February together with additional numerical analyses by TUDT and ECN. Testing of standard OPTIMAT coupons will run in parallel in several test rigs, while numerical analyses with FE blade models will continue for the first half of 2003. Due to the time delay encountered, the first phase is expected to conclude in May instead of March 2004.

Pre-draft version of Design Recommendations

In the following a sketch is given of what the Design Recommendations could look like for the part addressed by TG2.

- Define whether FE shell analysis is necessary at all for both static and fatigue load cases of large rotor blades or a conventional, 1D type, of analysis leads to an acceptable design.
- Depending on the analysis type, i.e. conventional 1D or FE 3D shell formulations, define what “failure” is according also to the certification rules and propose appropriate safety factor values respectively so as a common safety margin is achieved. This will be performed for both extreme static and fatigue design load cases.
- Depending on the analysis type, i.e. conventional 1D or FE 3D shell formulations, propose appropriate set of failure criteria respectively that reliably predict blade strength.
- For plane stress states, resulting from FE shell analyses, propose appropriate life prediction methodology

References

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