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1.5 Year assessment report TG2 (2003)

OB_TG2_R014_UP rev. 000

1st version
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OPTIMAT BLADES

TG 2

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Change record

Issue/revision	date	pages	Summary of changes
1st version	8/8/2003	7	na

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).

Short description of TG2 WP's

Phase I of TG2 consists of WP6 "Complex Loading" in which the objective 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.

Specific objectives for this period

Specific objectives for this first and a half year (01.01.2002 to 30.06.2003) 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, 2002).

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 were 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.

Taking into account the numerical analysis results, a series of preliminary tests was performed at VUB to study overall stress distribution as well as testing of several composite specimens of different geometry, prepared by LM, to study failure modes. A series of technical reports with test results were written and uploaded to the OPTIMAT site [3]-[5]. Nevertheless, failure modes of this series of cruciform test specimens were not satisfactory and another series production, of modified geometry as proposed in [2], was performed by LM and tested by VUB. Some demo experiments were also performed for the partners during the 4th consortium meeting (VUB, July 2003). Preliminary results from this test series [6] indicate that there are possibly two specific new cruciform geometries that yield appropriate failure modes. Additional tests with specimens of this type are ongoing.

Benchmark and Phase I tests

LM has started to produce test coupons as foreseen in the DPA's of the various TG's. Concerning UD material, standard OB coupons in the fiber direction were only delivered. Experiments were performed on standard OB UD coupons under static tensile and compressive loads as well as under CA cyclic loads (R=10). Benchmark test results were presented in a technical report [7], see OPTIMAT site. Phase I main test results were first presented at the 4th consortium meeting (VUB, July 2003) and subsequently in a technical report, uploaded in OPTIMAT site [8]. Both static and cyclic tests were performed; from the logistics point of view, static tests are accounted for WP6 (TG2), while cyclic tests for WP3, TG1 (for this type of tests there is an overlap between TG1 and TG2). All tests were performed using OB standard unidirectional (UD) coupons. In total, 25 static tensile tests and 22 cyclic tests, R=-1, were conducted. Static tests were performed for the determination of elastic properties and strength of UD material. According to the test plan, 25 coupons were scheduled for tensile tests to define the respective elastic property and static strength distribution characteristics. Results from 15 coupons are available, until now for the determination of tensile Young modulus, E_1, Poisson ratio v_{12}, and tensile strength, X.

Fatigue tests were performed to determine the S-N curve under reversed loading (R=-1). Load was applied on coupons as a sinusoidal waveform at frequencies ranging from 2 Hz to 5.55 Hz depending on max stress level. Maximum strain rate varied from 8.5% s^{-1} to 14.1% s^{-1} for the different stress levels. Test frequency for the first coupon tested was determined such as to avoid temperatures higher than 35^{o}C on coupon surface, near the tab region. To satisfy the aforementioned criterion, the laboratory was continuously air-conditioned and a fan was used to direct cool air on coupons surface. Surface temperature was monitored for a number of coupons using a PT100 thermo resistance. All coupons tested under CA cyclic stress were instrumented with two 6-mm single strain gauges, placed back to back to measure longitudinal strains at the first two cycles of each test, which were performed always, regardless of the cyclic stress level, at a frequency of 0.02 Hz. Frequency 0.02 Hz corresponds to a strain rate ranging from 0.085% s^{-1} to 0.051% s^{-1} for this series of tests according to the selected stress level.

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 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. So far, the task is not completed due to some difficulties in exchanging data (proprietary rights) between UP and TUDT.

<u>Bottle necks</u>

Bi-axial tests, either in specimens of tubular shape or cruciform geometry, both under static and fatigue loading, will be used to validate failure theories and life prediction schemes and will prove, or not, the importance of considering complex stress states in the design of large rotor blades. However, due to various reasons, production of specimens needed for this kind of tests has not yet started. For the cruciform specimen geometry, although LM has produced two different series of preliminary test specimens with more than 8 different local geometries, the technology for this type of tests is not yet mature; existing experience for different type of laminate stacking sequence, e.g. cross-ply, was not enough till now to overcome the problems encountered with the MD laminate, representative of rotor blade construction. Nevertheless, preliminary results (unpublished yet) from the new test series performed by VUB indicate that a solution to the problem is possibly reached. On the other hand, although DLR & Stuttgart Univ., but also VUB, have considerable experience and proved technology in testing tubular composite specimens, no such type of specimens has been produced so far.

