`

First assessment report

Period 1-1-2002 to 30-6-2002

OB_PC_R004 rev. 000

Draft version

Confidential

L.G.J. Janssen
A.M. van Wingerde
D.R.V. van Delft
Ch. W. Kensche
Th.P. Philippidis
P. Brøndsted
P.A. Joosse
A.G. Dutton

OPTIMAT BLADES

PCC

Change record

Issue/revision	date	pages	Summary of changes
draft	19-09-03	Na	na

ACKNOWLEDGEMENT
Research funded in part by European Commission in the framework of the specific research and technology development programme Energy, Environment and Sustainable Development.

The Research performed by ECN and WMC is funded in part by Novem, Utrecht. Project number: 2020-01-12-10-002

PARTICIPANTS

1. Energy research Centre of the Netherlands, ECN.WE, (NL, financial co-ordinator)
2. Knowledge Centre Wind turbine Materials and Constructions, WMC (NL, technical co-ordinator)
3. Deutsches Zentrum für Luft- und Raumfahrt e.V. DLR.IBK (DE, contractor)
4. Deutsches Windenergie-Institut GmbH, DEWI (DE, contractor)
5. Council for the Central Laboratory of Research Councils, CLRC.RAL (UK, contractor)
6. Risø National Laboratory, RISØ.DM (DK, contractor)
7. Centre for Renewable Energy Sources, CRES.WED (GR, contractor)
8. Vrije Universiteit Brussel, VUB.FTW.MEMC (BE, contractor)
9. University of Patras, UPAT.DME (GR, contractor)
10. Technical Research Centre of Finland, VTT.ET (FI, contractor)
11. Germanischer Lloyd WindEnergie GmbH, GL WIND (DE, contractor)
12. Det Norske Veritas Danmark A/S, DNVD.WTC (DK, contractor)
13. LM Glasfiber A/S, LMG.RD (DK, contractor)
14. Polymarin Beheer BV, POLYMARIN (NL, contractor)
15. Nordex Energy GmbH, NORDEX (DE, contractor)
16. Gamesa Eolica SA, GAMESA.ED (ES, contractor)
17. GE Wind Energy GmbH (DE, contractor)
18. Vestas Wind Systems A/S, VESTAS.RD (DK, contractor)

TABLE OF CONTENTS

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 assessment report over the first one and a half year 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.

The programme of this project explicitly includes a start-up phase, meant to discuss and finalise the test programme, and to carry out preliminary tests, analyses and literature studies.
A major topic during this start-up phase is the definition of the detailed test programme including the shape of the test specimens and material to be tested for the first phase of the project as a reference material. In order to arrive at consistent test results across the whole project, it is desirable to arrive at a uniform test specimen for the bulk of the tests. To support the choice for the test specimens a first preliminary test series has been executed by the Task Groups involved in testing. From the results of this first test series the shape of the test specimens was changed and it was concluded that additional tests were needed to reduce the occurrence of tab failures.
While the preliminary test were carried out, the Task Leaders set up preliminary Detailed Plans of Action for their Task Groups. During the first progress meeting of the Technical Committee the draft DPAs were compared and overlapping tests were eliminated. After the results of the second test series became available the DPAs were finalised. From the preliminary tests it had to be concluded that it was almost impossible to define a shape for the test specimen that was suited to perform all the uni-axial experiments foreseen in the project. Finally a shape was chosen that gives the best compromise for all the different uni-axial test conditions.
Furthermore the test specimens for the biaxial test were selected and subjected to preliminary tests. Especially for the cruciform specimen a lot of finite element analyses were needed to achieve insight in the specimen behaviour.
A special Technical Committee Meeting was organized to discuss the test specimen problems and to tune the different test programmes of the five Task Groups.
After this meeting the concept DPAs were finalized. In the Progress Meetings in December 2002 the concept DPAs were approved by the Steering Committee.

The fact that two preliminary test series and considerable discussion were necessary to define the shape of the test specimen, 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 is given in chapter 8. 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 resulted in about ten months delay.
During this first period some contract modifications were proposed and approved by the scientific officer of the European Commission.
There were also some changes in partners in this first period. These changes have been approved by all participants, but have not yet been authorised by the Contract Office of European Commission. Hopefully this can be arranged soon.

3. ACTIVITIES DIRECTLY RELATED TO THE PREVIOUS REVIEW REPORT

not applicable

4. KEY EVENTS DURING THE REPORTING PERIOD

During the first year of the project the following key events took place:

4.1. Kick off Meeting

The project kick off meeting was held on 11-12 March 2002 at the Delft University of Technology. This meeting was attended by 17 out of the 18 participants and by the Scientific Officer from the European Commission. This meeting consisted of meetings of the different Task Groups, the Technical Committee, the Steering Committee and the Project Co-ordination Committee.

First Progress Meeting
The first progress meeting was held on 17-20 June 2002 at Risø National Laboratory.
This meeting was organised to discuss the Detailed Plans of Action for Task Group 1-5 within the different Task Groups to present and discuss the resulting Plans in the Technical Committee.

Additional Technical Committee Meeting
On September 6th 2002, an extra Technical Committee meeting was organized to discuss the results of the preliminary test programme, the Detailed Plans of Action for the different Task Groups and to eliminate the unnecessary overlap in the DPAs. The planning and time schedule to finalize the DPAs and to send them to the Steering Committee for approval was agreed upon.

DPAs
The DPAs were sent to the Steering Committee for approval by the end of October 2002.

Second Progress Meeting
The second progress meeting was held on 16-19 December 2002 at DLR in Stuttgart. During these days there were separate meetings for the Technical Committee, The Project Coordination Committee and the Task Forces. The DPAs were approved by the Steering Committee, and the order list for the first series of test specimen was specified in detail.

Third Progress Meeting
The third progress meeting was held on June 30th to July 2nd at VUB in Brussels. This meeting was organized somewhat different from the previous ones. This meeting started with a general meeting in the afternoon of the first day followed by Task Group meeting on the second day and concluded by a Technical Committee meeting on the third day. All participants were in favour of this scheme so it will be used for the next meeting too.

The test specimen production at LM has been seriously delayed. Due to this delay all of the testing activities at the different institutes, except at Risoe, are far behind schedule. In fact the test specimen production came on line only a few months ago. But it appears that, from now on, the specimen production is going ahead well and that the LM can provide all the laboratories with sufficient specimen to execute their experiments. An updated priority list is necessary to ensure a smooth distribution of test specimens. LM expects to need about 20 weeks to produce the remaining test specimens for the first phase of the project. However the delay can't be made up due to the available testing capacity at the laboratories, although all partners will do their utmost to minimize the delay at the end of the project. During the meeting in June/July this year it was decided that in spite of this delay, the Mid Term Assessment is still planned for July 2004.

5. LIST OF DELIVERABLES MADE DURING THE REPORTING PERIOD

In Table 1, an overview is given on the status of the deliverables for the first year of the project. Most deliverables became available with a delay due to the problems the project encountered in the definition phase.
In this table, only a part of the reports produced during the first year is given. An overview of all reports produced is given in Annex I to this report. All reports are available on the web site of the project (www.ecn.nl/optimat).

Table 1 List of deliverables during the reporting period

No	Deliverable title	Form	Date	Dissemination level	Report
1	Test report describing the material, laminates and fatigue tests	Report	5	CO	OB_TG3_R005 rev. 0
2	Microstructural model and identification of degradation parameters.	Report	5	PU	OB_TG3_R006 rev. 0 Not yet public
3	Definition of extreme conditions and procedures for testing under extreme conditions.	Report	5	PU	OB_TG3_R004 rev. 1 Not yet public
4	Definition report of typical thick laminate.	Report	5	PU	OB_TG4_R001 rev. 2 Not yet public
5	Suitable repair techniques for small specimens	Report	5	CO	OB_TG4_R002 rev. 0
6	Review of residual strength predictive models	Report	5	CO	OB_TG5_R003 rev. 0
7	DPA for phase 1	Report	6	CO	OB_TC_R004 rev. 3
9	Approved DPA for phase 1	Report	6	CO	See above Approved in December
43	Preliminary Technology Implementation Plan (TIP)	Report	6	PU/CO	Not yet available
8	Progress reports according to Energy Guidelines for Contract Preparation	Report	7,13, etc	CO	OB_PC_R002 rev. 1 OB_PC_R003 rev. 1 OB_PC_R004 rev 0 (this report)
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 rev 0 (this report)
12	Phenomenological micro mechanics models for sensitivity analyses	Report	18	PU	Not yet available

6. SCIENTIFIC AND TECHNICAL PERFORMANCE

In this period, a large number of tests have been carried out, resulting in a choice for the standard OPTIMAT test specimen. The overview of the tests is given below, followed by an overview of the work carried out in this period by the various TGs.

6.1. Overview of the first stage of the preliminary experimental program for Phase 1

<u>Introduction</u>

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.

However, this approach requires that essentially one geometry has to be used for the whole programme. Since there are many compression tests, as well as fatigue tests with compressive loads, buckling should be taken into consideration. The use of anti-buckling devices was dismissed, because it was feared that these devices might affect especially the fatigue behaviour of the test specimens and be rather sensitive to the implementation by various institutes. This means that a relatively stocky test specimen should be selected. On the other hand, some free gauge length is necessary for measurements, especially for NDT (non-destructive testing) and clip gauges, so the gauge length has to be chosen as large as possible, while preventing buckling.

<u>Materials tested and notation</u>

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.
Test specimens were provided by LM Glasfiber A/S Denmark, cut from different plates.

