Progress report
period: 1-7-2003 to 31-12-2003
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OPTIMAT BLADES

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1. INDUSTRIAL OBJECTIVES AND STRATEGIC ASPECTS

As the required financial investments to achieve the expansion of the installed capacity of wind turbine grow, the economical pressure on reliable and structurally optimised blades, that are fit for their designed life, will increase. Especially for larger wind turbines, optimisation of the use of material becomes more effective and necessary since the blade mass increases more than proportional to the blade energy output capacity. Very large blades may even become practically impossible without further knowledge of the material behaviour since the dominating loads on the material are caused by the blade mass. At the same time, economical utilisation of large wind farms, offshore and onshore, consisting of MW wind turbines demands reliable and non-stop operation. This is especially true for offshore turbines, due to poor accessibility.

Rotor blades are unique because of a combination of factors:

- *Blades are subjected to complex and severe fatigue loads (variable amplitude loads), comprising often more than one billion of fatigue cycles.*
- *Blades are subjected to a variety of external environmental conditions.*
- *The inner structural parts of the blades where most of the material is located consist of thick laminates that have a complex stress state.*

Therefore, a sound and accurate understanding of the structural behaviour of the material under complex loading, complex stress states and a variety of environmental conditions and their possible interactions is necessary, in order to optimise the use of material in the blade and to obtain reliable blades. This also includes the knowledge of thick laminates and the effects of residual stresses.

The project aims to provide accurate design recommendations for the optimised use of materials within wind turbine rotor blades and to achieve improved reliability. This considers the design of new blades, but also the prediction of the residual strength and life. The latter can be used to extend the life of the blade or avoid unexpected failures, which will result in a better use of material. Furthermore, the possibility of repair will prevent waste of material. To achieve this overall objective, the project will investigate the structural behaviour of the composite material under the unique combination of conditions experienced by rotor blades such as variable amplitude loading, complex 3-D stress states, extreme environmental conditions, thick laminates and their possible interactions. Techniques will be developed for life extension, condition assessment and repair. The major deliverable of the project will be improved design recommendations for the next generation of rotor blades.

With the accurate and reliable design recommendations resulting from this project, reliable blades with optimised use of materials can be designed. Together with the application of condition assessment and repair, this will result in:

- *Reliable blades (fewer unexpected or premature failures)*
- *Reduced use of material and environmental impact*
- *Life extension of blades*
- *Less waste of material (fewer rejected blades and components)*
- *Larger availability of the wind turbine*
- *Extension of the possible size of turbine*

All these aspects can contribute to the reduction of costs for wind energy. This concerns investment costs by lighter components and less waste of material as well as running cost due to the larger availability.

The increased reliability and weight reduction of the blades will stimulate further the offshore exploitation with large capacity wind turbines. This supports the increase in wind energy and by that helps to reach the White Paper target of 40GW of installed power by 2010.

The possible reduction of the material use will lower the impact on Earth's resources and environment. The reduction can result from direct weight saving and from the increased reliability which prevents the need for replacements and waste of material.

2. EXECUTIVE SUMMARY

This report is the progress report over the second half year of 2003 of the Optimat Blades project.

The ambitious objectives of this project required a consortium of 18 partners from 8 EU countries. These partners include 10 research institutes from 7 EU countries and 6 wind turbine and/or blade manufactures from 4 EU countries. Also the two main Certification Bodies, which carry out the certification in most of the EU countries, are included. The participation of these partners will also ease the dissemination of the results within the European Community.

The work is performed by Task Groups (TG) that each perform a cluster of comprehensive Work Packages (WP). The management of the project is done by a scientific/technical coordinator and a financial/administrative coordinator. Furthermore a Steering Committee (SC) and a Technical Committee (TC) are installed. The Task Group leaders are members of the Technical Committee, which is chaired by the scientific/technical coordinator. The industrial partners and the Certification Bodies form the Steering Committee.

In the organisation scheme of the project, as described in the "Description of Work", there was no committee foreseen in which all partners of the project were represented. For that reason it was decided during the kick off meeting to install a Project Coordination Committee.

During the current reporting period, test specimen production and delivery has clearly picked up speed. After an initial slow start-up in the first months of 2003, LM has made up for lost time and at the end of the reporting period, most partners had abundant specimens for testing. LM has depleted its resources for this phase already, so it was decided to work out a proposal to transfer part of the budget from other industrial partners (who did not have a large share in the specimen production anyway) to LM to ensure continuation of specimen production. The budget transfer proposal has been sent to the scientific officer
Some difficulty in the establishment of the S-N curves, a sound determination of which is crucial to all task groups in the project, has led to an unforeseen delay. Apparently, the standard OPTIMAT specimens were found to be sensitive to temperature/frequency effects, which caused unrepresentatively low lifetimes when the testing frequency was chosen too high. Some of these effects also seemed to obscure effects of buckling or bending in the compression fatigue tests on the UD specimens.
Nevertheless, most of the basic S-N curves, and the associated testing frequencies per load level have been established and may be used in subsequent phase I testing. Some of the specialised geometries, especially the cruciform specimen, have been defined and are currently under investigation. The S-N curve load levels and testing frequencies are documented in a general test description, which has been developed and made available online to ensure consistent testing across the OPTIMAT BLADES laboratories. Additional consistency in testing, specifically to measuring strains, is foreseen through the development of an OPTIMAT standardized strain sensor.

The Task Leaders describe their progress in some detail, and have reached the consensus that the total delay of the testing programme may be estimated at 10 months as was already indicated in the First Assessment report.

3. ACTIVITIES DIRECTLY RELATED TO THE PREVIOUS REVIEW REPORT

In the first Assessment Report [1] it was discussed, that due to the fact that two preliminary test series and considerable discussion were necessary to define the shape of the test specimen, which, combined with extensive efforts to define a consistent and realistic test programme, resulted in a delay of several months in the start-up phase. In order to reduce the delay as much as possible, all Task Groups intensified their activities for the year 2003. These intensified activities request however a prompt delivery of necessary test specimens. But the specimen production suffered a delay of several months in the beginning of 2003. Therefore it will be impossible to keep up with the original time schedule. The adjusted time schedule was presented in [1] and again in chapter 8 of this report. From the time schedule, it can be seen that the delay caused by the initial problems of defining a universal test specimen geometry, requiring two preliminary test series and the subsequent delays in test specimen manufacturing results in about ten months delay.
This foreseen time delay has again been discussed during the progress meeting in December 2003 at VTT.

From information of the scientific officer it is clear that the extension issue has to be discussed during the midterm assessment. This midterm assessment meeting was according to the original work program foreseen to take place in April 2004. Due to the delays, the midterm assessment is postponed until December 2004. The scientific officer approved this postponement under the condition that at this date all the milestones will have been reached, which should have been attained before the MTA date according to the original work program.

4. KEY EVENTS DURING THE REPORTING PERIOD

During the period 1-7-04 to 31-12-04 the following key events took place:

Fourth Progress Meeting
The fourth progress meeting was hosted in the first week of December by VTT in Helsinki.
The overall delay of 10 months was discussed and confirmed by all partners.
At that time specimen availability was generally good. Some partners needed extra specimens on short notice. LM requested extra budget for the continuation of the specimen production. It was agreed that all industrial partners contribute financially to the production efforts of LM.
The preliminary test results and suspected temperature and frequency effects were discussed. The general test procedure was further developed, and the development of a project-specific clip gauge was initiated, to ensure cost-efficient and consistent strain measurements throughout the remainder of the project.
Cruciform specimen selection was finalised, and the first tubular specimens had become available for testing at DLR.
Load levels and the corresponding frequencies were fixed for most of the project S-N curves, and included in the general test specification. Also, the layout of the database and the data submission procedure was discussed and streamlined.

5. LIST OF DELIVERABLES MADE DURING THE REPORTING PERIOD

In Table 1, an overview is given of the deliverables of the project. For an overview of all documents produced in 2003, please refer to Annex I. All documents are available on the project web site (www.ecn.nl/optimat).

Table 1 List of deliverables during reporting period (in black)

No	Deliverable title	Form	Date	Dissemi nation level	Report
1	Test report describing the material, laminates and fatigue tests	Report	5	CO	OB_TG3_R005
2	Microstructural model and identification of degradation parameters.	Report	5	PU	OB_TG3_R006
3	Definition of extreme conditions and procedures for testing under extreme conditions.	Report	5	PU	OB_TG3_R004
4	Definition report of typical thick laminate.	Report	5	PU	OB_TG4_R001
5	Suitable repair techniques for small specimens	Report	5	CO	OB_TG4_R002
6	Review of residual strength predictive models	Report	5	CO	OB_TG5_R003
7	DPA for phase 1	Report	6	CO	OB_TC_R004
9	Approved DPA for phase 1	Report	6	CO	See above Approved in December
43	Preliminary Technology Implementation Plan (TIP)	Report	6	PU/CO	OB_PC_005 (first draft)
8	Progress reports according to Energy Guidelines for Contract Preparation	Report	7,13, etc	CO	OB_PC_R002 OB_PC_R003 OB_PC_R004
10	Small specimens of reference material	Specimens	10	CO	Are being produced
11	Validated composite mechanics and FEM formulation guidelines and recommendations for rotor blade design.	Report	12	PU	Not yet completely available. Parts are available in other reports. The final version will issued in Jan. 2004
46	First assessment report	Report	15	CO	OB_PC_R004
12	Phenomenological micro mechanics models for sensitivity analyses	Report	18	PU	OB_TG3_R014
21	Effects of extreme conditions on properties of the reference material	Report	26	PU	OB_TG3_R015
22	Effect of environmental ageing on reference material	Report	26	PU	OB_TG3_R016

6. SCIENTIFIC AND TECHNICAL PERFORMANCE

In this reporting period, a large number of benchmark tests have been carried out, resulting in most of the baseline data, which forms the basis for the rest of the test programme.

OVERVIEW OF EXPERIMENTAL PROGRAM FOR PHASE 1

Introduction

One of the unique aspects of the project is the integral approach to the test programme. The results are believed to be invaluable for the future design guidelines, since all tests are carried out in a consistent way, allowing data of the various task groups to be compared without considerations of various lay-ups or test geometries as is necessary when data from separate testing programmes has to be combined.

This approach requires that all specialized tests have sufficient baseline data as a reference point. Results from tests under extreme conditions, residual strength tests, block fatigue tests, all at different R-ratios and with various predefined target lifetimes, are ultimately compared to establish the hypothesized interaction effects. A solid, common set of S-N curves at these R-ratios and stress levels is needed as a basis. Moreover, S-N curves must be generated at different testing institutes to ascertain that results from different institutes are identical.
This benchmark process will be discussed in general in the following paragraphs. Further on, more detailed reports will be given on the progress per Task Group.

Materials tested and notation

The tested coupons are made of the reference E-glass/epoxy materials for the Optimat Blades project [1]. These are:

- 'UD' or 'unidirectional material': 1150 g/m^2 in 0° direction and 50 g/m^2 in 90° direction with a 50 g/m^2 Chopped Strand Mat
- '±45°' or 'biaxial material': non-woven stitch-bonded glass roving in 2 layers, 400 g/m^2 in +45° and 400 g/m^2 in –45° with two thin additional layers of 2 g/m^2 in 0° and 90°

For the matrix material, SP systems Prime 20 epoxy is used with slow hardener. The tabs for the tests are made out of GRP (Glass fibre Reinforced Plastic).
The thickness per layer, was specified by LM to be about 0.88 mm for the unidirectional material and 0.61 mm for the biaxial material [1]. Test specimens were provided by LM Glasfiber A/S Denmark, cut from different plates.

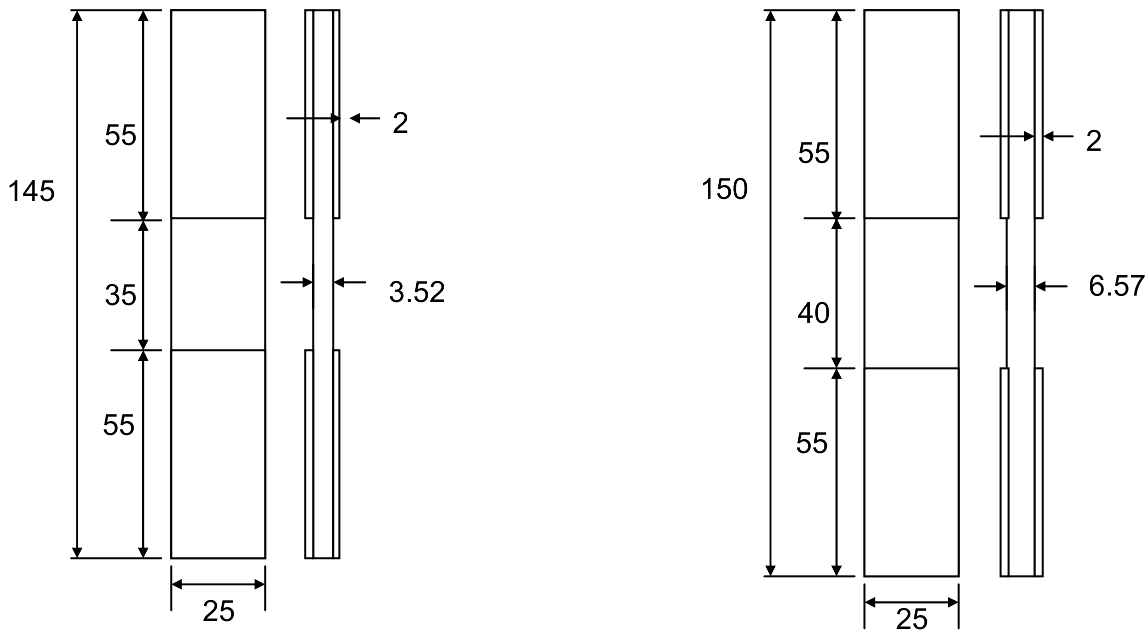
After the preliminary programme, two standard lay-ups were chosen and named UD2 and MD2, respectively. These are the lay-ups used for all standard test specimens. Table 2 gives the characteristics of these laminates.