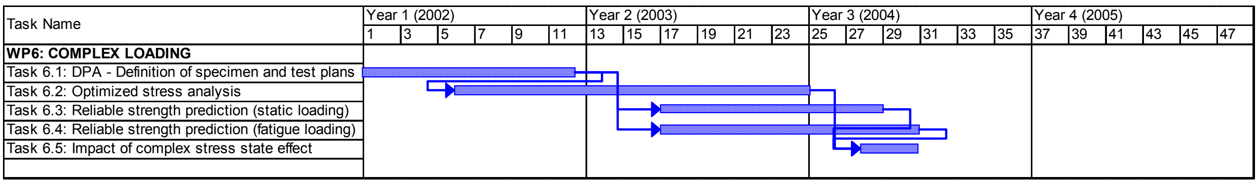
To implement plane stress (complex stress states) formulations, either in FEM calculations or failure prediction schemes, the complete set of in-plane material properties is needed, meaning that for the UD material, specimens in the transverse to the fiber direction as well as appropriate for measuring shear properties must be tested. For a number of reasons, standard OB UD coupons only in the fiber direction have been produced so far and as a result, a large number of special tests concerning basic UD material characterization is still pending. This highly affects other TG's as well, e.g. TG5, where input from CA cyclic test in the transverse direction and shear are a prerequisite to define appropriate stress levels for the residual strength tests.

To the moment of writing this report, it is not clear:

- when tubular specimens will be produced
- if cruciform specimen geometry will prove appropriate for the type of test required and when specimen production will start
- if everything goes well and all specimens required are delivered, it is not known if availability of test rigs of sub-contracting institutes or even owned by a partner will be as planed before 1.5 year.

<u>New time schedule</u>

The time schedule has been up-dated in view of the delays encountered either in finalizing the DPA's or in specimen manufacturing and delivery. If no further delays occur, the first experimental phase is expected to conclude end of June instead of March 2004.



Planned activities for the next half-year period

In this first and a half year, considerable time was needed for the initial phase of defining the standard OB 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. Selection of optimum cruciform specimen geometry is not yet concluded and a series of new tests will be probably performed by VUB to finalize the issue. On the other hand, tube testing by DLR and possibly VUB is expected to start by the end of September 2003. Testing of standard OB coupons will run in parallel in several test rigs, while numerical analyses with FE blade models will continue for the second half of 2003.

Deliverables

In WP6, deliverable #11 “Validated composite mechanics and FEM formulation guidelines and recommendations for rotor blade design” is due since the end of the first year (month 12). However, concerning the first part of the report, related to mechanics of composites and FEM calculations, a detailed overview and comparison between various methods of analysis was performed and reported accordingly in the frame of TG4 by UP [9] and ECN, TUDT [10], [11]. The overlap was not taken into account by the time of compiling the “Deliverables list” in the proposal. Nevertheless, the part of the report related to “guidelines and recommendations for rotor blade design” is still needed and is expected to be delivered by the end of January 2004, after the end of Task 6.2 “Optimized stress analysis”.

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

1. T. P. Philippidis, A. P. Vassilopoulos, T. T. Assimakopoulou, V. A. Passipoularidis, A. Smits, D. van Hemelrijck, OB_TC_R009.pdf
2. A. M. van Wingerde, D. R. V. van Delft, OB_TG2_N000.doc, rev 000
3. . D. van Hemelrijck, A. Smits, OB_TG2_R006.doc, rev 000
4. A. Smits, D. van Hemelrijck, OB_TG2_R007.doc, rev 000
5. D. van Hemelrijck, A. Smits, OB_TG2_R008.doc, rev 000
6. A. Smits, D. van Hemelrijck, OB_TG2_R014_VUB.doc, rev 000
7. T. P. Philippidis, A. P. Vassilopoulos, T. T. Assimakopoulou, V. Passipoularidis, OB_TG2_R012rev.000

8. T. P. Philippidis, A. P. Vassilopoulos, T. T. Assimakopoulou, V. A. Passipoularidis, OB_TG2_R013.pdf
9. T. P. Philippidis, A. E. Antoniou, A. Kyrsanidi, OB_TG4_R005
10. A. Van Vingerde, P. A. Joosse, D. R. V. van Delft, G. de Winkel, OB_TG4_R004
11. P. A. Joosse, OB_TG4_R003