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

	# of layers		lay-up	OptiDAT name	nominal thickness [mm]
	UD	biaxial			
plate 1	5	--	$0°_5$	UD1	4.5
plate 2	5	2	$\pm45°/0°_5/\pm45°$	MUD1	5.6
plate 3	5	6	$(\pm45°,0°)_5$; ±45°	MD1	7.8
plate 4	4	--	$0°_4$	UD	3.5
plate 5	4	5	$(\pm45°,0°)_4$; ±45°	MD	6.6

Test specimen geometry of the first preliminary programme (plates 1 to 3)

The test specimens have been cut from the plates, described in Table 2.
The plan form of the specimens is either rectangular or dog bone-shaped (see Figure 1). Both specimen shapes were investigated since both had their advantages and the partners could not agree on choosing either one, without extensive testing.
Dogbone shapes were believed to diminish or eliminate tab failure, but the stresses do tend to be unevenly distributed over the width of the specimen (unless long dogbones are used). On the other hand straight shapes are considered more appropriate for UD material.

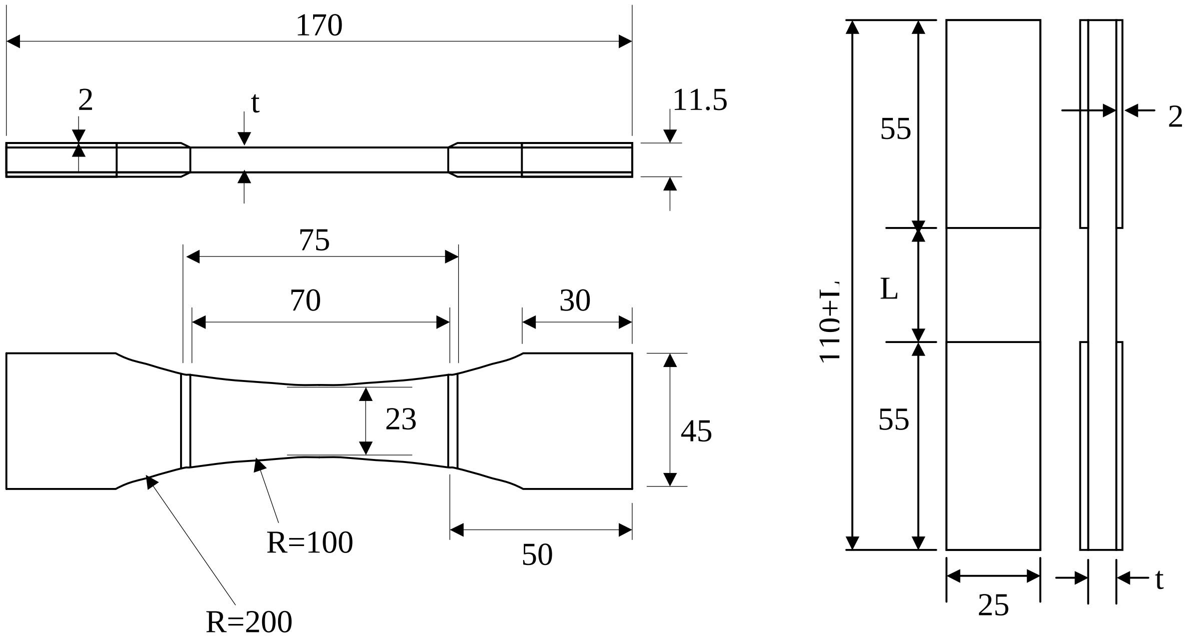


Figure 1 Dimensions of specimens D01 (dog bone shaped, left) and R01

Conclusions from the first preliminary programme (plates 1 to 3)

- *Problems encountered during testing, like tab failures, tear-outs and test results exceeding the maximum capacity of the test rigs for most partners, can be solved by reducing the thickness. It was decided to lower the number of UD layers in each material from 5 to 4.*
- *UD was preferred over MUD (Multidirectional surface UniDirectional) material, mainly because some tests, such as off-axis tests and hygro thermal tests would have to be carried out on pure UD anyway. Testing both MUD and UD would put too much strain on the test facilities, which might be put to better use elsewhere.*
- *The reduction in UD material would aggravate the risk of buckling, which was already high, particularly for the dogbones, due to its longer gauge length.*
  Failure for the dogbones occurred typically by a rectangular part tearing out from the dogbone, even when material with a 45° facing (MUD) was tested. Furthermore, some partners had a preference for straight specimens, so straight specimens were selected over dogbones.
- *The tab length is reduced to 55 mm, so that all institutes will be able to carry out the tests with the non-tapered tabs fully enclosed by the grips.*

6.2. Overview of the second stage preliminary experimental program for Phase 1

Straight specimens were selected, in part due to the better performance of the straight specimens. In order to counter the buckling problem, it was decided to investigate gauge lengths of 30, 35 and

40 mm for UD material, and 35, 40 and 45 mm for the (thicker) MD material, instead of the 50 mm gauge length used in the straight specimens of the first test series.

Conclusions from the second preliminary programme (plates 4 and 5)

The test results still indicated minor buckling for the largest gauge lengths of both UD and MD (Multidirectional) material, respectively 40 and 5 mm. In order to maximize the measuring area, the gauge length selected was set at 35 mm for UD material and 40 mm for MD material. The larger gauge length of the MD material allows for more room for measurements.

In addition, preliminary FE analyses indicated that MD material suffers from a higher degree of disturbance in the stress field due to the presence of tabs. One quarter of the test specimen (blue part in the top figure) is modelled (see Figure 2).
The variation of strain along the bottom of the two strain figures (see Figure 3 and Figure 4) which is the line of symmetry of the test specimen is about 6% for UD material (Figure 3) and about 24% for the MD material (Figure 4) but slightly over 10% when 2.5 mm away from the tab area (right hand side of the stress pictures).