Table 2: Laminate lay-up and nominal thickness of the standard test specimens

Name	UD	biaxial	lay-up	nominal thickness [mm]
UD2	4	--	$0°_4$	3.5
MD2	4	2	$(\pm45°,0°)_4; \pm45$	6.6

Test specimen geometry

The standard OPTIMAT specimens have a rectangular planform, see Figure 1. These specimen shapes resulted from an extensive preliminary testing programme, which mainly compared dog-bone shaped specimens and rectangular specimens. Both specimen shapes were investigated since both had their advantages and the partners could not agree on choosing either one, without extensive testing.
The straight (rectangular) shape was considered to be appropriate for UD2 material. For consistency, the MD2 laminate was also cut into rectangular specimens.



Geometry for UD2 material: R03
(dimensions in mm)

Geometry for MD2 material: R04

Figure 1: Standard OPTIMAT specimen geometries (dimensions in mm)

Results from the benchmark programme

During the execution of the benchmark tests with these OPTIMAT blades 'standardized' specimens, a temperature/frequency effect, which was more severe than had been expected, was encountered. Apparently, the standard specimens seem to be very sensitive to heat generated in the fatigue tests, causing specimens to fail at much lower lifetimes than would be expected for these materials.

DLR and UP have established load levels and frequencies for a number of materials and R-ratios. The other partners will use these for their fatigue tests. They were basing the test frequencies on a measured temperature of 35° C at the side, about 5-10 mm below the tabs at a certain load level and applying the constant energy approach (energy~$f \cdot \varepsilon^2$) to determine the frequency at other load levels. It was thought that, although the temperature inside the test specimens would be higher, the 35° limit would result in sufficient margin to avoid preliminary failure due to overheating, thus giving the 'real' fatigue life as it would be for use in wind turbines.
However CRES, using lower frequencies because of an environmental temperature of 30° C, obtained better fatigue results for their R=-1 tests on 0° UD material. A frequency of about 25% to 50 % lower than the recommended UP/DLR frequencies resulted in a factor of 2...3 higher life. This

highly unexpected result, which could be due to the test set-up (clamping and eccentricity), sparked an intense discussion on the matter of testing frequencies on the fourth progress meeting. It was decided to carry out a number of additional tests in order to get additional information on the effects of temperature and test frequency on the fatigue life:

- In addition to the tests at 60° within TG3, RISØ and VTT will (for R=-1 only) perform tests at 10°/20°/30°/40° and 50° C at the recommended load levels [3].
- WMC will do the benchmark tests of MD material at the recommended frequency and measure the temperature.
- In addition, WMC will do benchmark tests on UD material at R=-1 at half the recommended frequency [3] and measure the temperature.
  3 tests will be carried out at the high load level, aiming at 1000 cycles and 3 tests at the low load level, aiming at 1000000 cycles.
- CRES will redo the tests at the recommended frequency and DLR will supply them with 6 extra test specimens for this purpose.

Elimination of possible frequency/temperature effects during this stage of the project is crucial for success. Although the abovementioned extra tests are of paramount importance to the validation of the futures results, they are not expected to cause extensive delays, since enough S-N information has become available to complete part of the Phase I test programme.

Another unpleasant surprise that arose during the fourth progress meeting was, that LM is no longer planning to use the Prime 20 Epoxy in their blades, due to production technology related problems. This resin is used in the standard OPTIMAT blades specimens and this was expected to contribute to acceptation of the project's results as relevant to the wind turbine industry.
This surprise was, however, less grave than it seemed. Apart from the fact that the project has progressed too much for the resin to be changed in this phase, the main aim of the experimental programme in this phase is to investigate interaction effects on a reference material. The results of this phase are therefore very useful anyway. In the next phase, where an alternative material will be tested, updating of the resin system may be considered.

Finally, UP has noted some bending in a limited amount of their compressive static and fatigue tests on the UD standard specimen. Some discussion arose as to the nature and cause of these measurements, and their possible links to the compressive strength of the material. For the fatigue tests, it seemed, that part of the low lifetimes may be either explained by bending or buckling, or by the abovementioned frequency effects. This discussion did not result in any adaptations of the specimen shape, since addition of extra UD layers would ultimately, through delamination of these layers in fatigue, lead to buckling of the specimens anyway, and since adding extra parameters to the project in this stage might lead to greater confusion than clarification.

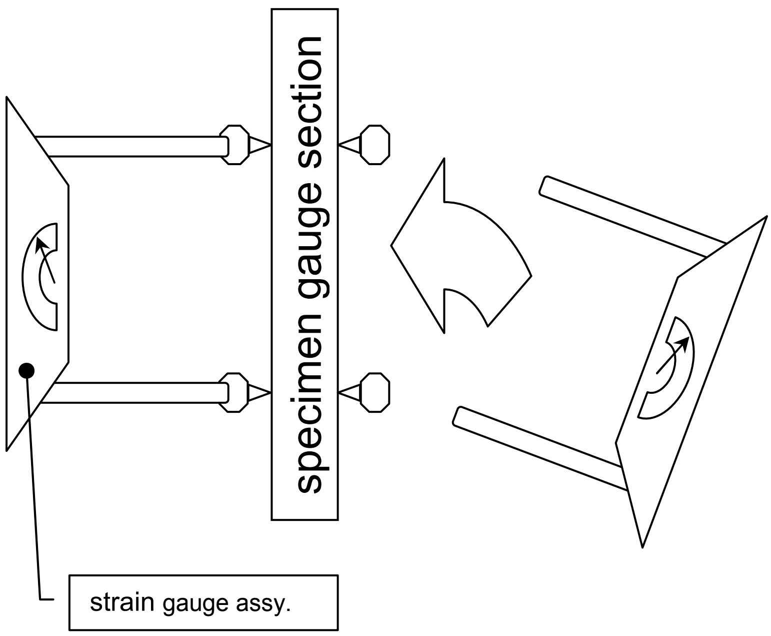


Figure 2: Schematic of OPTIMAT strain sensor (side view)

Since in most task groups measurement using extensometers is indispensable to record stiffness degradation in the course of fatigue lifetime ('ordinary' strain gauges are unfit for this task due to their limited fatigue life and rapid deterioration of the bonding between gauge and specimen), and since commercial extensometers are very costly, and are sensitive to failures, WMC and ECN have initiated an effort to produce an in-house design of custom-built extensometers. In addition to cost-effective strain measurement, this will also lead to a large degree of consistency in strain measurement across participating laboratories.

Essentially, the sensor consists of a set of knife-edges, which are placed onto the specimen gauge section (see the side view in Figure 2). A strain gauge assembly, connected to the extensometer's beams, can be connected to the knife-edges. The advantage of this design is, that the extensometer can be taken off and reinstalled at will, without the need of repositioning the knife edges.

The initial design of this extensometer has been tested and is under further development. A limited number of the prototype will be manufactured and distributed among the partners for testing. Upon success of the prototype, this strain sensor is to be used throughout the remainder of the project.

Conclusions from the benchmark programme

To date, the benchmark programme has resulted in a document describing the benchmarked load levels and associated frequencies, which should be used in all other tests [3]. These load levels and frequencies are replicated in Table 3.Completion of the missing S-N curves is expected on short notice. However, tests that utilise the readily established S-N curve information can commence as soon as possible.

Table 3: Load levels and frequencies from benchmark programme

		R-value:	-1		0.1		10	
Material	Load level	Target number of cycles	Stress [MPa]	Frequency [Hz]	Stress [MPa]	Frequency [Hz]	Stress [MPa]	Frequency [Hz]
UD 90º	1	1000	46.92	0.84	-	-	136.84	2.73
	2	50000	26.95	2.54	-	-	115.01	3.86
	3	1000000	17.63	5.93	-	-	100.68	5.04
	4	10000000	12.72	11.39	-	-	90.89	6.18
MD2	1	1000	1.83	0.63	2.62	1.52	-	-
	2	50000	1.21	1.44	1.77	3.34	-	-
	3	1000000	0.89	2.57	1.31	6.10	-	-
	4	10000000	0.69	4.39	1.04	9.68	-	-
UD 0º	1	1000	1.58	0.82	2.14	1.50	-	-
	2	50000	0.97	2.17	1.43	3.35	-	-
	3	1000000	0.67	4.56	1.05	6.19	-	-
	4	10000000	0.50	8.09	0.83	9.93	-	-

For completeness, Annex II presents the overview of the tests for Phase I.

DETAILED REPORT FOR TASK GROUP 1

Short description of TG1 WPs

WP3 (Variable amplitude fatigue loading)
The objective of WP3 is to investigate the applicability of common damage accumulation rules or lifetime prediction models and to improve their capabilities. To meet this objective, extensive testing including constant amplitude and variable amplitude tests is foreseen to generate adequate test data. The correlation between constant amplitude as well as simplified variable amplitude tests and complex load spectra tests is especially emphasised.

WP4 (Establishment of New Wisper Spectrum)
After definition and collection of blade spectra measured at large modern wind turbines, a synthesis of a new spectrum (NEW WISPER) will be performed which then shall be validated experimentally.

Specific objectives for this period

WP3:

- Continuation of a benchmarking in lifetime analyses with different engineering models of life assessment and existing material data, which shall result in a new basis to decide for an apt damage accumulation theory and/or material fatigue model.
- Establishment of S-N curves of reference material at various stress ratios, to design a constant amplitude life diagram.
- Variable amplitude tests with WISPER as well as block testing on the reference material.

WP4:

- The recovery and adaptation of WISPER synthesis: Assessment of the WISPER synthesis procedure used by the inventors of WISPER, Lex Ten Have et al.
- Synthesis of New WISPER spectrum and derivation of a New WISPER test sequence.

Overview of technical achievements

WP3:
In the previous reporting period the lifetime prediction benchmarking indicated that the results were influenced significantly by model-independent parameters such as statistical evaluation and rainflow counting. These differences were eliminated.
Fatigue tests were performed to determine the S-N curves for the MD material for stress ratios -1 (Tension-Compression) and 0.1 (Tension-Tension). Load was applied force-controlled on coupons as a sinusoidal waveform at load-dependent frequencies. The testing frequencies at a certain load level were determined using the constant energy approach (energy $\sim f\cdot\varepsilon^2$), that keeps the dissipated energy constant. To avoid overheating of the relatively thick specimens low testing frequencies had to be used.
For the UD material a series of specimens was tested in static tension and compression and in fatigue under reversed loading (R=-1) to cross-check the results determined by TG2. These results were in good agreement and reported on the OPTIMAT site [4].

WP4 :
Proposal for a NEW WISPER Synthesis Procedure
The procedure used to establish the old WISPER load standard as laid out in the comprehensive report by Ten Have NLR in 1992 was recovered by the partners. During this assessment the needs for adaptation of the process to today’s engineering requirements and to today's wind energy technology standard as well as the characteristics that shall be preserved have been identified.

These items have been discussed and decisions on how to deal with the specific items in the NEW WISPER synthesis process have been made, resulting in a proposal for a NEW WISPER synthesis procedure.
The baseline for the set-up of a new procedure for a NEW WISPER test load sequence is threefold:

- Standard techniques as used by the participating partners and laid out in the existing standards (here IEC 61400-13) shall be used to make use of best and established practice and to ensure acceptability in the wind turbine industry.
- Simplicity and transparency of the synthesis process shall be achieved.
- In order to maintain confidentiality of the data used the participating work group members shall supply processed data only.

The following outlines the suggested synthesis process:

1	Turbine	The turbine represented in the data bases used shall be described by a common set of parameters.
2	Site Description	The site represented in the data bases used shall be described by a common set of parameters
3	Data selection from the capture matrix	The data base shall be given by a IEC 61400-13 capture matrices of 10-Min time histories for normal power production and transient operation.
4	Normalization of flatwise bending	In order to be able to combine the loads measured on various machines with different designs a normalization of the load level is required. As normalization level the load range between the load at 20% and 80% power output has been chosen.
5	One year wind speed time history of 10min mean	For determination of the low cycle fatigue content and the number of starts / stops to be considered a one year wind speed time history of 10-minute-average values was prepared. The time history satisfies an IEC class II wind speed distribution. The applicable number of starts, stops and rotor speed transients are to be taken from that one year wind speed time history using peak trough counting and establishing a Markov matrix from that one year wind speed time history.
6	Annual cumulated Rainflow load spectrum	Using the wind speed histogram the annual load spectra for the individual machines are to be derived by each data supplying partner.
7	Normalization of cyclic content (rotational speed)	As rotational speed of the turbines varies a normalization in this respect is required.
8	Add low cycle loads for each turbine (RISØ proposal) and transient loads	To account for the low cycle fatigue loading the RISØ approach is adopted and a sequence of 10-min-maximum and 10-min-minimum normalized flatwise loads according to the one year wind speed time history are to be derived from the data base, to be Rainflow counted. The counted load cycles will be added to the normalized annual flatwise Rainflow matrix
9	Compose flatwise Rainflow summatrix of all turbines	The normalized flatwise Rainflow matrices of all 5 turbines shall be added and divided by a factor of 5. From this matrix an annual range pair spectrum shall be derived The normalized flatwise Rainflow matrices of all 5 turbines shall be added and divided by a factor of 5. From this matrix an annual range pair spectrum shall be derived
10	Get Sequence from Rainflow matrix	To obtain a load sequence from the rainflow summatrix standard fatigue equivalent techniques are to be applied. The exact technique to be applied is currently matter of investigation. The commercially used software products for fatigue analysis do have such functionality,

however, applicability in the NEW WISPER case must be checked.

The actual work has begun but is not yet finished. At the same time commenting and mutual agreement on the details of the suggested proposal for a NEW WISPER assembly process are not concluded yet.
The proposed scheme as laid out above has been sent to the participating partners to comment and to contribute on the basis of their working experience.
While the last details on the synthesis procedure are currently being cleared the normalization of the data bases is in progress. At the same time the partners have begun to implement those steps of the complete algorithm that are not yet standard techniques in their daily work i.e. accounting scheme for low cycle fatigue.

Comparison of planned activities to accomplished work

WP3:
A time delay of roughly 9 months was stated for the previous reporting period. Despite great efforts to regain lost time, the delay could not be reduced. To comply with the agreed temperature limit during testing low frequencies had to be used, so that the establishment of the first S-N curves took a long time. Additionally the adherence of the agreed procedure for the accomplishment of the fatigue tests was not followed exactly by all laboratories. This caused different fatigue results and involved additional delay in testing progress. After longer discussion the load levels and testing frequencies for the first S-N curves were approved by the Technical Committee not before the Progress Meeting in December 2003. To avoid further irregularities which might cause additional delay or doubtful test data a general test specification was established [3].
The time lag owing to the time-consuming establishment of S-N curves and the required formal approval of S-N curves made further tests impossible.

WP4:
Due to the delay in other project tasks the time schedule as proposed in the last annual progress report has not been maintained

1. *Identification of Data Bases*
   The official release of the data sets is still pending due to inactivity of individual industrial partners.

2. *Recovery and Adaptations of WISPER Synthesis* Due Date: March 22nd 2003
   The assessment of the old WISPER synthesis procedure has been concluded.

3. *Preparation and Supply of Processed Data* Due Date: April 11th, 2003
   The work on the data processing tools and on the data itself has started.

4. *Synthesis of NEW WISPER* Due Date: May 2nd, 2003
   While the actual synthesis work will be done only by the two partners, DEWI and ECN, all partners shall work on their own data bases to supply preprocessed data for syntheses.

5. *Reporting* Due Date: June, 27th,2003
   The work carried out in the preceding steps and the crucial results will have to be compiled into a description of the NEW WISPER standard that shall be of use for the potential user.

Planned activities for the next half-year period

WP3:
The benchmarking of the lifetime prediction methods will be finished after repeating the calculations based on the various models used by the participating labs. A report on these results will be published [4].
The establishment of the load levels for constant amplitude fatigue testing has to be continued. Due to the time delay probably not all foreseen stress ratios according to the DPA will be considered. The variable amplitude tests will start with the load spectra tests. The extent of block tests will be adapted to the tightened time schedule, i.e. the number of tests will be reduced.

WP4:

1. *Identification of Data Bases*
   The official release of some data sets is still pending due to inactivity of individual industrial partners. Alternative sources of data are considered.

2. *Recovery and Adaptation of WISPER Synthesis concluded* – final comments pending. These comments will have to be in before reporting to be considered.

3. *Preparation and Supply of Processed Data* Due Date: March 12th, 2004
   Each of the data supplying parties (CRES, DEWI, ECN) will process their data to a defined degree according to the suggested scheme laid out above. The work on the data processing tools and on the data itself will be continued

4. *Synthesis of NEW WISPER* Due Date: March 31st, 2004
   The data will then be compiled into a NEW WISPER range pair range spectrum and subsequently a rain flow equivalent sequence will be derived.

5. *Reporting* Due Date: June,2004
   Reporting shall be concluded before the next regular meeting on which the results of work package 4 will be presented.

Deliverables

No deliverables in this reporting period.

Pre-draft version of design recommendations

No modifications have been made to the pre-draft version presented in last year’s report.

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 WPs

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 the 4th semester (01.07.2003 to 31.12.2003) were:

- Testing of OPTIMAT coupons and special specimens for multi-axial loading (static and fatigue loading) planned for the 1st phase of the project
- Build FE and conventional blade models for theoretical analysis and assessment of complex stress state effect
- Review and validation of failure theories for static and CA cyclic loading, FE models

Overview of technical achievements

Static tests of OB standard coupons

104 static tests using OB standard coupons were performed in the frame of the main testing program, phase I, accounted for WP6: 26 UD tensile, 26 UD compressive, 26 Transverse tensile and 26 Transverse compressive. Static tests were performed for the determination of in-plane elastic properties and strengths. According to the test plan, 26 coupons were scheduled for each case to define the respective elastic property and static strength distribution characteristics. Results from all coupons were uploaded to OPTIDAT and also presented in [5]. Thorough statistical evaluation and definition of probabilistic property distributions, e.g. see Fig.3, were

Statistics	X	E1	v12	e1T_max%
Min	695.03	36.74	0.24	1.898
Max	836.03	41.38	0.3459	2.355
Sum	22518.42	1132.21	8.4267	60.647
Mean	776.4972	39.04172	0.290576	2.091275862
Median	781.34	39.03	0.2853	2.08
Variance	1306.319	1.065715	0.000736	0.009185064
Std. Dev.	36.14304	1.032335	0.027137	0.09583874
Std. Err.	6.711594	0.1917	0.005039	0.017796807
Valid Obs.	29	29	29	29
Total Obs.	29	29	29	29
95 Conf Int	13.74808	0.392679	0.010322	0.036455107
COV%	4.654625	2.644183	9.339083	4.582788024

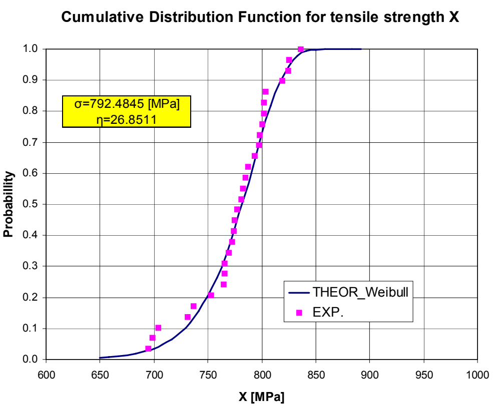


Figure 3: Data format for statistical property distributions from static tests on UD material

performed for the tensile, E_1, and transverse Young modulus, E_2, major, v_{12}, and minor v_{21} Poisson ratios, tensile, X, and compressive strength, X', along the fiber and in the transverse direction, Y and Y' respectively.

CA cyclic tests of OB standard coupons

120 CA fatigue tests were performed on standard OB UD coupons. In the fiber direction, OB UD 0^o: 29 cyclic tests @ R=-1, 19 cyclic tests @ R=0.1, 9 cyclic tests @ R=10 (overlap with WP3, TG1), 2 cyclic tests @ R=∞. In the transverse to the fiber direction, OB UD 90^o: 27 cyclic tests @ R=-1, 8 cyclic tests @ R=0.1, 26 cyclic tests @ R=10. The number of coupons tested per loading condition, R, is some times greater than planned due to problems arising from details in testing procedure, e.g. see Fig.4, or power grid failures. Test results were uploaded to OPTIDAT and also presented in [5]. Fatigue tests were performed to determine S-N curves under different loading conditions (R=-1, 0.1 and 10) of UD OPTIMAT coupons along the fiber and in the transverse direction. Load was introduced as a sinusoidal waveform at frequencies ranging from 0.84 to 6.70 Hz depending on maximum stress level. Test frequency for the first coupon tested was determined such as to avoid temperatures higher than 35^oC 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 the 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.

Biaxial static tests of cruciform coupons

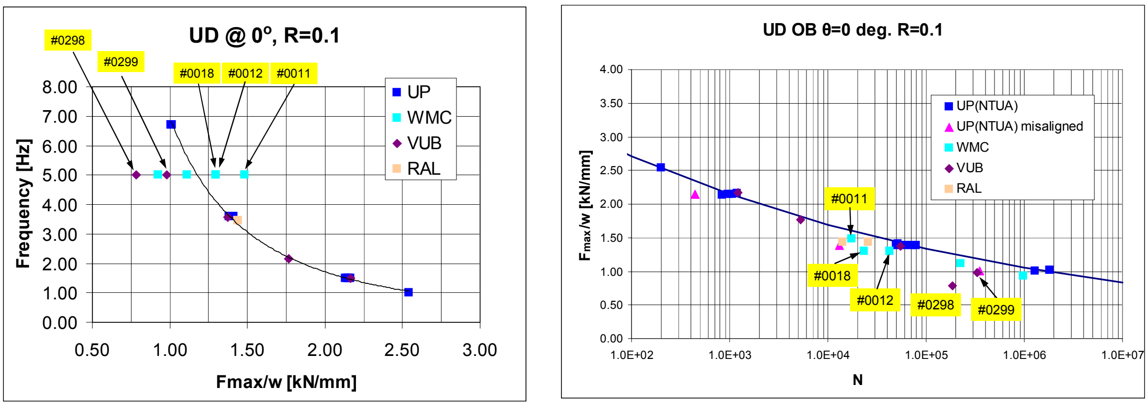


Figure 4: Sensitivity investigation of CA test results on frequency, coupon clamping & alignment, etc.

25 Preliminary biaxial tests, 5 experiments for 5 different specimen geometries, 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. The geometries tested were assigned the numbers 2, 3, 4, 5 and 7. A technical report with test results was written and uploaded to the OPTIMAT site [6]. Cruciform coupons, prepared by LM, are made of MD lay-up, albeit of different thickness for the various geometries: [(±45/0)4/±45] for geometries 3, 4, 5 and 7, [(±45/0)3/±45] for geometry 2. In the middle of the specimens of geometries 3, 4, 5 and 7 a set of (0/±45) layers is milled away at each side of the specimen resulting in [(±45/0)2/±45] lay-up. All specimens were tested in biaxial tension using a servo-hydraulic biaxial test bench with a loading capacity of 100kN in both directions. In the gauge area of each specimen, a three element rosette strain gauge was bonded on both sides. Strain measurements were obtained in 0° direction (direction of UD fibers), 90° direction (perpendicular to UD fibres) and in 45° direction. The strain gauge type is FRA-6 from Tokyo Sokki Kenkyujo Co., Ltd. The gauge length is 6 mm and the gauge width is 2.4 mm. A digital video camera is used during testing to allow for specimen failure visualization. The test speed was 5kN/minute in the direction of the 0° fibres, and was adapted in transverse direction depending on the loading-ratio. Most of the specimens were loaded

with a ratio Fx/Fy of 3.85, which is the strength ratio between 0°- and 90°- directions of the MD lay-up. One specimen per geometry was tested at a load ratio of 5.775/1, which is one and a half times the ratio of the strengths and some specimens were tested with a ratio 2.57/1, which is the ratio of the strengths divided by 1.5. Highest stresses at failure in the 0o-direction were obtained for geometry 5, see Fig.5, whereas, the highest obtained failure stresses in the transverse direction were from geometry 7. Highest failure strains are obtained for geometry 5 and 4. Looking at the failure modes for the load ratio 5.775/1, particularly good results were mostly obtained for geometry 5, see Fig.6. These facts considered together, lead to the conclusion to continue the main tests of phase I with geometry 5.