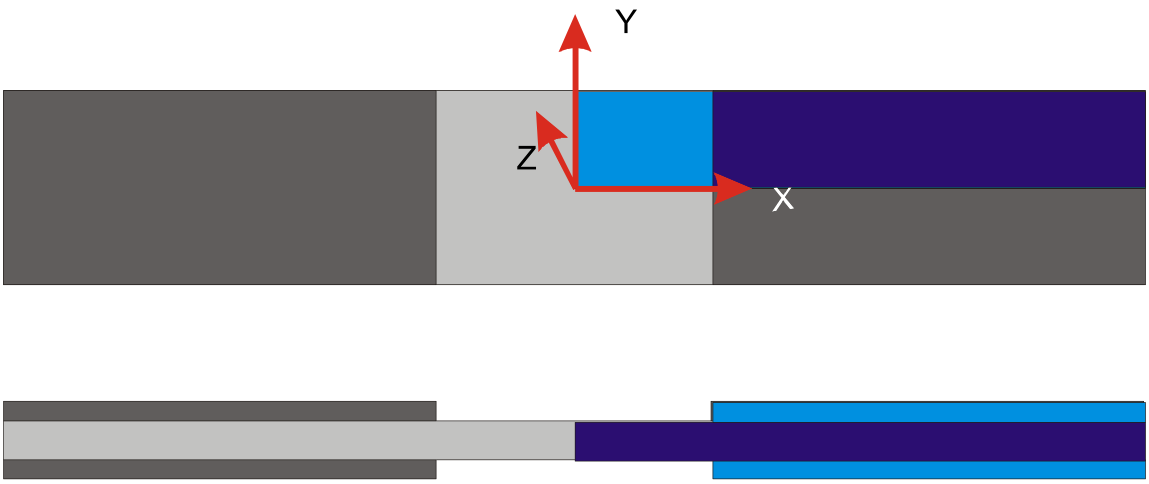


Figure 2 FE model of the test specimen

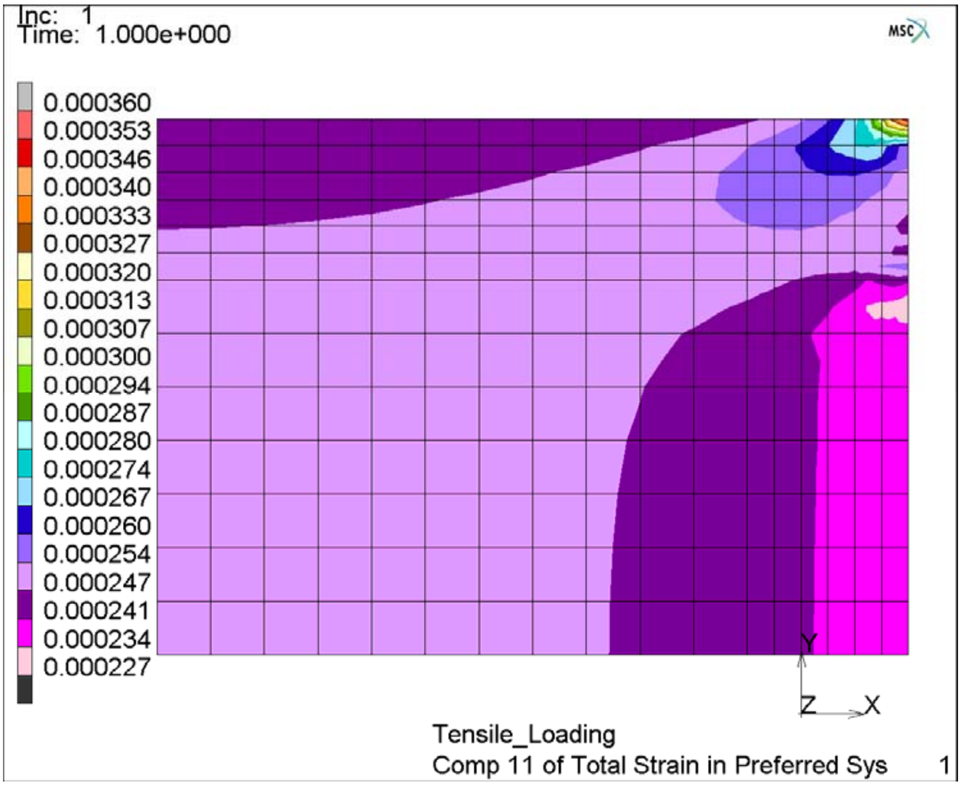


Figure 3 FE results of the UD test specimen

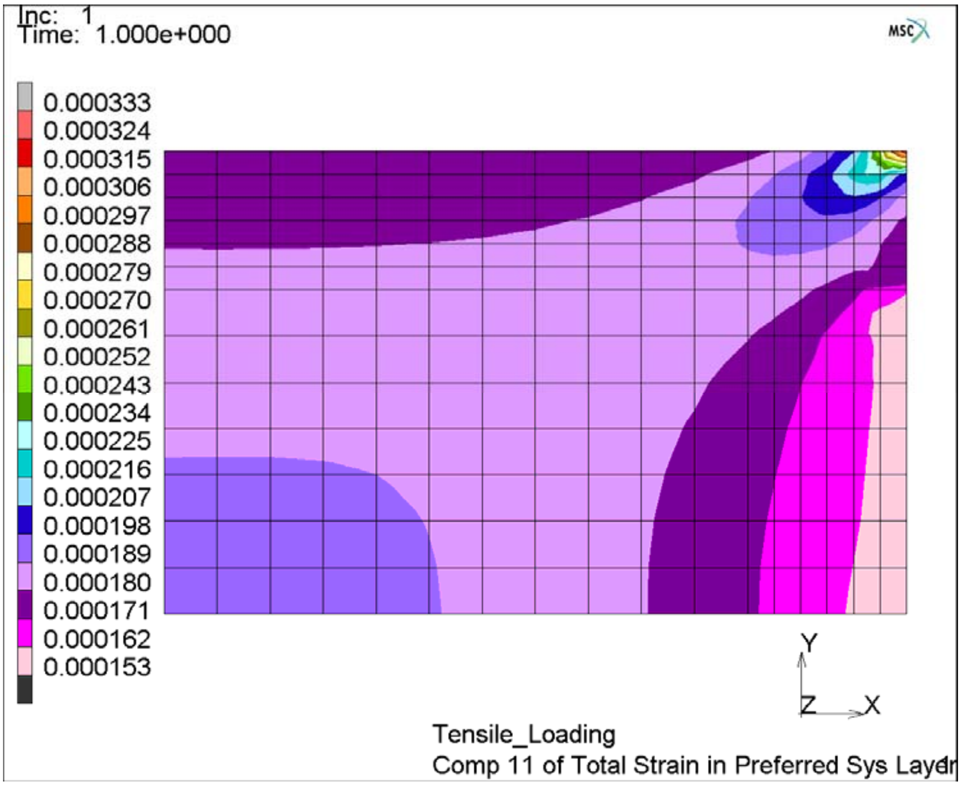


Figure 4 FE results of the MD test specimen

An overview of all compressive tests of the preliminary programme is shown in Figure 5.

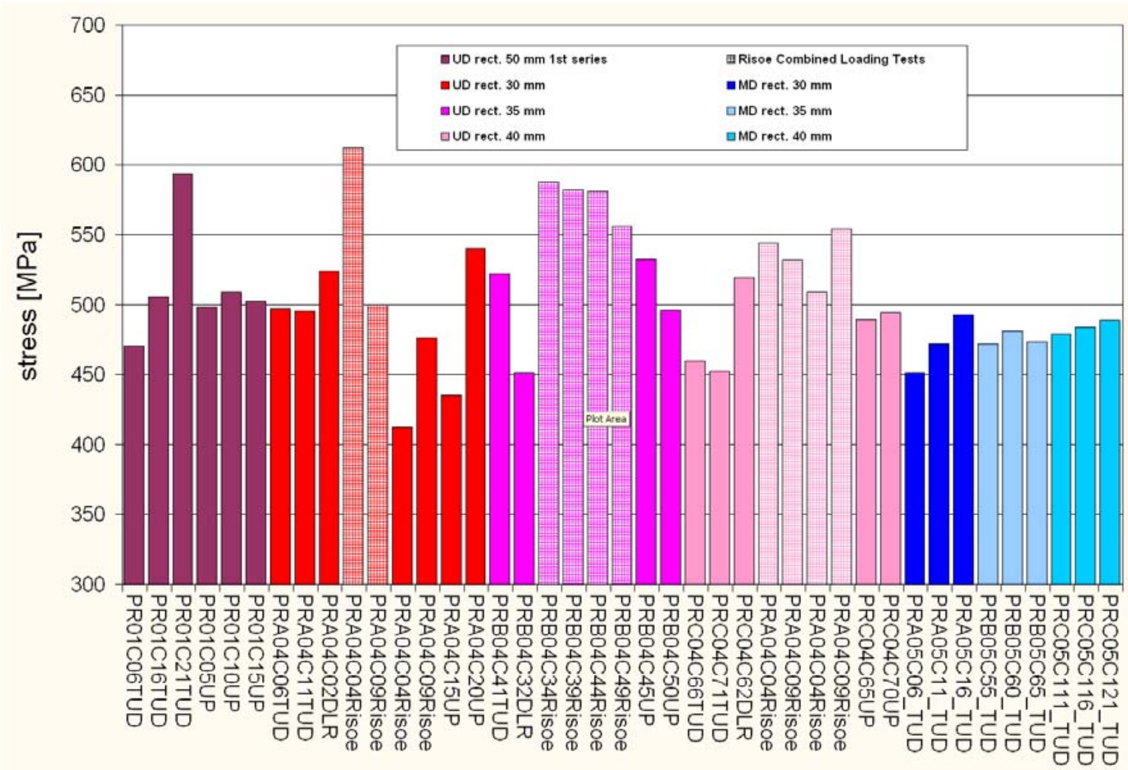


Figure 5 Overview of the compressive tests results of the preliminary programmes

The tests of the **P**reliminary programme are denoted by **P*V(W)xxYz(z)z*** in which:

V	D or R	test specimen shape (Dog bone or Rectangular).
W	A, B, or C	(for plates 4 and 5) free length between the tabs of 35, 40 and 45 mm respectively.
xx		number LM used for the plate, in this series 04 (= GEV)
Y	T, C or F	type of test (static Tension, static Compression, or Fatigue)
zz(z)		number of the individual test specimens; for plate 5 up to three digits are used.

It is worthwhile to note that the guidelines against buckling in ASTM D 6641/D 6641M – 01 and ISO 14126 proved rather conservative: the predicted buckling load for PR01C was about 250 MPa or 40 to 50% lower than the measured load in the tests: the 6 left most data points in Figure 5.

6.3. Overview of the test results of the benchmark tests

After the preliminary programme, all partners that were to carry out experimental work during the project conducted a number of identical tests, both static and fatigue tests.
The benchmark serves several purposes:

- *Establishing basic static and fatigue characterisation of the reference material, including statistical data on variation)*
- *Comparison of the various test institutes*
- *Comparison of the plate-plate variation of the reference material as delivered by LM*
- *Check on measurement procedures and result reporting (such as in the overview database OPTIDAT)*

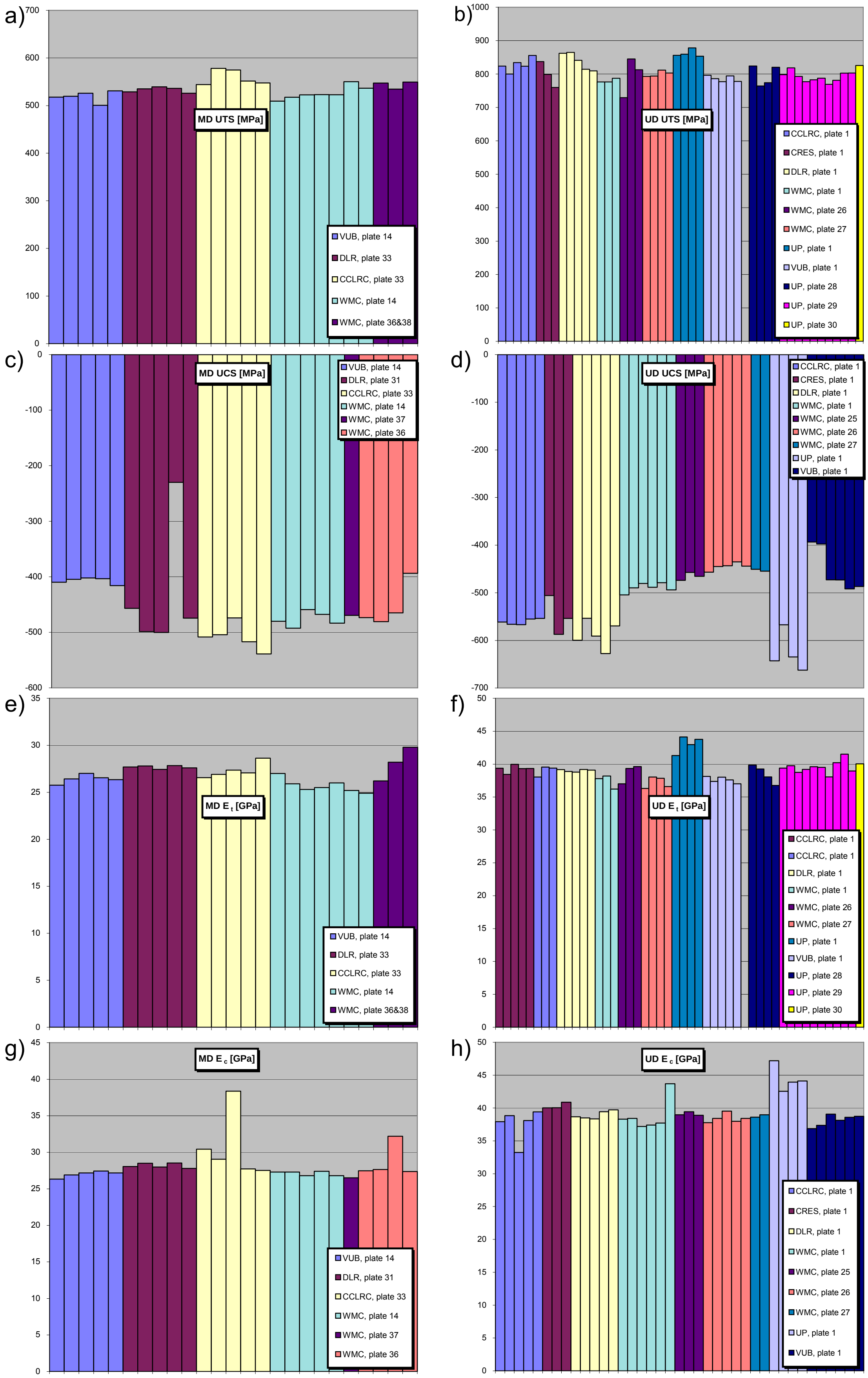


Figure 6 Overview static tests in benchmark

Overall, apart from a few individual test results, the results of the static tests look fairly consistent. UP seemed to obtain slightly higher results (see for instance Figure 6d), which could due to a stiffer and better aligned test set-up for UCS. However, it is unlikely that the Young's modulus as in Figure 6h would be likewise affected. After checking, it turned out that UP grinded it's test specimens carefully, taking off some epoxy and thus reducing the thickness of the test specimen, without affecting the strength, therefore resulting in higher stresses. Furthermore, the largest differences seemed to occur in the UCS of the UD material, as is to be expected: this test is most strongly influenced by the set-up of the test machine (alignment, stiffness against lateral movement, type of grips).