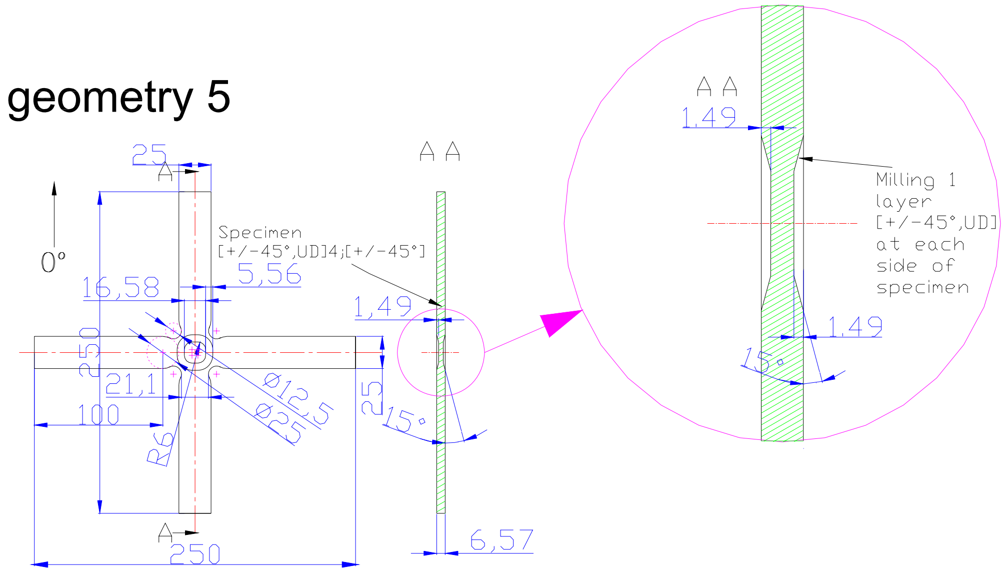


Figure 5: Preferred cruciform specimen geometry

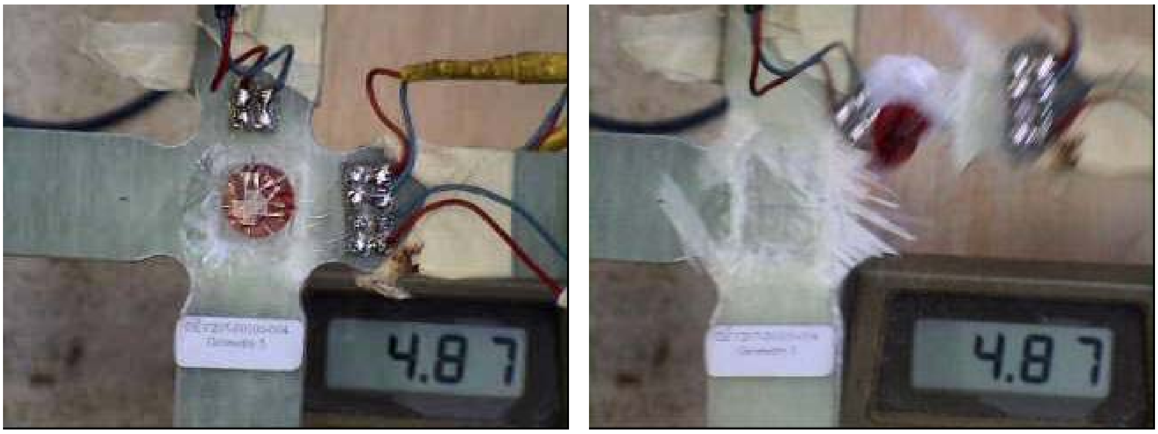


Figure 6: Cruciform specimen GEV 207 S0100-004 (geometry 5) at failure

Optimized stress analysis

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 were performed. A technical report entitled “Comparison between uni-axial and bi-axial stresses”[7], was prepared by ECN, and is to be uploaded to the OPTIMAT site. 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 was not completed due to some difficulties in exchanging data (proprietary rights) between UP and WMC, but a settlement was reached and the work is expected to be done in the 1st semester of 2004.

Review and validation of failure theories

A comprehensive investigation and comparison of multi-axial failure theories for composites, both under static and dynamic loading conditions, especially with regard to their implementation into commercial FE codes, is underway at UP. Progressive damage analyses and non-linear material response towards reliable Last Ply Failure predictions are also in consideration. Theoretical calculation of failure loads for simulated tests with UD and MD coupons loaded off-axis, but also multi-axial tests will be compared to corresponding test results, when available. An example of First Ply Failure predictions using Tsai-Hahn and Puck criteria (implemented as external user subroutines into ANSYS) is presented in Fig.7. Results for failure index (inverse strength ratio) are for the outermost UD layer of an OB MD coupon loaded in compression with an equivalent stress resultant of 40 kNm^{-1}. Due to symmetry, the upper right quarter of the coupon was only modeled.

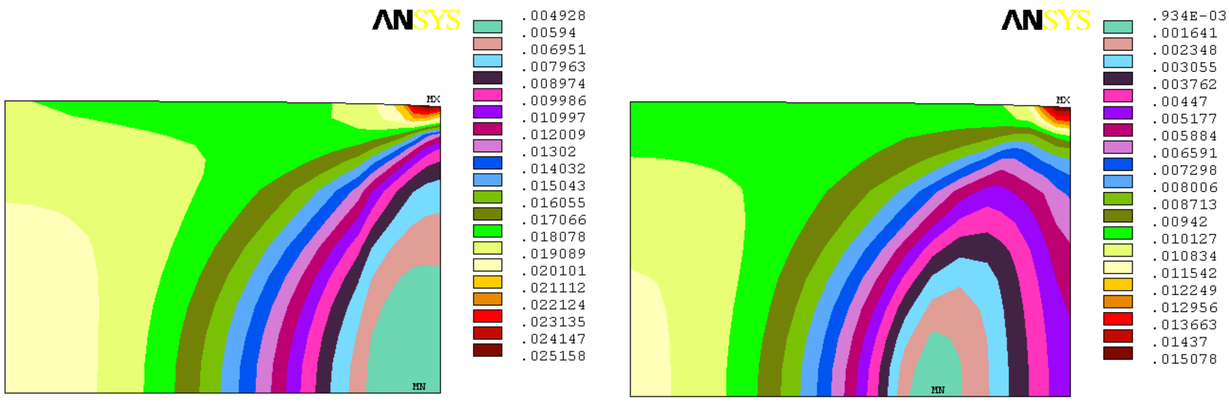


Figure 7: Tsai-Hahn (left) and Puck (right) criteria FPF predictions for MD coupon under compression

Comparison of planned activities to accomplished work

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, a consensus has been probably reached on the optimal coupon geometry and production of the specimens for the main phase I is expected to start at LM. The tubular specimens were to be produced by Nordex. However LM has taken over this activity, and came up with the first specimens, for verification at DLR, during the progress meeting in December at VTT.

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, [±45] ISO coupons have not been produced so far and as a result, a considerable number of special tests concerning basic UD material characterization, e.g. in shear, are not yet performed. This highly affects other TG's as well, e.g. TG5, where input from CA cyclic test in shear are a prerequisite to define appropriate stress levels for the residual strength tests.

On the other hand, standard OB UD coupon was proved inadequate for compression in the fiber direction and additional preliminary investigations are under way to determine the appropriate number of layers to avoid buckling. Even if an agreement is reached on the optimal geometry, it is not easy to estimate the expected delay on the modified time schedule.

In summary, according to the DPA of TG2:

- 465 specimens were scheduled for phase I
- 275 specimens are not yet delivered
- 169 specimens have been tested successfully, i.e. circa 89% of specimens delivered were tested

Planned activities for the next half-year period

In the first semester of 2004, the effort will be towards performing as many as possible bi-axial tests in order to reduce delays observed in the modified time schedule. Testing of standard OB coupons will run in parallel in several test rigs, while numerical analyses with FE blade models will be concluded.

Deliverables

No deliverables in this reporting period.

Pre-draft version of design recommendations

No modifications have been made to the pre-draft version presented in last year’s report.

DETAILED REPORT FOR TASK GROUP 3

Short Description of TG3 WPs

WP8

In this work package, the degradation mechanisms of fibre reinforced polymer materials under extreme climatic conditions, and the effect on the mechanical properties and design data for the reference material, are investigated.

WP9

This work package pertains to phase II of the project and aims to characterise the variability of extreme conditions for alternative materials by additional experiments.

Main objectives for Phase 1

The main objectives for this 24 month period were as follows:

- generate the Detailed Plan of Action (DPA), which includes an overview of geometries, laminates, selected extreme conditions, and degradation parameters, an experimental plan and time schedule
- Identification of extreme conditions
- identification of degradation parameters
- phenomenological modeling and experimental determination

Overview of technical achievements

DPA of WP8 and WP9

After a considerable amount of discussion, the DPA has been drafted in accordance with the choices made regarding the specimen geometries for the whole project. The DPA has been approved by the Scientific Committee in their Stuttgart meeting of December 16.

Extreme conditions

Extreme conditions that are relevant to service conditions of wind turbines are determined. The determined conditions are: temperature variations at ambient relative humidity –40C, +60C and RT, as well as salt water environmental conditions. The salt water extreme conditions means that the specimens are submersed in the salt water. One half of them is kept for 6 month and tested after, another half is kept longer, 12 month, and tested after exposure.

Degradation parameters

Stiffness degradation as function of applied strain and number of loading cycles is identified as damage parameter. It allows to determine a rather small amount of damage long time before final failure of the specimen. Furthermore, damage mechanics and fracture mechanics based modeling can link stiffness degradation to different failure mechanisms acting on laminate and microscopic levels. With this method is possible to study damage evolution rate for different fracture mechanisms.

Phenomenological modeling and experimental determination

The statistical methods, such as linear regression, maximum likelihood using pooled or censored data, statistics for conditioned random variables, Weibull statistics, or combination of mentioned are available to describe fatigue life diagrams and its tolerance bounds. All the methods have been analysed theoretically and compared in order to formulate methods that satisfy the considered tests and its objectives. The linear regression in log-log domain with 95%95% confidence limits is selected. It gives the most conservative design curve for fatigue life. The extreme conditions has no apparent effect on the fatigue life of reference UD material (R=0.1), see Figure 8.

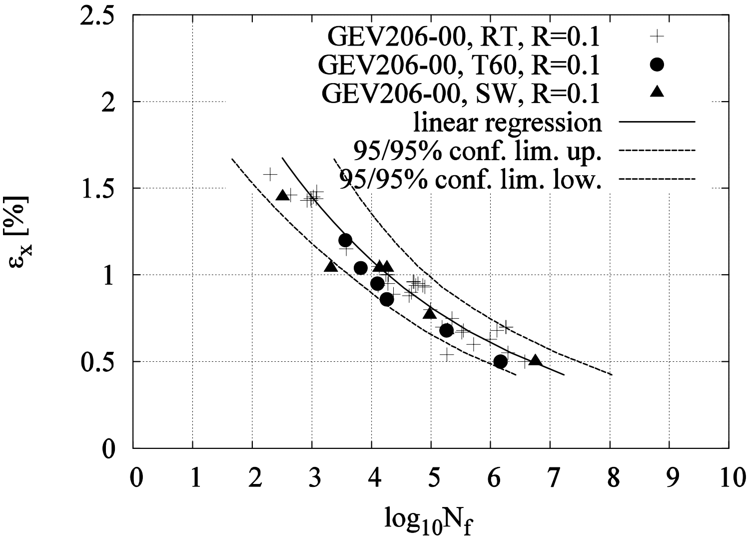


Figure 8: Effect on the fatigue life of reference UD material (R=0.1)

However, Considerable degradation of mechanical properties has been observed for UD basic material as a result of exposure to salt water for 6 month, see Table 4, and Table 5. The additional tests are selected and mentioned theoretical tolls are selected that will be used in order to reveal the mechanisms.

Table 4: Elastic properties of GEV206

Properties	GEV206 RT	SW1	SW2
Young's modulus, $E_1^{(+)}\,(GPa)$	39.1(3.44)	36.3(1.95)	
Young's modulus, $E_2^{(+)}\,(GPa)$	15.2(0.78)		
Shear modulus, $G_{12}\,(GPa)$	8.62(0.85)	3.52(0.09)	
Poisson's ratio, $\nu_{12}^{(+)}$	-0.36(0.12)	-0.29(0.05)	

NOTES:
RT- room temperature
T60- temperature T=+60C
T40- temperature T=-40C
SW1- conditioned in salt water for 6 month
SW2- conditioned in salt water for 12 month

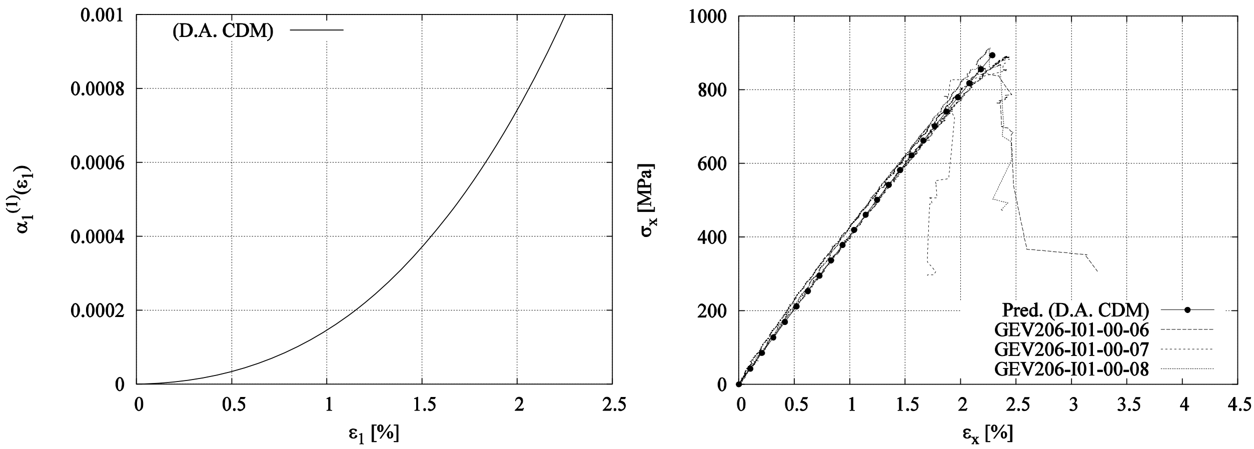
Table 5: Strength properties of GEV206

PROPERTIES	GEV206 RT	SW1	SW2
Tensile strength, $\sigma_1^{(+)}\,(MPa)$	802(20.6)	664(16.8)	
Tensile strength, $\sigma_2^{(+)}\,(MPa)$	55(2.7)		
Compression strength, $\sigma_1^{(-)}\,(MPa)$	686(59.5)		
Compression strength, $\sigma_2^{(-)}\,(MPa)$	161(8.94)		
Shear stress to failure, $\sigma_{12}\,(MPa)$	49.8(1.15)	28.5(2.21)	
Tensile strain to failure, $\varepsilon_1^{(+)}(\%)$	2.53(0.4)	1.92(0.10)	
Tensile strain to failure, $\varepsilon_2^{(+)}(\%)$	0.48(0.04)		
Compression strain to failure, $\varepsilon_1^{(-)}(\%)$	1.84(0.18)		
Compression strain to failure, $\varepsilon_2^{(-)}(\%)$	2.12(0.26)		
Shear strain to failure, $\gamma_{12}\,(\%)$	1.30(0.32)	1.46(0.28)	

NOTES:
RT- room temperature
T60- temperature T=+60C
T40- temperature T=-40C
SW1- conditioned in salt water for 6 month
SW2- conditioned in salt water for 12 month

Fatigue lifetime can be predicted using statistical stiffness degradation measurements. This method has been already used by several authors, that we can find in literature. The methods are acknowledged, and will be utilized and further developed to account for particular applied conditions. Further, the damage mechanics based modelling can be utilized to connect statistical stiffness degradation measurements to particular damage mechanisms acting on macro and micro scale. This approach is on its development stage. The isothermal formulation for laminates of particular lay-up only is available for the moment. It is generalized for arbitrary laminate, subjected to isothermal environmental conditions.