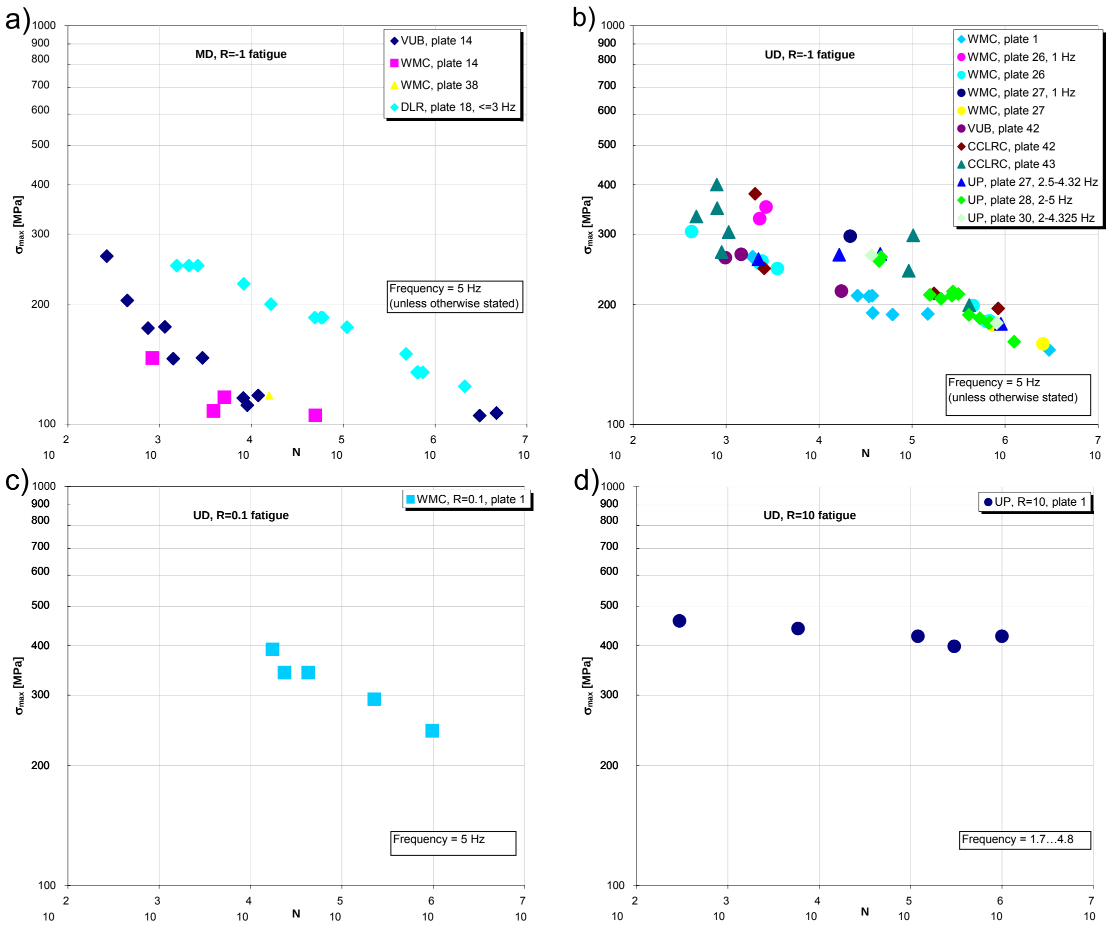


Figure 7 Overview fatigue tests in benchmark

After having gained confidence in the static benchmark tests, the fatigue tests were carried out. Here, a dramatic difference occurred between WMC and VUB on the one hand and DLR on the other, see Figure 7a. It turned out that the tests carried out at 5 Hz will have to be discarded, as the heat introduced in the test specimen seriously affects the fatigue life. This came as a bit of a surprise, since similar tests in older research programmes (albeit with slightly thinner test specimens) had been carried out at up to 12 Hz. Verification with the MD tests, compare the data for WMC of plate 26 and plate 26 1Hz in Figure 7b, showed that the test frequency is indeed the cause of the differences and all parties will carry out subsequent tests at a lower frequency.

The observed differences in test results between partners and subsequent conclusions about testing methodology bear strong testimony to the fact that the benchmark test series are an essential part of the OPTIMAT BLADES project test programme.

6.4. Detailed report for task group 1

Short description of TG1 WP's

WP3 (Variable amplitude fatigue loading)
Besides the selection of the reference material and the definition of the fatigue testing program, existing lifetime prediction methods, such as shown in Figure 8), are compared and constant as well as variable amplitude fatigue tests shall be carried out with the reference material.

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 the period

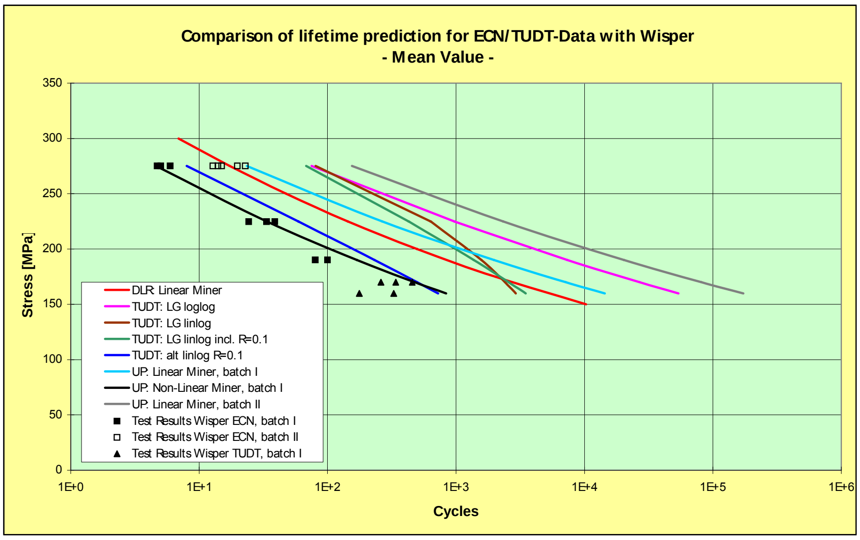


Figure 8 Results of different lifetime prediction models of TUDT, UP and DLR

WP3:

- *A benchmarking in lifetime analyses with different engineering models of life assessment and existing material data shall result in a new basis to decide for an apt damage accumulation theory and/or material fatigue model.*
- *The generation of a detailed plan of action (DPA), including a fatigue test program for the constant and variable amplitude tests.*
- *Establishment of S-N lines of reference material at various stress ratios, to design a constant amplitude life diagram.*
- *Variable amplitude tests with WISPER and New WISPER as well as block testing on the reference material.*

WP4:

- *The generation of the Detailed Plan of Action (DPA)*
- *The identification of the available data bases*
- *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:
The Detailed Plan of Action (DPA) was established and checked.

In the lifetime prediction benchmarking, first calculations have shown that the basics such as statistical evaluation of fatigue data and rainflow counting algorithm have to be adopted before the different existing models can be compared. First results were presented at the EWEC in Madrid.
In preparation of the experimental investigations, 2 preliminary programs causing time delay were necessary to find the suitable specimen geometries then described in the DPA. Beyond that, additional tests had to be performed to find strain/load-dependent frequencies not to exceed maximum temperatures on the surface over 35°C.
The static tests according to the DPA are finished. The evaluation showed that the results of the participating testing institutes were within the tolerance bounds. Problems with significant differences in engineering constants found could be solved by relating them to sensitivities in the thickness measurement of the specimens.
Although the specimens were delivered very late to the parties some basic fatigue tests could be accomplished at least at a stress ratio of R=-1 for the definition of the load levels to be taken for the establishment of the constant amplitude fatigue tests.

WP4:
Five databases have been identified so far with normalized and processed data:

- *A stall controlled WEC, 500 kW, 3 blades, fixed speed*
- *A stall controlled WEC, 1320 kW, 3 blades, fixed speed*
- *A full span pitch controlled WEC, 750 kW, 3 blades, variable speed*
- *A full span pitch controlled WEC, 1500 kW, 3 blades, variable speed*
- *A full span pitch controlled WEC, 2500 kW, 3 blades, variable speed*

The procedure of recovery and adaptation of the WISPER synthesis is based on literature and has been studied. As a starting point, the partners were asked to identify those items that need adaptation to today's requirements. Some of the items have been discussed, however, the larger part of the adaptation and development work had to be delayed since the procedure for data processing needs to be commonly agreed beforehand.

Bottle necks

A time delay of roughly 9 months (see Chapter 8) must be stated

In WP3 due to:

- *Unforeseen long search for an apt specimen geometry*
- *Late delivery of specimens*
- *Validation of an apt testing frequency.*

In WP4 due to:

- *Missing acquisition of official releases for the data sets*
- *Serious delay in adaptation and development work for the renewed WISPER assembly.*

Activities for the next half year

In WP3, the benchmarking of the lifetime prediction methods must be continued with the various models used by the participating labs.
Experimentally, the establishment of the load levels for constant amplitude fatigue testing has to be continued. The constant amplitude fatigue curves for the stress ratios according to the DPA must be established for the design of a constant amplitude life diagram.
In WP4, the assessment of the old WISPER synthesis procedure and the development of a new procedure shall be concluded. Each of the data supplying parties (CRS, DEWI, ECN) will process their data to a defined degree, i.e. the data will be supplied in a normalized form and in terms of rainflow counts per mode of operation. The data will then be compiled into a NEW WISPER range pair range spectrum and subsequently a rainflow equivalent sequence will be derived.

Deliverables

Test report describing the material, laminates and fatigue tests (Nr. 1),
DPA for Phase 1 (Nr. 7),

Approved DPA for Phase 1 (Nr. 8),
Contribution to the Preliminary Technology Implementation Plan (TIP, Nr. 43).

6.5. 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 behaviour under complex stress states ' (WP6 and WP7).

Short description of TG2 WP's

Phase 1 of TG2 consists of WP6 "Complex Loading" in which the objective is to investigate the effect of complex stress states, e.g. plane stress conditions, on failure prediction both under static or cyclic loading. The combined action of all three in-plane stress tensor components will be taken into account in defining failure in contrast to one-dimensional approaches where only a normal and shear stress components are considered separately. To meet the objective, extensive testing for material characterization of basic UD ply is foreseen accompanied by uni- and multi-axial tests on MD laminates of various stacking sequences. Test results will be used to implement validated failure theories in conventional and FE large blade models and derive, in cooperation with certifying organizations, design guidelines for large rotor blades.

Specific objectives for this period

Specific objectives for this first and a half year (01.01.2002 to 30.06.2003) were:

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

Overview of technical achievements

DPA of WP6
After a considerable amount of discussion, especially in TC meetings, preliminary testing and analyses, the DPA has been drafted in accordance with the choices made regarding various specimen geometries for the whole project. The DPA has been approved by the Steering Committee (DLR, Stuttgart, December 16, 2002).

Preliminary tests
Preliminary tests were conducted in the frame of TC by all TLs. The scope of the tests was to determine the optimal coupon geometry, suitable for all kinds of tests, i.e. static, fatigue, residual strength, both in tension and compression that are foreseen in the various DPAs of OPTIMAT Task Groups. Test results were included in a technical report [2], uploaded at the OPTIMAT site. In addition, preliminary biaxial tests were performed on cruciform specimens to investigate candidate geometries of reduced stress concentration, which in combination with the available test frame at VUB should produce acceptable failure modes. In the frame of TG2, multi-axial tests are also foreseen, consisting of combined torsion and tension/ compression applied to tubular specimens (to be performed mainly at DLR) besides to the tensile tests on cruciform specimens (to be performed mainly at VUB). Although in the former case the experimental set-up and specimen geometry are well defined and previous experience is already available, this is not the case for the cruciform specimens subjected to tensile loads. Therefore, a detailed FE analysis was performed by ECN and TUDT [3], in which a large number of biaxial test specimen geometries were modelled to investigate the influence of variations in shape, thickness and material properties. The aim was to derive a set-up where the highest stresses would occur in the central area, so as to cause failure also there.

Taking into account the numerical analysis results, a series of preliminary tests was performed at VUB to study overall stress distribution as well as testing of several composite specimens of different geometry, prepared by LM, to study failure modes, as shown in Figure 9 and Figure 10.

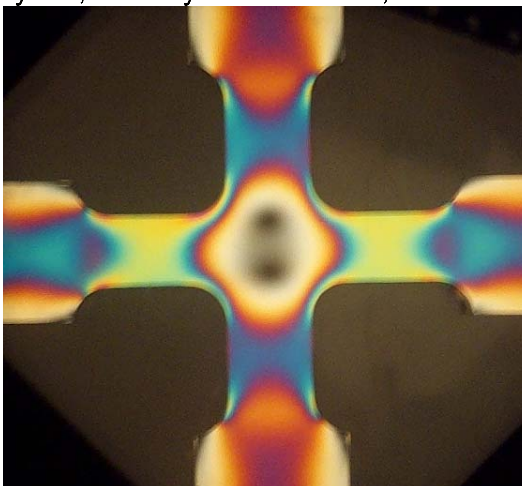


Figure 9 ISOCHROMATICS in a transparent cruciform loaded biaxially. Fx= Fy =300 N

Figure 10 Photos of specimen R 20 E, Loading ratio=2.2/1

A series of technical reports with test results were written and uploaded to the OPTIMAT site [4], [5], [6]. Nevertheless, failure modes of this series of cruciform test specimens were not satisfactory and another series production, of modified geometry as proposed in [3], was performed by LM and tested by VUB. Some demo experiments were also performed for the partners during the 4th consortium meeting (VUB, July 2003). Preliminary results from this test series [7] indicate that there are possibly two specific new cruciform geometries that yield appropriate failure modes. Additional tests with specimens of this type are ongoing.

Benchmark and Phase 1 tests

LM has started to produce test coupons as foreseen in the DPAs of the various TG's. Concerning UD material, standard OB coupons in the fibre direction were only delivered. Experiments were performed on standard OB UD coupons under static tensile and compressive loads as well as under CA cyclic loads (R=10). Benchmark test results were presented in a technical report [8], see OPTIMAT site. Phase 1 main test results were first presented at the 4th consortium meeting (VUB, July 2003) and subsequently in a technical report, uploaded in OPTIMAT site [9]. Both static and cyclic tests were performed; from the logistics point of view, static tests are accounted for in WP6 (TG2), while cyclic tests are done for WP3, TG1 (for this type of tests there is an overlap between TG1 and TG2). All tests were performed using OB standard unidirectional (UD) coupons. In total, 25 static tensile tests and 22 cyclic tests, R=-1, were conducted. Static tests were performed for the determination of elastic properties and strength of UD material. According to the test plan, 25 coupons were scheduled for tensile tests to define the respective elastic property and static strength distribution characteristics. Results from 15 coupons are available, until now for the determination of tensile Young modulus, E_1, Poisson ratio v_{12}, and tensile strength, X.

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

Optimised stress analysis

Existing FE model of relatively large blade, 30 m, was used at UP to identify areas where normal stress in the blade axis was dominant and regions where complex stress states were developing for experimental simulation in biaxial tests, see Figure 11. 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 modelling philosophies are under way. Objective of the exercise is to compare failure indices from both analyses and calibrate safety factors for each case so as to reach the same safety margin. So far, the task is not completed due to some difficulties in exchanging data (proprietary rights) between UP and TUDT.

Figure 11 Characteristic states of stress resultants in a rotor blade of 30 m

Bottle necks

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

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

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

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

Planned activities for the next half-year period

In this first and a half year, considerable time was needed for the initial phase of defining the standard OB specimens through preliminary tests. Drafting of the DPA has taken more time than anticipated and considerable delay was encountered. To limit the time delay, the initial activities of WP6 have been started before formal approval of the DPA. Furthermore, more test rigs will be used than foreseen by UP. Selection of optimum cruciform specimen geometry is not yet concluded and a series of new tests will be probably performed by VUB to finalize the issue. On the other hand, tube testing by DLR and possibly VUB is expected to start by the end of September 2003. Testing of standard OB coupons will run in parallel in several test rigs, while numerical analyses with FE blade models will continue for the second half of 2003.

Deliverables

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

6.6. Detailed report for task group 3

The experimental and theoretical work is carried out according to DPA, work package 8.
The main objectives of the reported period, as it follows from DPA, are listed in the section “Specific objectives for this period” below. The overview of the obtained results is outlined in the section “Overview of technical achievements”. Furthermore, the list of produced deliverables is presented.

Short description of TG3 WP’s

Phase 1 of TG3 consists of WP8 “Mechanical properties at extreme conditions” in which the objective is to investigate the effect of extreme conditions as identified by rotor blade manufacturers, e.g. high (60°) and low (-40°) temperatures and high humidity levels and influence of (salt) water on failure both under static or cyclic loading. Therefore tests under static and fatigue load will be carried out under extreme conditions and the results will be compared to tests under ambient conditions. SEM analysis will be used to identify damage mechanisms. Test results will be used to establish damage models and derive design guidelines from the validated damage models. In phase 2 of the project WP9 ”Extreme conditions for alternative materials” will extend the validity of the model to other materials.

Specific objectives for this period

The main objectives for this 18-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 modelling and experimental determination*

Overview of technical achievements

DPA of WP8
After a considerable discussion, the DPA (document, OB_TG3_O004) 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 –40° C, +60° C and RT (room temperature), as well as salt water environmental conditions. The salt water extreme conditions mean that the specimens are submersed in the salt water. One half of them is kept in salt water for 6 months and tested after, another half is kept 12 months, and tested after exposure. More details on Extreme conditions are reported in DPA (document, OB_TG3_O004) and in report on Definition of extreme conditions and procedures for testing under extreme conditions (document OB_TG3_R004).

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 modelling can link stiffness degradation to different failure mechanisms acting on laminate and microscopic levels. With this method it is possible to study the damage evolution rate for different fracture mechanisms.