A corresponding test program is compiled that renders all the necessary data for characterization of considered mechanical properties at selected extreme conditions. The experiments have been carried out, and the damage evolution law for corresponding damage mode can be characterized experimentally at different environmental conditions. The fibre fracture in the UD material at static tensile loading conditions is described with corresponding damage tensor, and it’s values are measured experimentally, see Figure 9a. Further the quantified damage tensor is used into the damage dependent constitutive law of the laminate, and the strain stress behaviour is described, see Figure 9b. That way, the validity of the general formulation of the approach is conformed, and will be used for other damage modes for different extreme conditions.



a) b)

Figure 9:

The Micromechanics approach is developed that predicts the damage evolution law, and will be compared with experimentally measured.
SEM work is curried out in order to identify the damage mechanisms, and work is still in progress as much as input for the modelling is needed.

Comparison of planned activities to accomplished work

Considerable time was needed for the initial phase of defining the standard Optimat specimens. Drafting of the DPA has taken much more time than anticipated, amongst others due to the time that was needed before formal approval was given by the SC. All the preparation work is accomplished, and testing of basic material has been curried out, and it is still in the progress. The testing and analysis of the basic material is planned to be accomplished Apr. 2004.

Planned activities for the next period

The testing of reference material at extreme conditions will continue according to the updated time planning. The phenomenological modeling and damage analysis will continue parallel with testing. The first phase is expected to be accomplished on Apr. 2004.

Deliverables

The produced deliverables are listed in Table 6 “List of Deliverables”.

Table 6:	List of Deliverables			
No	Deliverable title	Form	Date	Document
1	Test report describing the material, laminates and fatigue tests	Report	5	OB_TG3_R005
2	Microstructural model and identification of degradation parameters.	Report	5	OB_TG3_R006
3	Definition of extreme conditions and procedures for testing under extreme conditions.	Report	5	OB_TG3_R004
7	DPA for phase 1	Report	6	OB_TG3_O003
9	Approved DPA for phase 1	Report	6	OB_TG3_O004
12	Phenomenological micromechanics models for sensitivity analyses.	Report	18	OB_TG3_R014
21	Effects of extreme conditions on properties of the reference material	Report	26	OB_TG3_R015
22	Effect of environmental ageing on reference material (report)	Report	26	OB_TG3_R016

Pre-draft version of Design Recommendations

No modifications have been made to the pre-draft version presented in last year’s report.

DETAILED REPORT FOR TASK GROUP 4

Short description of TG4 WPs

The following work packages are part of the work within task group 4

WP 10 Comparison of thin and thick plate properties
This WP has as the objective to establish the accuracy of thin-walled theory for the thick to very thick laminates as found in wind turbine blades. This is done by comparison to finite element calculations and test results of thick flat plates.

WP 11 Repair of highly loaded flat blade parts
This WP has as the objective to implement suitable repair methods that will bring back functionality and strength to the blades by benchmarking and verification on small components

Specific objectives for this period

The specific objectives for this reporting period were:

WP 10

- Production of thick specimens. These thick specimens have the same geometry as the thin specimens, with all dimensions multiplied with a factor of five
- Start with testing of thick specimens in the 2500 kN test bench of WMC.

WP 11

- Production and test of repaired specimens.

Overview of technical achievements

WP10 Thick laminates
Since production of thick specimens was scheduled at the end of test specimen production, no thick specimens were available in the reporting period and testing has not yet been done.

WP11 Repair
CRES has tested and reported the first series of repaired specimens. It appeared that the strength of the repaired specimens is about 65% of the reference specimens. Since the target strength for repairs within the Optimat project has been defined as 80% the investigated repair technique parameters produce results below the set standards.

Comparison of planned activities to accomplished work

As is general for all task groups in the project also in TG4 the actual testing was delayed due to the unavailability of test specimens.
Also the analysis work in WP10 is delayed because of the unavailability of the complete material characterisation.
The over-allocation of the 2500 kN test bench at WMC may require some re-scheduling of the tests on the thick specimens.

Planned activities for the next half-year period

In the next period, the test specimens will become available and hence testing will continue.
Preparatory work will be done for the FEM analyses in WP10.

WMC will test the first series of repaired specimens from Polymarin and CRES will continue testing the next series of repaired specimens from Gamesa and repaired specimens from LM

Deliverables

The deliverables due for the work packages in this task group are:
WP10
Deliverable number 4: Definition report of typical thick laminate, due month 5.
The definition of typical thick laminates and the background for arriving at this definition are part of the DPA for Task group 4. This document also incorporates the test plan for work package 10. The document is available from the OPTIMAT blades website as OB_TG4_R001 - COMPLETE

WP11
Deliverable number 5: Suitable repair techniques for small specimens, due month 5.
The report *"Repair techniques for composite parts of wind turbine blades"* by D.J. Lekou and P. Vionis, Optimat blades nr: OB_TG4_R002, is available on the Optimat blades website - COMPLETE

CRES prepared a report (OB_TG4_R006) containing results from long reference and 1st set of repaired specimens:
D.J. Lekou *"Results of Static tests on Long MD Specimens"* Report OB_TG4_R006 rev.000 - [8] COMPLETE

See also the list of documents in Annex I.

- Specimens by GAMESA tested in static tension at CRES
- Specimens by POLYMARIN to be tested at WMC

Pre-draft version of design recommendations

No modifications have been made to the pre-draft version presented in last year's report.

DETAILED REPORT FOR TASK GROUP 5

Short description of TG5 WPs

Work Package 13 (Residual Strength and Condition Assessment) has the objective to establish engineering models to account for the reduction in residual static strength and material lifetime induced by cyclic loading. This is to be achieved through a programme of specimen testing on the reference OPTIMAT Blades material and the evaluation of suitable condition monitoring strategies for blade materials subjected to fatigue loading.
Work Package 14 (Residual Strength of Alternative Materials) will validate the engineering models developed in WP13 by comparing theoretical predictions and experimental data from alternative materials.

Specific objectives for this period

Only WP13 is relevant to the reporting period.
The specific objectives within WP13 for the reporting period were as follows:

- Execution of bulk of WP13 test programme
- Evaluation of results from condition monitoring techniques

Overview of technical achievements

Testing
The test plan requires fatigue testing of the reference OPTIMAT Blades materials at three constant amplitude load levels (intended to result in nominal lifetimes of 10^3, $5x10^4$, 10^6 cycles) for three R-ratio values (0.1, 1.0, -1.0) and periodically extracting a set of test coupons at given fractions (20%, 50%, 80%) of the nominal lifetime for proof-testing and subsequent testing to failure (i.e. residual strength test). 8 coupons will be tested at each test point (4 compressive strength; 4 tensile strength); the testing requirements are shared between 5 institutions. Additional testing will be carried out up to 10^7 cycles for a limited number of test coupons. Two basic lay-ups (UD and MD) are to be tested (compared to the single Phase 1 material envisaged in the proposal).
Testing on the main part of the WP13 test programme has been severely delayed initially due to:

(i) lack of specimens within the project as a whole and
(ii) delays within TG1 and TG2 in evaluating and signing off the basic S-N curves to allow the definition of suitable lifetime loading conditions.

Full S-N characterisation is now available for the MD material. Other Task Groups have reported ongoing difficulties in establishing the S-N characterisation for the UD material in the longitudinal direction for the fatigue stress ratio R=10 and in the transverse direction for R=0.1.
The MD test programme has now started and is proceeding. The UD test programme continues to cause problems due to unexpected early failures during the fatigue phase.

Comparison of planned activities to accomplished work

The main test matrix for WP13 (Task 13.2) was originally scheduled to commence in project month 6 and proceed for 18 months. The start of this testing has been effectively delayed by 18 months behind the original schedule. Current estimates, based on the refined test matrix in the DPA, are that the test programme will require *at least* 15 months of continuous rig test time for some partners (assuming no significant problems). The development of a suitable modelling framework (Task 13.4) has already begun and will continue in parallel with the tests; it should be possible to complete and report on this task within 1 month of the end of the test programme. Assuming all partners started serious testing in December 2003 (project month 24), completion of WP13 cannot be expected before project month 39. A safety margin of an additional 3 months should be allowed for problems in rig scheduling, qualified manpower availability, servicing of test rigs, etc. It is therefore likely that WP13 will extend until project month 42.

Planned activities for the next half-year period

For each material (UD-longitudinal, UD-transverse, MD)/R-ratio (0.1, -1.0, -10) combination, TG5 must carry out a set of tests at each of 3 discrete load levels, corresponding to the nominal target lifetimes (1.0e3, 5.0e4, 1.0e6) [plus, for UD longitudinal and MD material, limited tests at the load corresponding to a target lifetime of 1.0e7].
There will be 8 specimens at each material/R-ratio/nominal lifetime/life fraction "test point", 4 to be residual strength tested in compression, 4 in tension. Due to a decision of the partners, these specimens will always be equally split between 2 laboratories, meaning that each will fatigue 4 specimens to each test point and then test 2 to failure in compression and 2 in tension.
During the next 6 months, priority will be placed on the shorter nominal target lifetime (1.0e3, 5.0e4, 1.0e6) tests, to establish as full a test matrix at as early a stage as possible.

Deliverables

- D6 Review of existing residual strength predictive models (report) – COMPLETE
- D24 Experimental data base from residual strength tests (report/CD) – Due Month 26, Expected Month 42
- D25 Validated engineering model for residual strength prediction (report) – Due Month 26, Expected Month 42
- D26 Validated engineering model for residual life evaluation and strategy for condition assessment – Due Month 26, Expected Month 42

Pre-draft version of design recommendations

No modifications have been made to the pre-draft version presented in last year's report.

7. EXPLOITATION AND DISSEMINATION OF RESULTS

Although only limited experimental results have become available to date, which are not yet appropriate for extensive publication, some overview presentations explaining the purpose and set-up of the project were given on various conferences to make the composites and wind energy communities aware of the foreseen experimental efforts. In addition, results of the analysis methods benchmark were published. These publications are listed in Annex I of this report, and are accessible via the OPTIMAT website.

Table 7: Overview of OPTIMAT publications

Authors	Title	Conference	Remarks
O. Krause, Ch.W. Kensche, R.P.L.Nijssen, T. P. Philippidis, A.P. Vassilopoulos	A BENCHMARK ON LIFETIME PREDICTION OF COMPOSITE MATERIALS UNDER FATIGUE	European Wind Energy Conference 2003 (EWEC 2003), 16-19 June 2003, Madrid, Spain	
A.M. van Wingerde , R.P.L. Nijssen, D.R.V. van Delft, L.G.J. Janssen , P. Brøndsted , A.G. Dutton , J.J. Heijdra, C.W. Kensche , Th. P. Philippidis , T.K. Jacobsen	Introduction to the OPTIMAT BLADES project	idem	Associated poster won outstanding poster award
R.P.L. Nijssen, D.R.V. van Delft, P.A. Joosse, A.M. van Wingerde, C. W. Kensche, T. P. Philippidis, P. Brøndsted, A.G. Dutton	OPTIMAT BLADES - OPTIMAL AND RELIABLE USE OF COMPOSITE MATERIALS FOR WIND TURBINES -	14th International Conference on Composite Materials (ICCM-14), July 14-17, San Diego, CA	
R.P.L. Nijssen	Spectrum Loading in Wind Turbine Rotor Blade Composites	Chemical and Engineering Seminar (J. Mandell) September 17th, 2003, Montana State University, MT	no publication available
Brøndstedt, P., Peltola, E., van Wingerde, A., van Hemelrijck, D.	Properties of blade materials under extreme conditions	BOREAS VI, Wind Energy Production in Cold Climate, April 9-11, 2003, Pyhätunturi, Pyhä, Finland	

8. MANAGEMENT AND CO-ORDINATION

In the previous progress report [1], the management and organisation were described in some detail and the need for the Project Co-ordination Committee was explained. This organisational structure has worked much to the satisfaction of all participants.

CONSORTIUM AGREEMENT

There have been no changes to the consortium agreement.

CONTRACT MODIFICATIONS TO ANNEX I "DESCRIPTION OF WORK"

There were no modifications to Annex I during the reporting period. The financial overview is given in Annex III to this report.