Phenomenological modelling and experimental determination
A variety of fatigue characterization methods for composite materials are found in literature, such as statistical description of fatigue life diagrams, statistical description of stiffness degradations, and damage mechanics based stiffness degradation.
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 will be analysed theoretically and compared in order to formulate methods that satisfy the considered tests and its objectives.
Fatigue lifetime can be predicted using statistical stiffness degradation measurements. This method has been already used by several authors that we can find in the literature. The methods are acknowledged, and will be utilized and further developed to account for particular applied conditions. Detailed information is given in corresponding report, "Microstructural model and identification of degradation parameters", document, OB_TG3_R006. 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 has to be generalized for arbitrary laminate, isothermal conditions to start with.
A corresponding test program is compiled. It renders all the data necessary for characterization of considered mechanical properties at selected extreme conditions.

Preliminary test series
The static tests of ISO and OPTIMAT specimens are carried out according to DPA, WP8, in order to characterize mechanical properties of the basic material at reference and extreme conditions, as well as in order to compare performance of OPTIMAT specimen with ISO specimens in different tests.

The elastic properties and the strength of UD and MD composite are measured experimentally for reference material at ambient room conditions. Measurements of the stiffness degradation, that take place due to the damage accumulation, are carried out for UD and MD composite.
Using maximum stress criteria, the ply discount approach is used to describe the stiffness degradation and strain stress behaviour of MD laminates. The ply discount predictions were limited to single event transverse cracking and debonding in shear. There is a reasonable good agreement between experimental data and theoretical predictions, but the approach breaks down in describing behaviour of MD close to final failure.
A more sophisticated approach is needed to account for damage evolution laws, in order to give more realistic description of macroscopic and microscopic behaviour of UD and MD.
The detailed results are given in corresponding report, OB_TG3_R007_RISØ.

Bottle necks

The critical path in the time chart is the testing after salt-water conditioning. Therefore, the delay of still missing Iosipescu and 30°-off axis specimens, needed for determining shear properties, can result in delays at the end, or missing data.

Activities for the next half year

According to the updated time schedule, testing on basic material at extreme conditions will continue in the second half of 2003 and first half of 2004. The phenomenological modelling and the damage analysis will continue parallel with testing as planned.

Deliverables

The produced deliverables are listed in Table 2 “List of Deliverables”.

Table 2-III 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

6.7. Detailed report for task group 4

Short description of TG4 WP’s

WP 10 Comparison of thin and thick plate properties
This WP aims 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 aims to implement suitable repair methods that will bring back functionality and strength to the blades. The repair methods will be compared by benchmarking and verification on small components

Specific objectives for this Period

WP 10

- *Generate the Detailed Plan of Action (DPA) for the work package, which includes an overview of geometries, laminates and repair configurations to be tested, an analyses plan and time schedule*

- *Prepare a theoretical assessment of the strength and stiffness for the thin, flat specimens, both with classical laminate theory and with the aid of finite element models*
- *Production and test of thin, flat specimens (static and some in fatigue loading)*
- *Start with 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

- *Generate the Detailed Plan of Action (DPA) for the work package, which includes an overview of geometries, laminates and repair configurations to be tested, an analyses plan and time schedule*
- *Identify, together with the blade manufacturers, characteristic defects for which repair is found useful. Define a suitable repair method*
- *Production of the test specimens. This production encompasses both repaired specimens and unrepaired reference specimens of identical geometry.*

Overview of technical achievements

DPA of WP10 and WP11
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 Scientific Committee in their Stuttgart meeting of December 16 has approved the DPA.

WP10 Thick laminates
Analysis
TU Delft has drafted the analysis plan for this WP (see OB_TG4_N003). Since no measured material properties are available for the material under consideration, material data has been selected from literature. Geometries, lay-ups and load sets (see OB_TG4_N002) of the standard Optimat Blades specimens have been defined.
So far, UP and ECN have performed FEM calculations, LM will do so in the next year.

UP has performed thin laminate plate theory (CLT) and FEM analyses (see OB_TG4_R001). The CLT predictions give similar results as those done by WMC (see OB_TG4_R003) and are used to compare with the ANSYS (FEM package) results. UP has used the Tsai-Hahn criterion similar like the Tsai-Wu criterion. The model consists of shell elements, at one side the tabbed specimen is constrained; at the other side the tabbed part has a constant displacement. Only linear material behaviour is possible. The strains in the middle of the specimens are comparable to those predicted by CLT, a strain peak occurs in the corner near the 'tab'. UP has drafted a procedure in which non-linear material behaviour and post-FPF behaviour can be included. This will be implemented in the next year.

ECN has performed FEM analyses using the MSC.MARC package (see OB_TG4_R004). Like the ANSYS package, the material model is limited to linear stress-strain curves and first-ply-failure. The specimen is modelled including tabs. The grips are modelled as stiff, steel blocks that are in contact with the tabs. An external force is loading the grips at one side, while the grips at the other side are constrained. The Tsai-Wu (similar to UP) and Hoffman criteria are used as failure criteria. Although the strain patterns and levels are different from UP's, due to model differences, the overall view is similar: a large peak at grip near the free edge. For a large number of load cases, the patterns of the reserve factor are similar to the transverse strains, indicating that the transverse strain (see Figure 12) is dominant in most load cases.

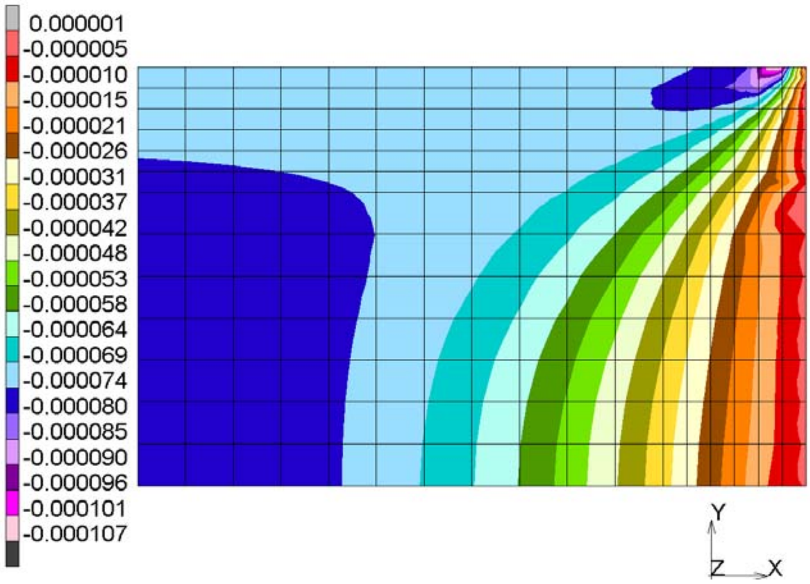


Figure 12 Transverse strains for the MD specimen (OB_TG4_R004)

WP11 Repair

CRES has written an overview of repair techniques that could be used for wind turbine blades (document OB_TG4_R002). It addresses damage models and analyses, repair design and analysis and techniques for, amongst others, structural restoration, such as shown in Figure 13.

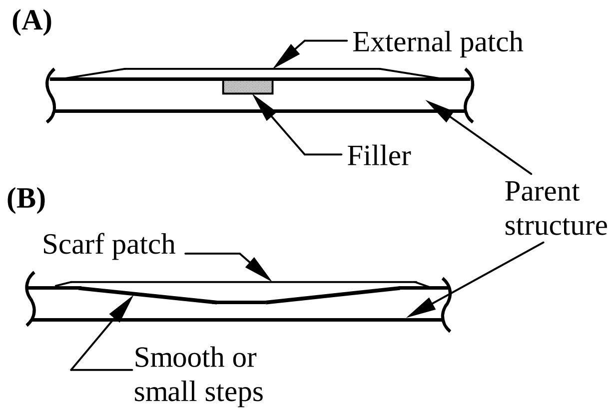


Figure 13 Plug/patch (a) and scarf (b) repair systems (OB_TG4_R002)

CRES has also distributed a questionnaire on repair to the industrial partners from which Gamesa and LM Glasfiber have responded. From the answers on the questionnaire, it becomes clear that both industries are interested in repair of similar defects. Both are interested in scarf repairs, Gamesa is also interested in the plug/patch repair system. During the Stuttgart meeting (December 2002) Polymarin agreed with the scarf repair method. The slope of the scarf repair is still a matter of discussion. The industrial partners will sort this out in the next year.

Gamesa has produced specimens for the testing of repairs. These include unrepaired reference specimens with the same geometry as the specimens with repairs and a series of specimens with scarf repairs. CRES has spent considerable effort in selection of a suitable not destructive testing method. Presumably because the repair was of a very good quality, the methods used for ultra-sonic testing could were not able to distinguish flaws in the repaired specimens.

At WMC the first series of reference specimens from Polymarin have been received.

These have been tested and the tensile strength and modulus agreed very well with the values of the standard Optimat specimens of the same MD material.

Bottlenecks

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.

Activities for the next half-year

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.
CRES will start testing of the repaired specimens from Gamesa and WMC will test repair specimens from Polymarin.

Deliverables

(Refer to list of 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, OB_TG_4_R001. This document also incorporates the test plan for work package 10.

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.

6.8. Detailed report for task group 5

Short description of TG5 WP's in this period

Work Package 13 (Residual Strength and Condition Assessment)
The objective of this work package is the establishment of 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)
The work package comprises a validation of 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:

- *Development of Detailed Plan of Action (DPA), including an overview of test specimen geometry, residual strength test methodology, condition monitoring techniques, time schedule, and detailed test plan per partner*
- *Literature review of residual strength reduction due to cyclic loading effects*
- *Manufacture of test specimens*
- *Completion up to two-thirds of WP13 test programme*
- *Evaluation results from condition monitoring techniques*

Overview of technical achievements

DPA of WP13

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 2002 (project month 12). The basic plan involves 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). 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).

Literature review

A literature review has been carried out by UP [13].

Manufacture of test specimens

As for other task groups, the manufacture of specimens with the finally agreed geometry has been delayed due to the specimen design phase taking considerably longer than first envisaged and subsequently by the manufacturer being overwhelmed by the total number of specimens required. Two preliminary batches of test specimens were supplied for evaluation and tested by laboratories within the Task Group during project year 1. Testing in project year 2 has been further delayed due to specimen supply problems. However, two partners (CCLRC-RAL and VUB) have now performed static strength tests (UD and MD material) and R=-1 fatigue tests (UD material) as part of the initial benchmark exercise and all partners now (project month 18) have sufficient specimens to start work on the main part of the test programme.

Testing

Two batches of preliminary specimens were tested in order to evaluate the specimen design, which was complicated by the desire to have a single, common geometry, resulting in conflicts between the various objectives both within the Task Group and in interaction with the other task groups (e.g. requirement for a compression test specimen with sufficient surface area for application of condition monitoring techniques).
Static and fatigue benchmark tests were carried out on the selected basic UD and MD materials. Testing on the main part of the WP13 test programme could not be started due to lack of specimens within the project as a whole and the consequent failure to develop basic S-N curves to allow the definition of suitable lifetime loading conditions.

Bottlenecks

As noted above, the initial bottleneck of insufficient specimen distribution now seems to have been resolved.
A major bottleneck for Task Group 5 remains the provision of suitable basic S-N curve specifications to allow definition of the desired lifetime increments, required before all partners can begin testing. The S-N curve specifications for longitudinal UD material and MD material are to be provided by TG1 and for transverse UD material by TG2. These curves are required for R = 0.1, R = -1.0, and R = 10, making a total of 9 S-N curve specifications (initially these are required up to a maximum lifetime of 10^6 cycles, but later will be required for longitudinal UD and MD materials up to 10^7 cycles).

New time schedule

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 is now 13 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 start testing in September 2003 (project month 21), completion of WP13 cannot be expected before project month 36. 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 39.

Activities for the next half year

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 (10^3, $5 \cdot 10^4$. 10^6). Furthermore, for UD longitudinal and MD material, limited tests will be carried out at the load corresponding to a target lifetime of 10^7 cycles.
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 (10^3, $5 \cdot 10^4$, 10^6) 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 database from residual strength tests (report/CD) – Due Month 26, Expected Month 39
D25 Validated engineering model for residual strength prediction (report) – Due Month 26, Expected Month 39
D26 Validated engineering model for residual life evaluation and strategy for condition assessment – Due Month 26, Expected Month 39

7. EXPLOITATION AND DISSEMINATION OF RESULTS

Rogier Nijssen gave a number of presentations concerning the work within TG1

- Alternative fatigue lifetime prediction formulations for variable amplitude loading *21st ASME Wind Energy Symposium in conjunction with 40th AIAA Aerospace Sciences Meeting. Reno January 2002*
- *Towards Alternative Fatigue Lifetime Prediction Formulations for Variable Amplitude Loading 33rd International SAMPE Technical Conference. 5-8 November 2001. Seattle, USA*
- *Alternative Fatigue Lifetime Prediction Formulations for Variable-Amplitude Loading ASME Journal of Solar Energy Engineering JSEE*
- Variable Amplitude Loading in Wind Turbine Rotor Blade Composites *Eighth International Fatigue Congress. Fatigue 2002. Stockholm, Sweden*
- *Alternative fatigue formulations for variable amplitude loading in fibre composites for wind turbine rotor blades Conference on fracture of polymers, composites and adhesives. Les Diablerets, Switzerland*

At the EWEC conference in Madrid in June 2003 there were two posters on the Optimat Blades project.
One was prepared by DLR, *A benchmark on lifetime prediction of Composite Materials*, Krause, *et al.*
The second poster was prepared by WMC*, Introduction to the Optimat Blades Project*, Van Wingerde a.o.
This second poster was awarded as an outstanding poster. The arguments of the jury were:

- *The poster gives a clear overview over this large project*
- *The partners in the project represent all parties related to the subject. From R&D institutes, via industry to certifying bodies and can be seen as a pre-phase for a sixth framework centre of excellence.*

Internally, a website is used on which all reports and publications are available, as well as an extensive database OPTIDAT with all optimat test results (currently about 600) and contact if not of the OPTIMAT partners etc. A limited version of this web site with the public information could be created from this, allowing other people better access to the public OPTIMAT reports.

8. MANAGEMENT AND CO-ORDINATION

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), which perform a cluster of comprehensive Work Packages (WP). The management of the project is done by a scientific/technical co-ordinator and a financial/administrative co-ordinator.
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 co-ordinator. The industrial partners and the Certification Bodies form the Steering Committee.

The new organisation scheme of the project is presented in Figure 14**Error! Reference source not found.**:

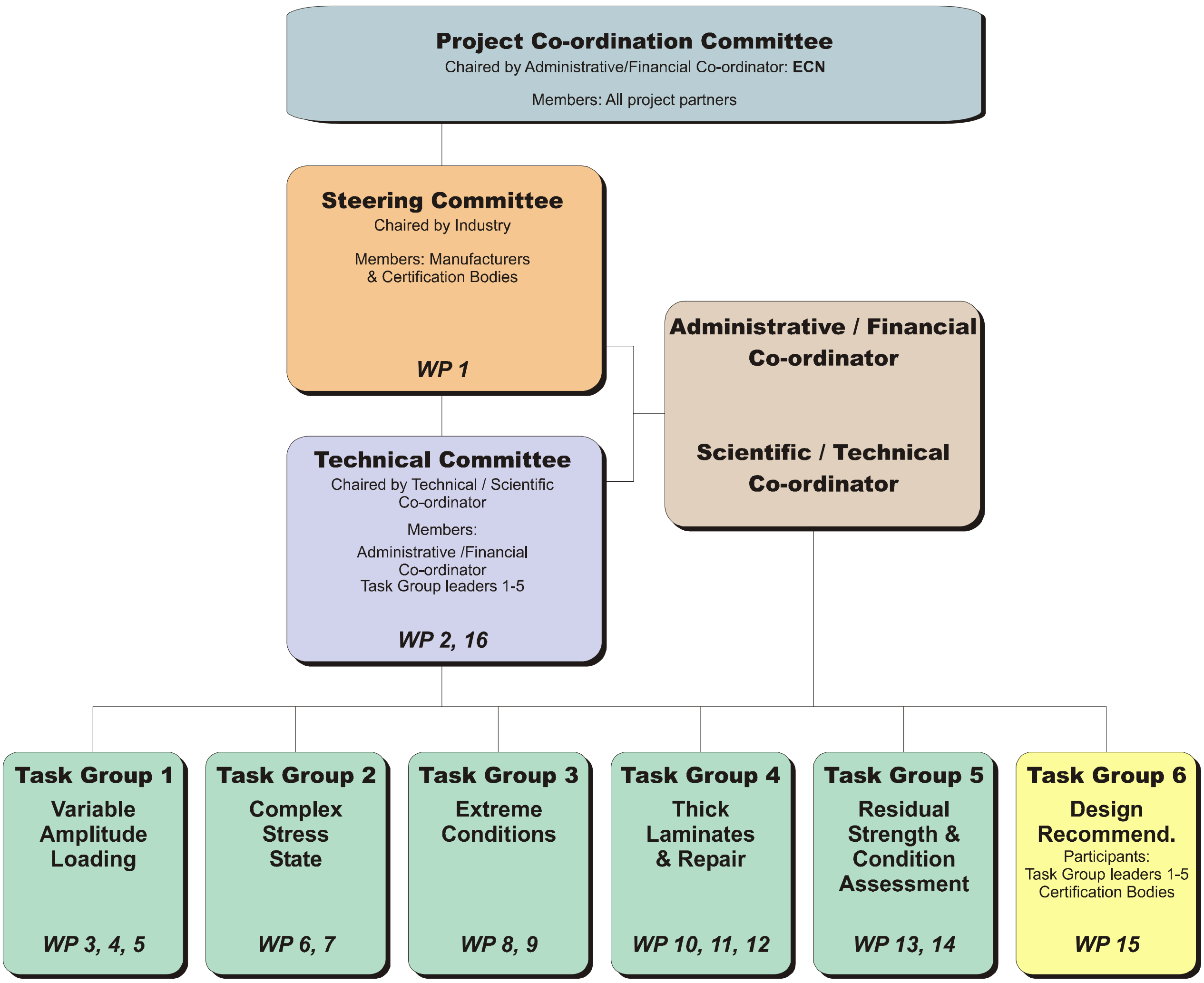


Figure 14 Organisation scheme

8.1. Project Co-ordinating Committee

In the organisation scheme of the project, as described in the "Description of Work", no committee was foreseen in which all partners of the project were represented. In the SC only10 and the TC only 7 of all project partners (18) are represented.
During the Kick off Meeting it was therefore unanimously decided by all partners present at that meeting (17 out of 18) that in order to deal with contractual matters in an orderly fashion, the organisation of the project had to be extended with the Project Co-ordination Committee (PCC), on top of the Steering Committee (SC) and the Technical Committee (TC). Also, according to Annex I, Description of Work, both committees have other tasks. The role of the PCC is clarified in the Consortium Agreement in Section 4.

8.2. Consortium Agreement

In order to define certain of their rights and obligations to each other with respect to the carrying out of the contract all parties agreed to set up a Consortium Agreement based on the Unified Consortium Agreement as provided on the Cordis web site. The Consortium Agreement has been finalized and signed by all partners. Copies have been sent to all partners and the EU.