However during the last progress meeting at VTT in Finland of the Optimat Blades project Dec. 2003, LM gave a presentation on their activities in Working Package 16.1 Production of small specimens for Phase 1 of the project.
WP 16 is planned, to be carried out entirely by the industrial partners of the project.

The Detailed Plans of Activities for Phase I of the five Task Groups require about 4170 small test specimens. This is a lot more than we anticipated for during the Project Definition Phase in 2001.

On behalf of the industrial partners LM is producing all these small test specimens. According to the budget available to LM (this budget was shifted from Polymarin to LM in an earlier stage of the project) they should produce these test specimens within about 4 person months (600 hours). This means that they have available about nine minutes per specimen, which is completely insufficient to produce the required large number specimens with the quality and accuracy that is needed for the project. LM has also taken over the production of the tubular specimens, which were to be produced by Nordex.

Until now LM produced and delivered 2400 specimens and spent about 17 person months (5) for engineering and (12) for production. To produce all 4170 LM will require about 30 person months. LM feels that they are taking a very large effort on behalf of the other industrial partners. The management of LM has indicated that this effort is unacceptable for them and they will stop the production if the available budget is not increased. This would jeopardize the whole project.

It was clear to everyone present at the progress meeting in December that LM is entitled to a higher budget for this effort.

Taking into account that the specimen production is an industrial task in this project and looking at the manpower matrix (table 4.1) of Annex I, Description of Work, it can be seen that all industrial partners have about 2 person months available for the production of test specimens for Phase II (WP16.2) of the project (in total 12 person months). However the number of specimens needed for this second Phase will be lower than the number of specimens that we are testing in Phase I.

Therefore it is proposed:

1. To transfer from Vestas, Nordex, GE (Enron) and from LM itself 1 person month from WP 16.2 to the WP 16.1-budget of LM.
2. Vestas has available 1 person month for the production of specimens for WP 8. However LM has produced these specimens too. Therefore this person month can be shifted to LM too.
3. Gamesa and Polymarin are producing large test specimens in Phase 1 and will do the same in Phase 2. They both require the available person months for specimen production to fulfil their obligations in this.

4. All industrial partners have available 2 person months for WP1, Steering Committee. As as can seen now the effort necessary for the Steering Committee is limited until now, most of the steering effort for the project is taken care of by the co-ordinators. Therefore it is proposed to shift also 1 person month from each industrial partner from WP1 to the WP 16 budget of LM.
5. LM itself has 6 person months for the Steering Committee. From this budget about 3 person months can be shifted from WP 1 to WP 16.1.

In doing so, 13 person months will be shifted to the production of the small test specimens for Phase I. Due to the fact that the hourly rates of the personnel planned for the activities in WP 1 are higher than the hourly rates of the LM personnel carrying out the small test specimens production in WP 16 somewhat more extra person months will be available for this production.

All industrial partners agreed to the proposed budget transfers. And the LM management stated that LM will continue the specimen production for WP16 according to the presented specimen production plans available at the general meeting at VTT in December 2003 and the proposed budget transfer scheme.

Proposed transfers:
From Vestas: 1 PM engineering WP1 and 2 PM technicianWP16 to LM, WP16.
From GE: 1 PM engineering WP1 and 1 PM technician WP16 to LM, WP16.
From Gamesa: 1 PM engineering WP1 to LM, WP16
From Nordex: 1 PM engineering WP1 and 1 PM technician WP16 to LM, WP16.
From Polymarin: 1 PM engineering WP1 to LM, WP16.
LM 3 PM WP 1 to WP 16.
In the table 8 the budget transfers are presented

Table 8: Budget transfers (excluding the original 4 person months from Polymarin)

Partner	Tariff Engineer [€/h]	Tariff Tecnician [€/h]	Transfer WP 1 [PM]	Transfer WP 8/16 [PM]	[h/PM]	Total budget [€]	EU contri. [%]	Contri. EU [€]
Vestas	55.88	55.88	1	2	135.67	22,743.-	45.00	10,234.-
GE	84.00	63.00	1	1	140.00	20,580.-	49.07	10,099.-
Gamesa	94.14	72.00	1	0	146.67	13,807.-	47.30	6,531.-
Nordex	120.00	80.00	1	1	135.67	27,133.-	38.25	10,378.-
Polymarin	100.00	68.00	1	0	140.00	14,000.-	47.50	6,650.-
LM	71.00	42.00	3	1	130.00	33,150.-	50.00	16,575.-
Total						**131,414.-**		**60.467.-**

All tariffs are based on the year 2002

Since LM has a 50% contribution from the EU, the extra budget available for LM is twice the EU contribution, € 120,935.-
In PM's this amounts to about 5 PM engineering and 14 PM technician. LM had available already 1 PM engineering and 3 PM technician for the small specimen production in phase 1, so in total LM will have available 6 PM engineering and 17 PM technician.

These transfers are on top of the transfer of the 4 person month from Polymarin to LM that were approved earlier.

This request for budget transfer has been forwarded to the scientific officer but has not yet been approved.

WEB SITE ORGANISATION

Currently, the online document archive contains some 170 documents. Also, the database OptiDAT, has been regularly updated and now contains data for over 1000 static and fatigue tests, mostly benchmark data.

CHANGES IN PARTNERS

On May 6 2002 we were informed that General Electric Company had acquired Enron Wind Turbine Business. In connection therewith General Electric has taken over the contractual relationship in our contract. The new partner in the project is: GE Wind Energy GmbH. All partners agreed to this change in the contract. In fact GE-Wind already signed the consortium agreement as a partner in the project. Due to a misunderstanding this change has not been formalized yet.

On November 17 2002 we were informed on the bankruptcy of Polymarin BV. During the progress meeting in December in Stuttgart it was announced that the activities of Polymarin BV had been taken over by Polymarin Beheer BV and that Polymarin Beheer BV would like to continue the involvement in the Optimat Blades project. All partners agree on the continuation of the activities of Polymarin by Polymarin Beheer BV.

The Technical Coordinator and initiator of the Optimat Blades project is the WMC-Group of the Faculty for Civil Engineering and Geosciences, CiTG, of Delft University of Technology. The group worked for many years in close cooperation with ECN.
The TU-Delft and ECN consider the activities of the group as very important, however they are not considered as core activities of the faculty CiTG. Therefore it has been decided that the WMC-Group will continue its work in a new foundation "Knowledge Centre WMC". This foundation has been established by TU-Delft and ECN. With its links to both organisations the new Knowledge Centre-WMC can continue to combine fundamental and applied research on wind turbine and FRP structures.
All activities from the (former) WMC-Group are being transferred to the new foundation, including the people that are carrying out the work. The transferred activities also include the work for the Optimat Blades project. This means contractually a new partner in the project. None of the partners in the project has objections against these modifications in the project.

KC-WMC and Polymarin Beheer BV already sent the information necessary to formalize the change to the scientific officer. The changes are not formalized yet.

Co-operation with University of Southampton
An endorsement by all partners of OPTIMAT was requested by Geoff Dutton on behalf of the University of Southampton, and agreed on by all partners. The co-operation involves a limited data access by UoS to the OPTIMAT data generated by RAL. The project work of RAL will have a considerable benefit from the activities of UoS.

TIME SCHEDULE

Due to all the drawbacks in defining the shape of the test specimen, for which two preliminary test series and extensive discussions were needed and the establishment of the test programme, the project is confronted with a delay of several months in this start-up phase. Furthermore, the delay in test specimen production resulted in additional delays. A more detailed time schedule has been produced on the basis of the input of all task leaders. From the revised time schedule for the first phase, figure 10, a delay of ten months is expected. Therefore it is proposed to extent the project with ten months.

And at the same time it is proposed to shift the first and second EU-assessment with the three months, so the assessment reports can be merged with the 18 and 36 months progress reports respectively. The proposed adapted time schedule for the second phase is given in figure11.

From information of the scientific officer it is clear that the extension issue has to be discussed during the midterm assessment. This midterm assessment meeting was according to the original work program foreseen to take place in April 2004. Due to the delays, the midterm assessment is postponed until December 2004. The scientific officer approved this postponement under the condition that at this date all the milestones will have been reached, which should have been attained before the MTA date according to the original work program.

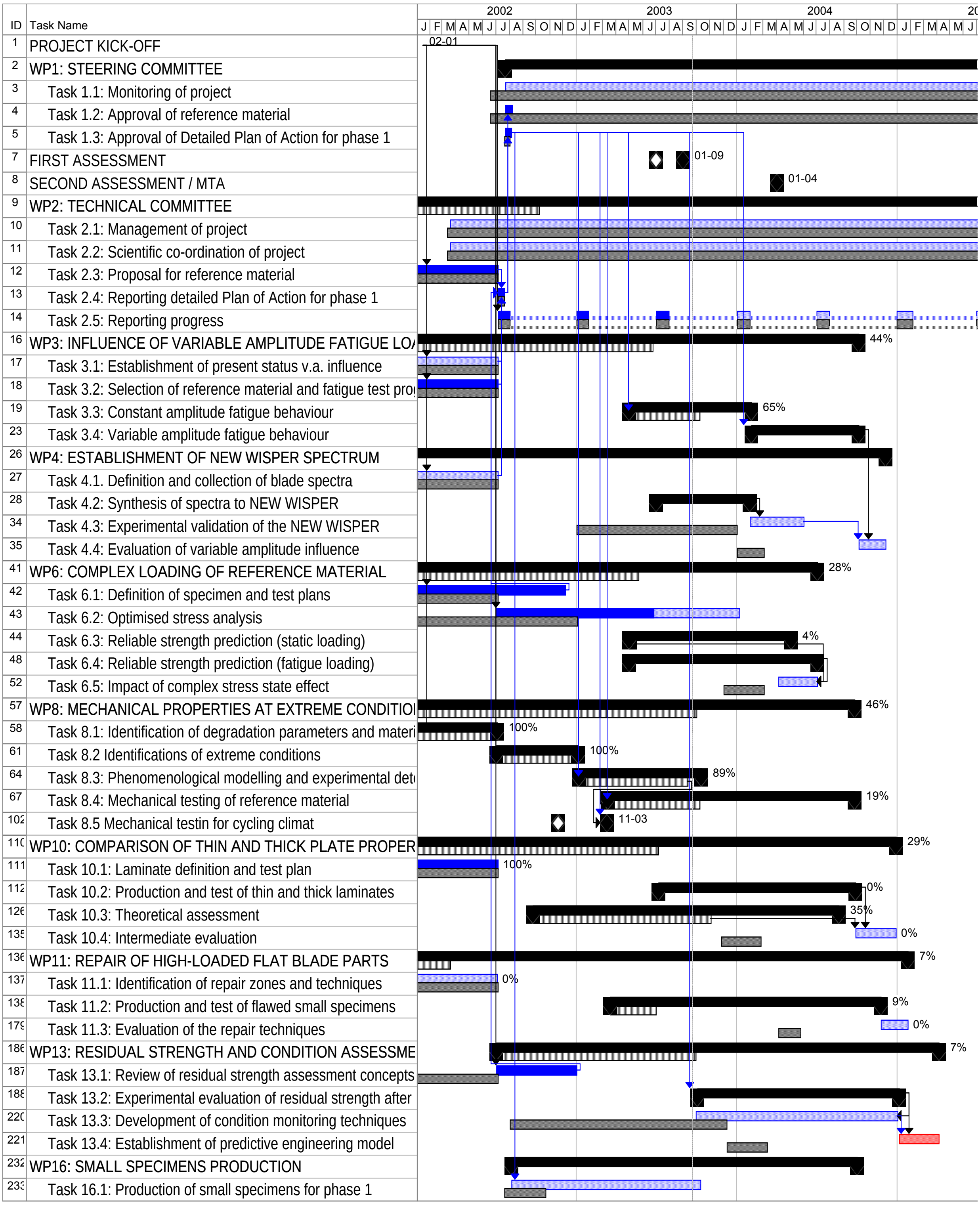


Figure 10: Time schedule Phase 1

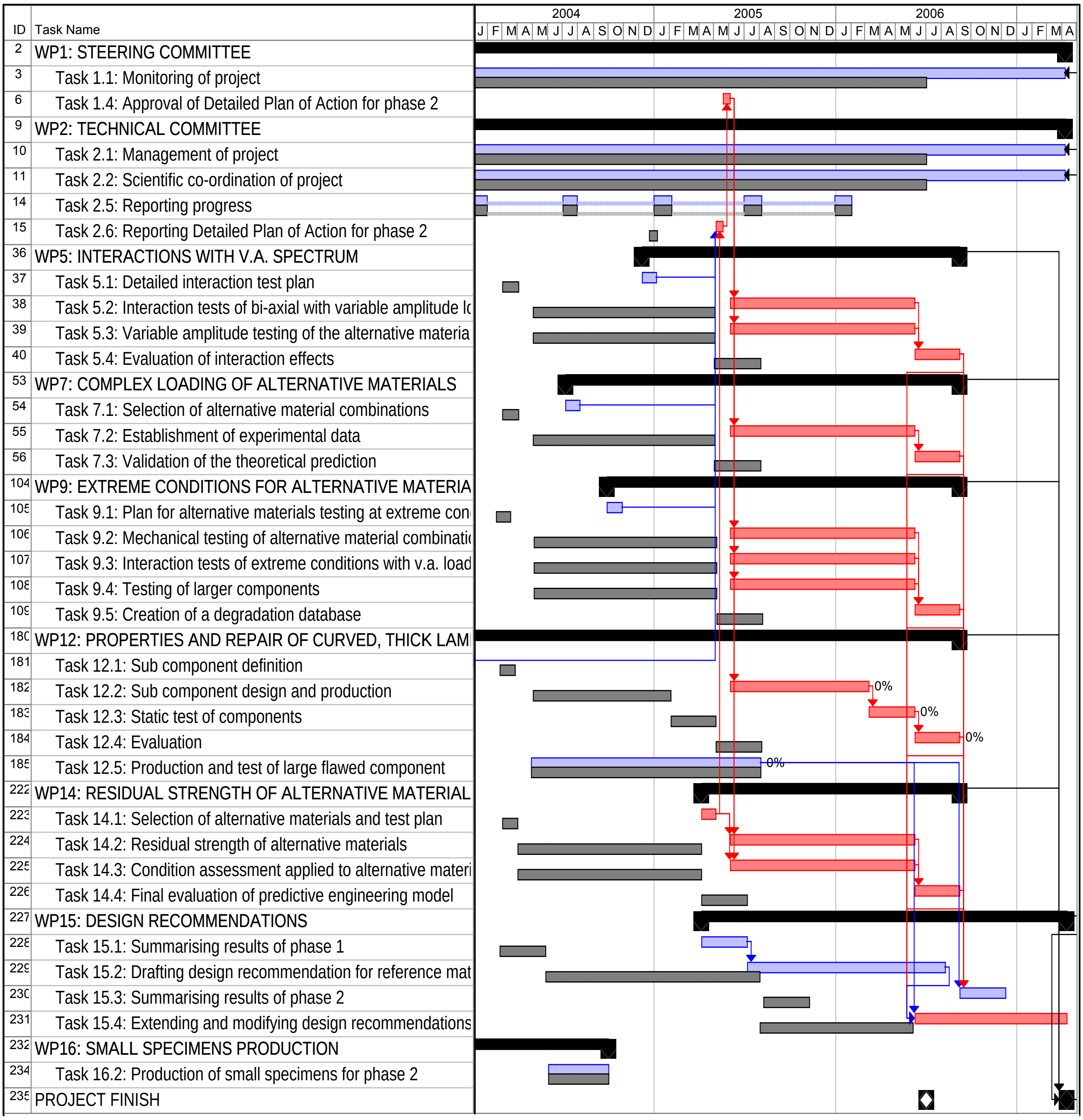


Figure 11: Time schedule Phase II

9. REFERENCES

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6. A. Smits, D. van Hemelrijck, "Test Results biaxial tests on cruciform specimens", OB_TG2_R016.pdf, rev 000, Februari 2004.
7. OB_TG2_R015, Comparison between uni-axial and bi-axial stresses. To be published.
8. D.J. Lekou "Results of Static tests on Long MD Specimens" Report OB_TG4_R006 rev.000, November 2003.
9. Annex I "Description of Work" OB_PC_O005

10. ANNEXES

ANNEX I: OVERVIEW OF REPORTS DELIVERED

The table below shows all new documents that were uploaded to the document archive in 2003 (revisions to earlier documents are not shown).

upload order	Report number	Task	Title	upload by
1	OB_SC_M002	SC	Minutes of 2nd SC meeting	LM
2	OB_TG4_N006	TG4	Time planning phase 1	TUD
3	OB_TG4_M001	TG4	Minutes of the 2nd plenary meeting	TUD
4	OB_PC_O010	PC	Cost Statement	ECN
5	OB_TC_M004	TC	Minutes of 4th Technical Committee Meeting	TUD
6	OB_PC_O011	PC	Guidelines for reporting	ECN
7	OB_TC_N006	TC	Cover pages OPTIMAT Blades	TUD
8	OB_TG5_M002	TG5	Minutes of 1st TG5 meeting	RAL
9	OB_TG5_M003	TG5	Minutes of 3rd TG5 meeting	RAL
10	OB_TG3_N001	TG3	List of specimens to be manufactured for WP8	RISØ
11	OB_TC_R008	TC	Preliminary tests Part 1	TUD
12	OB_TG2_R006	TG2	Biaxial testing of fibre reinforced composites	VUB
13	OB_TG2_R007	TG2	Preliminary test results of cruciform test specimens	VUB
14	OB_TG2_R008	TG2	Proposals for new geometries of cruciform specimens	VUB
15	OB_TG2_R009	TG2	Proposals for new geometries of cruciform specimens	VUB
16	OB_TG2_R010	TG2	FE analyses of new geometries of cruciform specimens	ECN
17	OB_TC_R009	TC	Preliminary tests.	UP
18	OB_PC_M002	PC	Minutes of the second PCC meeting	ECN
19	OB_TG4_N007	TG4	Shopping list for TG4	TUD
20	OB_TG4_N008	TG4	Shopping list for TG4	TUD
21	OB_TG2_R011	TG2	Yearly report (2002)	UP
22	OB_TG2_O001	TG2	ZIP Yearly reports	UP
23	OB_TG5_R002	TG5	Recommended procedure for conducting OPTIMAT Blades residual strength test	RAL
24	OB_TG3_R003	TG3	Yearly report, 2002	RISØ
25	OB_TG1_R002	TG1	Yearly report of TG1	DLR
26	OB_TG1_M001	TG1	Minutes of 2nd plenary meeting	DLR
27	OB_TG4_O003	TG4	Repair of Composite Laminates	TUD
28	OB_TG3_R004	TG3	Extreme conditions	RISØ
29	OB_TG3_R005	TG3	Test plan report	RISØ
30	OB_TG3_R006	TG3	Microstructural model and identification of degradation parameter	RISØ

31	OB_PC_R003	PC	Annual progress report 1st year	ECN
32	OB_TG5_R003	TG5	Review of residual strength predictive models	UP
33	OB_TC_R010	TC	Identification of Specimens	LM
34	OB_TG2_R012	TG2	Static and Fatigue Tests of OPTIMAT UD coupons.	UP
35	OB_PC_O012	PC	OPTIMAT overview paper for ICCM14 conference	TUD
36	OB_TG5_R004	TG5	Static testing of OPTIMAT UD specimens	RAL
37	OB_TG3_R007	TG3	Static tests of UD and MD apecimens using ISO geometries	RISØ
38	OB_TG5_R005	TG5	Static testing of OPTIMAT MD specimens	RAL
39	OB_TC_O004	TC	Poster EWEC 2003	TUD
40	OB_TC_R012	TC	Introduction to the OPTIMAT BLADES project	TUD
41	OB_TG1_R004	TG1	Static tests of Optimat MD and UD coupons	DLR
42	OB_TG1_R005	TG1	Benchmark on Lifetime Prediction	DLR
43	OB_TG5_A004	TG5	Agenda for TG5 meeting	RAL
44	OB_TG5_M004	TG5	Minutes of 4th TG5 meeting	RAL
45	OB_TC_M005	TC	Minutes of 5th Technical Committee Meeting	TUD
46	OB_PC_M003	PC	Minutes of the General Project Meeting	ECN
47	OB_TG2_R013	TG2	Static and Fatigue tests on the standard OB UD coupon	UP
48	OB_TG5_N001	TG5	S-N curve specification and temperature	RAL
49	OB_TG3_R008	TG3	Assessment report	RISØ
50	OB_TG2_R014	TG2	Assessment Report for 18 month period	UP
51	OB_TG1_R006	TG1	Benchmark Tests Standard OPTIMAT UD Specimen	DLR
52	OB_PC_R005	PC	Technological Implementation Plan	ECN
53	OB_PC_R006	PC	Time schedule	ECN
54	OB_PC_R007	PC	Time schedule	ECN
55	OB_TC_R013	TC	Load levels for CA testing	TUD
56	OB_TG4_R006	TG4	Results of Static Tests on Long MD specimens	CRES
57	OB_TG3_R009	TG3	Measurements of in-plane shear properties of GEV206 at ambient room conditions using V-notched beam test specimen	RISØ
58	OB_TG3_R010	TG3	Measurements of in-plane shear properties of GEV206 at ambient room conditions using 30-off axes test specimen	RISØ
59	OB_PC_A003	PC	Agenda of PCC meeting VUB	ECN
60	OB_TG5_R006	TG5	Benchmark testing TG5: static tension and compression tests	VUB
61	OB_PC_R008	PC	Fatigue tests of the UD reference material (GEV206-D02-00) using Ris geometry for the test coupons	RISØ
62	OB_TG3_R012	TG3	Fatigue tests of the UD reference material (GEV206-D02-00) using Ris geometry for the test coupons	RISØ
63	OB_TG3_R013	TG3	Fatigue tests of the MD reference material (GEV207-D02-00) using Ris geometry for the test coupons	RISØ
64	OB_TG1_R007	TG1	Test Results of Benchmark Static Tests on UD & MD coupons	CRES

65	OB_TG1_R008	TG1	Test Results of benchmark Fatigue Tests on UD coupons	CRES
66	OB_TC_O005	TC	Buckling of standard OB UD coupon in compression	UP
67	OB_TG2_O002	TG2	Static and fatigue tests of OB UD coupons at 0 and 90 deg.	UP

ANNEX II: OVERVIEW OF EXPERIMENTAL PROGRAMME FOR PHASE 1

Introduction

This document is a compilation of the experimental work scheduled within the DPAs (Detailed Plan of Action) of the five task groups TG1 to TG5, which carry out the experimental, numerical and analytical work within the Optimat Blades project.
The DPAs themselves are available on the Optimat website for the members of the consortium.

In order to present the tests in a more coherent way, the tests are grouped in subjects per table. Each line represents a certain kind of test, carried out on UD (uni-directional), MD (multi-directional) or "other" (for instance ±45°) material by the five task groups.
This representation has enabled the task leaders to eliminate duplicate tests within the various TGs, allowing them to optimise the experimental programme.

Over 2500 tests are foreseen in Phase I of the project, even after duplicate tests have been eliminated, hence it is worthwhile to eliminate overlap.

Since the number of tests is high, the various TGs will try to limit the number of tests even further, depending on the outcome of the tests carried out.

Notation

EXPLANATION	
AB, BA	Denotes possible sequence variations in 2 block tests with 2nd block to failure, e.g. 1st block R=0.1, 2nd block R=0.5 and vice versa.
C	Compression static
C-C	Compression-Compression fatigue
HL	1st block = high amplitude 2nd = low amplitude (block tests with 2nd block to failure)
HML	1st block = high amplitude, 2nd = medium amplitude, 3rd = low amplitude (block tests with 3rd block to failure)
IPS	In-plane Shear
LH	1st block = low amplitude 2nd = high amplitude (block tests with 2nd block to failure)
LMH	1st block = low amplitude, 2nd = medium amplitude, 3rd = high amplitude (block tests with 3rd block to failure)
MD	Multi-Directional laminate
MUD	Uni-Directional specimen with ±45° face layers
NW	New WISPER
NWX	New WISPERX
RW	Reversed WISPER
RWX	Reversed WISPERX
T	Tension static
T-C	Tension-Compression fatigue
T-T	Tension-Tension fatigue
UCS	Ultimate Compressive Strength
UD	Uni-Directional specimen (no +/-45° face layers)
UTS	Ultimate Tensile Strength
W	WISPER standard loading sequence
WX	WISPERX standard loading sequence

Static tests on Optimat standard test specimens

The Static tests not only serve to establish the static properties, but also as a starting point for the S-N line and residual strength tests and static tests under extreme conditions.

Static Tests on Optimat Blades specimens

lay-up	Test	Type of test	UD TG1	UD TG2	UD TG3	UD TG4	UD TG5	MD TG1	MD TG2	MD TG3	MD TG4	MD TG5	±45° (shear/tubes) TG1	±45° TG2	±45° TG3	±45° TG4	±45° TG5	Remarks
Axial (//)	T		15	25	5	3	10	20		5	3	10						
	C		15	25	5	3	10	20		5	3	10						
Transverse (⊥)	T			25	5	3				5	5							
	C			25	5	3				5	5							
10°	T			5					5									
	C			5					5									
60°	T			5					5									
	C			5					5									
30°	T				5													
Axial (//)	T	40°/-60°/100%			10					10								
	C	40°/-60°/100%			10													
30°	T	40°/-60°/100%			10													
Transverse (⊥)	T	40°/-60°/100%			10													
	C	40°/-60°/100%			10													

Tests for task group 3: at +60°C/-40°C/ 100% Relative Humidity (the latter series being immersed in water for one year, prior to testing)

Static tests on ISO/ASTM standard tests specimen

As mentioned in the test specimen proposal, we also need standard tests, that are expected to give a close approximation of the material properties, to relate to the Standard Optimat Specimen results.

Static Tests on ISO/ASTM specimens

lay-up	Test	Type of test	UD TG1	UD TG2	UD TG3	UD TG4	UD TG5	MD TG1	MD TG2	MD TG3	MD TG4	MD TG5	±45º (shear/tubes) TG1	±45º TG2	±45º TG3	±45º TG4	±45º TG5	Remarks
Axial (//)	T	all cond.			15					15				25				5 with tabs, 10 w/o tabs
	C	all cond.			15					15								5 with tabs, 10 w/o tabs
Transverse (⊥)	T	all cond.			15					15								5 with tabs, 10 w/o tabs
	C	all cond.			15					15								5 with tabs, 10 w/o tabs
Thickness	C					20												
Shear	IPS					5												
	13					5												
	23					5												
4 Point Bending						5					5							
Shear	IPS	40°/-60°/100%			30													
Hygro Thermal	α_1			25														
	α_2			25														
30°	T				15													NB: 30° lay-up, axial test

In order to obtain ply results, UD is deemed necessary for transverse and shear tests.
Tests for task group 3: are carried out at ambient conditions. +60°C/-40°C/ 100% Relative Humidity (the latter series being immersed in water for one year, prior to testing)

We intend to use:

- ISO 527-5 for tension
- ISO 14125 for 4-point bending
- ASTM 5379 (Iosipescu) for shear
- ASTM D 6641 (combined loading at ends and sides of the test specimen) for compression, see Figure 1.

Figure 1 Wyoming combined loading test set-up

Static tests on special test specimens

A number of tests are carried out on special test specimens, for instance 2-dimensional tests (cruciform and tubes) tests for TG2, and test on thick and repaired laminates for TG4.

Static Tests on special test specimens																		
			TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	
lay-up	Test	Type of test	UD					MD					±45º (shear/tubes)					Remarks
2D test specimens [2]																		
2D stress state		Cruciform							15									
		Tubes												15				
Long test specimens as reference for repaired specimens [4]																		
Axial (//)	T-T										20							
Bending	T up																	
	C up										20							
Repaired test specimens [4]																		
Axial (//)	T																	
(long spec.)											120							
Bending	T up																	
(long spec.)	C up										30							
Thick test specimens [4]																		
Axial (//)	T					5					5							
	C					5					5							
Transverse (⊥)	T					5					5							
	C					5					5							
Thickness	C										20							
	Shear																	
Bending	T up					5					5							
	C up																	
Hygro Thermal	α_1																	
	α_2																	
	β_1																	
	β_2																	
Repaired thick test specimens [4]																		
Axial (//)	T										5							
Bending	T up																	
	C up										5							

For the repaired test specimens, a large number of types are tested. For each industrial partner, currently, 4 types of repair with 5 specimens per repair type are proposed.

For the tests in thickness direction, not only the test in 3-3 direction are included, but also tests in 1-3 and 2-3 direction.

CA fatigue tests

Constante Amplitude Fatigue Tests

lay-up	Test	Type of test	UD TG1	UD TG2	UD TG3	UD TG4	UD TG5	MD TG1	MD TG2	MD TG3	MD TG4	MD TG5	±45º (shear/tubes) TG1	±45º (shear/tubes) TG2	±45º (shear/tubes) TG3	±45º (shear/tubes) TG4	±45º (shear/tubes) TG5	Remarks
Standard Optimat Specimens																		
Axial (//)	0.1	shear on long test	21		30			23		15				15				Riso dogbones; others OP
	0.5							21										
	-0.4							21										
	-1		46		30		20	32		15								Riso dogbones; others OP
	-2.5							21										
	10		21		30			23		15								Riso dogbones; others OP
	2							21										
Transverse (⊥)	0.1			15														
	-1			15														
	10			15														
10°	0.1			10														
60°	0.1			10														
10°	-1								10									
60°	-1								10									
Axial (//)	0.1	40°/-60°/100%			25					25								Riso dogbones; others OP
	0.1	submersed			**10**					**10**								Riso dogbones
	-1	40°/-60°/100%			15					15								Riso dogbones; others OP
	10	40°/-60°/100%			15					15								Riso dogbones; others OP
2D test specimens [2]																		
2D Stress state	0.1	Cruciform							30									
	-1	Tube												45				
Long test specimens as reference for repaired specimens [4]																		
Axial (//)	0.1										15							
Repaired test specimens [4]																		
Axial (//)	0.1										15							
Thick test specimens [4]																		
Axial (//)	0.1					10					10							
	-1					10					10							
	10																	
Repaired thick test specimens [4]																		
Axial (//)	0.1																	

In TG1, 6 tests are used for the preliminary S-N line establishment, followed by 15 tests: 5 tests at 3 stress levels per cell. For R=-1 he wants to double the amount of tests.
Tests for task group 3: at +60°C/-40°C/ 100% Relative Humidity (the latter series being immersed in water for one year, prior to testing)

VA fatigue tests and block tests on Optimat standard tests specimen

Variable Amplitude and Block Fatigue Tests																		
			TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	
lay-up	R	Type of test	UD					MD					±45º (shear/tubes)					Remarks
Standard Optimat Specimens																		
		W	15					15										
		WX	15					15										
		RW						15										
		RWX						15										
		NW	15					15										
		NWX						15										
T-T		AB*						30										
T-C		AB*						10										
C-C		AB*						10										
T-T	0.1	HL						20										
T-C	-1	HL						20										
C-C	10	HL						20										
T-T		AB*						15										
T-C		AB*						5										
C-C		AB*						5										
T-T	0.1	HL						10										
T-C	-1	HL						10										
C-C	10	HL						10										

Residual strength tests on Optimat standard tests specimen

Residual Strength tests																		
			TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	
lay-up	R	Type of test	UD					MD					±45º (shear/tubes)					Remarks
Standard Optimat Specimens																		
Axial (//)	0.1	20/50/80%					72					72					36	
	-1	20/50/80%					72					72						
	10	20/50/80%					72					72						
	0.1	long life					6											
	-1	long life					6					12						
	10	long life					6					6						
Transverse (⊥)	0.1	20/50/80%					72											
	-1	20/50/80%					72											
	10	20/50/80%					72											

In TG5, each cell denotes 8 static tests (4 tension, 4 compression) after 20% / 50%/ 80% of the lifetime at 3 stress levels as found in CA for a total of 72 tests per cell.
For the shear tests, only shear is tested, after 20% / 50%/ 80% of the lifetime at 3 stress levels as found in CA thus the number of tests per cell is 36.

Fatigue and residual strength test programme

After the static properties have been established, the general position of the most critical S-N line (R=-1) will be established by performing tests. Based on this S-N line, **three stress levels** will be selected for the CA fatigue tests, aiming for a fatigue life of 10^3, $4 \cdot 10^5$ and 10^6 cycles. For other R-values, a first estimate will be made, based on the Goodman diagram plus a few preliminary tests to establish three stress levels.

Although it requires some extra tests for establishing the S-N line, there are a number of arguments in favour of the use of fixed stress levels, rather than varying stress levels along the S-N line:

- At these three stress levels the residual strength tests of TG5 will be carried out, after 20%, 50% and 80% of the expected life of the test specimen.
- Also, for limited test series, such as extreme conditions within TG3 and thick laminates within TG4, we can just test at specific stress levels, where a wealth of comparison data

concerning (for instance scatter) at that stress level is available, eliminating the need for conversion.

- The same levels are used for the HL, LH, LMH, HML block tests in TG1.
- Relatively much data is available at the extremes of the S-N line, so that the slope can be determined more accurately.

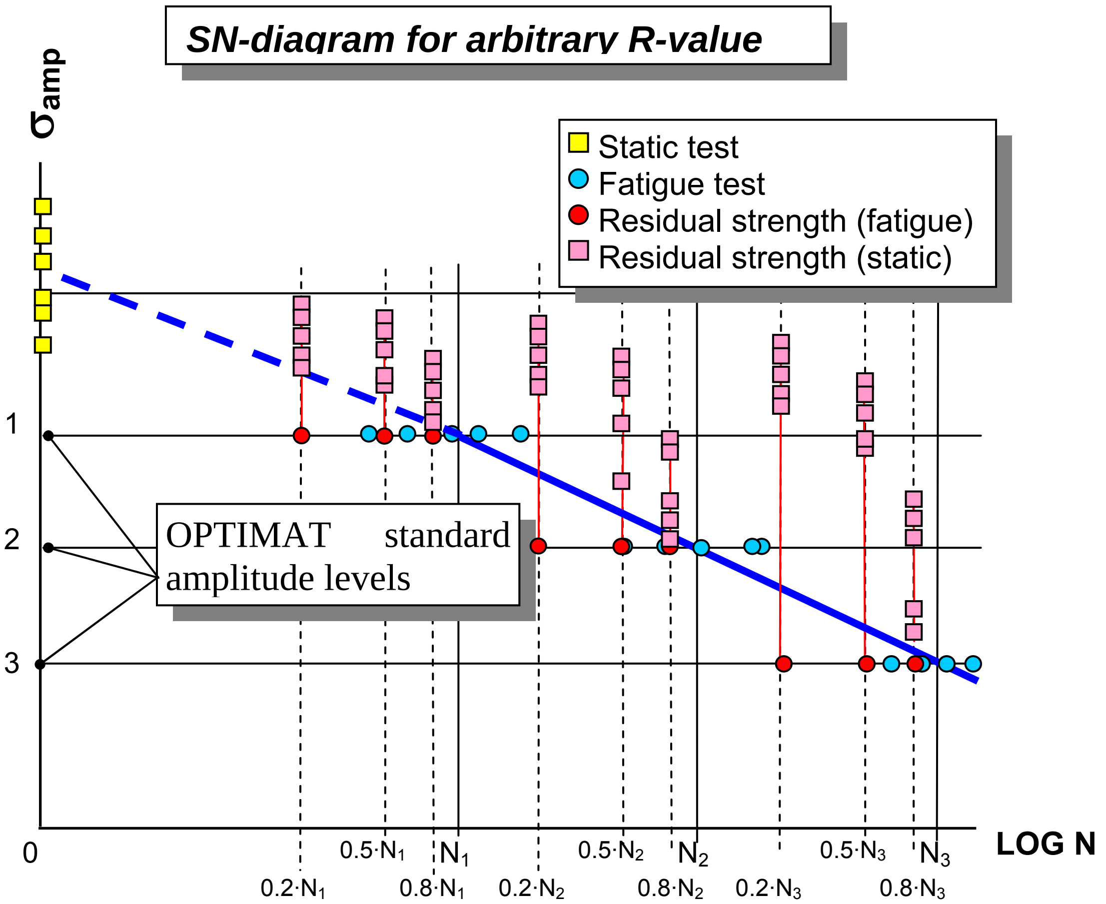

Figure 2 Static, fatigue and residual strength tests

ANNEX III: COST SUMMARY IN EURO

Participant Role (22)	Participant No (23)	Participant Short Name (28)	Number of person/months (29)	Personnel Costs (29)	Durable Equipment (29)	Subcontracting (29)	Travel and Subsistence (29)	Consumables (29)	Computing (29)	Protection of Knowledge (29)	Other Specific Project Costs (29)	Overhead Costs (29)	Total Costs (32)	Costs Basis : FC/FF/AC (29)	% Requested from the Community (29)	Contribution from the Community (29)
CO	1	ECN	26,4	246.422	0	0	22.500	0	0	0	0	150.588	419.510	FC	50,00	209.755
CO	1	Co-ordination	0,0	0	0		0	0	0	0	0	0	0	FC	0,00	0
CO	1	Total Co-ordinator costs	26,4	246.422	0	0	22.500	0	0	0	0	150.588	419.510	FC	50,00	209.755
CS	2	TUDT	88,0	406.929	50.823	0	27.500	31.570	0	0	54.448	325.544	896.814	FF	50,00	448.407
CR	3	DLR	42,5	213.323	0	11.005	14.499	29.000	0	0	0	156.255	424.082	FC	47,30	200.590
CR	4	DEWI	4,0	20.844	0	0	3.496	0	0	0	0	24.840	49.180	FC	47,30	23.262
CR	5	CCLRC	27,3	129.738	16.814	0	16.000	8.000	0	0	14.500	228.338	413.390	FC	50,00	206.695
CR	6	Risoe	33,0	176.251	0	0	13.500	11.000	0	0	13.000	193.874	407.625	FC	50,00	203.812
CR	7	CRES	32,0	128.869	0	0	14.500	30.096	0	0	0	115.993	289.458	FC	50,00	144.729
CR	8	VUB	22,0	92.380	5.000	15.000	8.500	15.000	0	0	0	24.176	160.056	AC	100,00	160.056
CR	9	UP	53,0	148.587		15.000	16.000	41.000	0	0	30.000	47.117	297.704	AC	100,00	297.704
CR	10	VTT	23,0	97.107	0	0	10.499	13.000	0	0	14.468	61.258	196.332	FC	50,00	98.166
CR	11	GL-Wind	6,0	34.732	0	0	10.000	0	0	0	0	41.680	86.412	FC	50,00	43.206
CR	12	DNV	6,0	44.191	0	0	10.000	0	0	0	0	55.240	109.431	FC	50,00	54.715
CS	13	LM	17,2	83.303	0	0	16.500	30.500	0	0	0	83.303	213.606	FC	50,00	85.763
CR	14	Polymarin	14,0	80.350	0	0	14.999	12.001	0	0	0	28.070	135.420	FC	47,50	84.312
CR	15	NORDEX	4,1	56.016	0	0	5.499	2.000	0	0	0	0	63.515	FC	38,25	24.292
CR	16	Gamesa	10,1	66.484	0	0	15.000	12.000	0	0	0	53.187	146.671	FF	47,30	69.375
CR	17	EW	4,0	29.400	0	0	5.499	2.000	0	0	0	11.760	48.659	FC	49,07	23.876
CR	18	Vestas	5,0	19.099	0	0	5.499	2.000	0	0	0	18.677	45.275	FC	45,00	20.373
		TOTAL (31	417,4	2.074.025	72.637	41.005	229.990	239.167	0	0	126.416	1.619.900	4.403.140			2.399.088

changed with respect to original plan