8.3. Contract modifications (Annex I)

Databases of load spectra

In the description of WP4 Task 4.1 (Annex I) it is stated that 10 databases will be processed and prepared for the NEW WISPER evaluation. This number is not correct anymore, since during the contract negotiations the amount of man months available for this task had to be reduced considerably. As a consequence it was agreed upon to reduce the number of databases from 10 to 6. Unfortunately this number was not changed in the text of the task description.
Furthermore the assembly of the databases will be performed by DEWI instead of TUDT.
The task description should be changed accordingly and should read as follows:

> *Set-up of criteria for acceptance and normalisation of available load measurement data and specification of a common data format for further processing and preparation of 6 databases. The load spectrum assembly method will be defined and applied for a flap wise load spectrum for each database for a selected turbulence level and a selected wind distribution. The assembly for all the databases will be performed by DEWI, supported by TUDT. This task will be co-ordinated by DEWI. ECN and CRES will support this task through contribution and preparation of data.*

Manufacturing of coupons

In the description of WP16 Task 16.1 it is indicated that Polymarin is tentatively selected to produce the small specimens for phase 1. In consultation with Polymarin and LM Glasfiber it is proposed and agreed upon to shift this task from Polymarin to LM Glasfiber.
This means that about four person months have to be shifted from Polymarin to LM in WP 16.

Budget changes:

Partner (9) University of Patras.
The Personnel Costs are reduced from €191,087 to €148,587
The Other Costs has been raised from € 0 to € 30,000
The Subcontracting has been raised from € 0 to € 15,000
The Overhead Costs are reduced from € 49,617 to € 47,117
The Total Costs remain unchanged € 297,704

The reasons for these changes are:

Necessary changes in the control unit of one of the tests rigs (Denison-Mayes DH100S) in order to meet the requirements for fatigue testing such as strain-controlled fatigue and operative clip-gauge control unit.
University of Patras is involved in a great number of coupon tests and since time also has elapsed, they are asked to fulfil their experimental work in a shorter time interval. To overcome the inconvenience they will use 3 test rigs: A 100 kN Denison-Mayes and a 250 kN MTS of University of Patras and the 250 kN MTS test rig of NTUA.

Partners (13) LM-Glasfiber and (14) Polymarin

LM-Glasfiber
The Personnel Costs are raised from € 64,263 to € 83,303
The Consumables are raised from € 26,500 to € 30,500
The Overhead Costs are raised form € 64,263 to € 83,303
The Total Costs are raised from € 171,526 to € 213,606

Polymarin
The Personnel Costs are reduced from € 108,350 to € 80,350
The Consumables are reduced from € 16,001 to € 12,001
The Overhead Costs are reduced form € 38,150 to € 28,070
The Total Costs are reduced from € 177,500 to € 135,420

The reason for these changes is:
In the description of WP16 Task 16.1 of Annex I, Description of Work, it is indicated that Polymarin is tentatively selected to produce the small specimens for phase 1. In consultation with Polymarin and LM Glasfiber it is agreed upon to shift this task from Polymarin to LM Glasfiber.
This means that about four person months and some consumables have to be shifted from Polymarin to LM in WP 16.

The adopted Cost Summary is given in Annex III to this report

The Scientific Officer has agreed on the modifications above.

8.4. Web site organisation

The partners agreed on the proposal to set up a web site to facilitate the distribution of the documents to all the partners in the project.
Meanwhile there are over one hundred documents in the document base and a data base has been set up for a uniform presentation of all test results

8.5. 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 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.

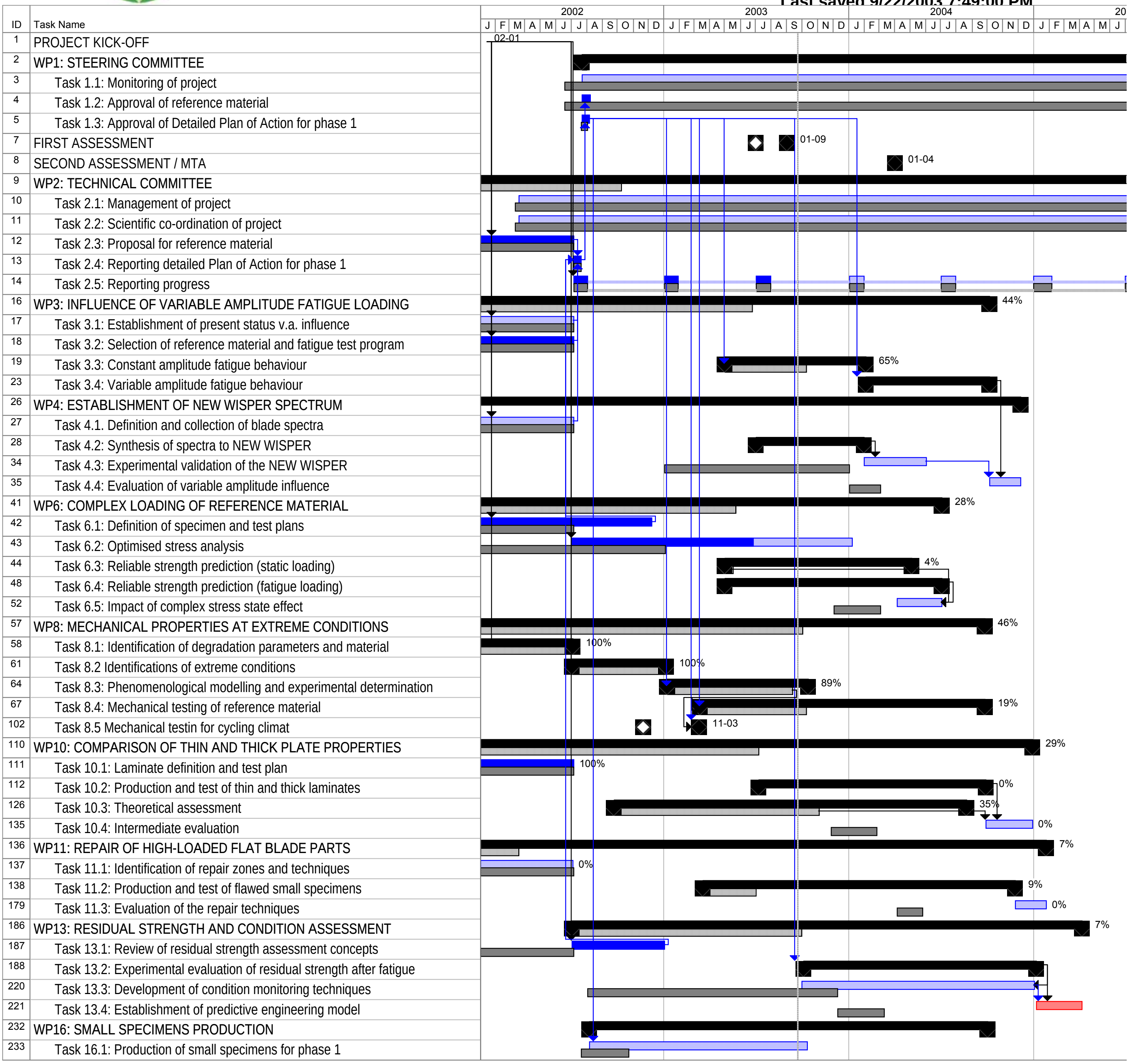
The Technical Coordinator and initiator of the Optimat Blades project is the WMC-Group of the Faculty for Civil Engineering and Geosciences, CiTG, of Delft University of Technology. The group worked for many years in close cooperation with ECN.
The TU-Delft and ECN consider the activities of the group 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.

Therefore all three new partners will on short notice, ask the scientific officer to contact the Contract Office to arrange the necessary changes in the contract.

8.6. 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 15, 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 30 months progress reports respectively.

The proposed adapted time schedule for the second phase is given in Figure 16:



The proposed adapted time schedule is given in Figure 15:

Figure 15 Adapted time schedule Phase 1

ID	Task Name
2	WP1: STEERING COMMITTEE
3	Task 1.1: Monitoring of project
6	Task 1.4: Approval of Detailed Plan of Action for phase 2
9	WP2: TECHNICAL COMMITTEE
10	Task 2.1: Management of project
11	Task 2.2: Scientific co-ordination of project
14	Task 2.5: Reporting progress
15	Task 2.6: Reporting Detailed Plan of Action for phase 2
36	WP5: INTERACTIONS WITH V.A. SPECTRUM
37	Task 5.1: Detailed interaction test plan
38	Task 5.2: Interaction tests of bi-axial with variable amplitude loading
39	Task 5.3: Variable amplitude testing of the alternative materials
40	Task 5.4: Evaluation of interaction effects
53	WP7: COMPLEX LOADING OF ALTERNATIVE MATERIALS
54	Task 7.1: Selection of alternative material combinations
55	Task 7.2: Establishment of experimental data
56	Task 7.3: Validation of the theoretical prediction
104	WP9: EXTREME CONDITIONS FOR ALTERNATIVE MATERIALS
105	Task 9.1: Plan for alternative materials testing at extreme conditions
106	Task 9.2: Mechanical testing of alternative material combinations
107	Task 9.3: Interaction tests of extreme conditions with v.a. loading
108	Task 9.4: Testing of larger components
109	Task 9.5: Creation of a degradation database
180	WP12: PROPERTIES AND REPAIR OF CURVED, THICK LAMINATES
181	Task 12.1: Sub component definition
182	Task 12.2: Sub component design and production
183	Task 12.3: Static test of components
184	Task 12.4: Evaluation
185	Task 12.5: Production and test of large flawed component
222	WP14: RESIDUAL STRENGTH OF ALTERNATIVE MATERIALS
223	Task 14.1: Selection of alternative materials and test plan
224	Task 14.2: Residual strength of alternative materials
225	Task 14.3: Condition assessment applied to alternative materials
226	Task 14.4: Final evaluation of predictive engineering model
227	WP15: DESIGN RECOMMENDATIONS
228	Task 15.1: Summarising results of phase 1
229	Task 15.2: Drafting design recommendation for reference material
230	Task 15.3: Summarising results of phase 2
231	Task 15.4: Extending and modifying design recommendations
232	WP16: SMALL SPECIMENS PRODUCTION
234	Task 16.2: Production of small specimens for phase 2
235	PROJECT FINISH

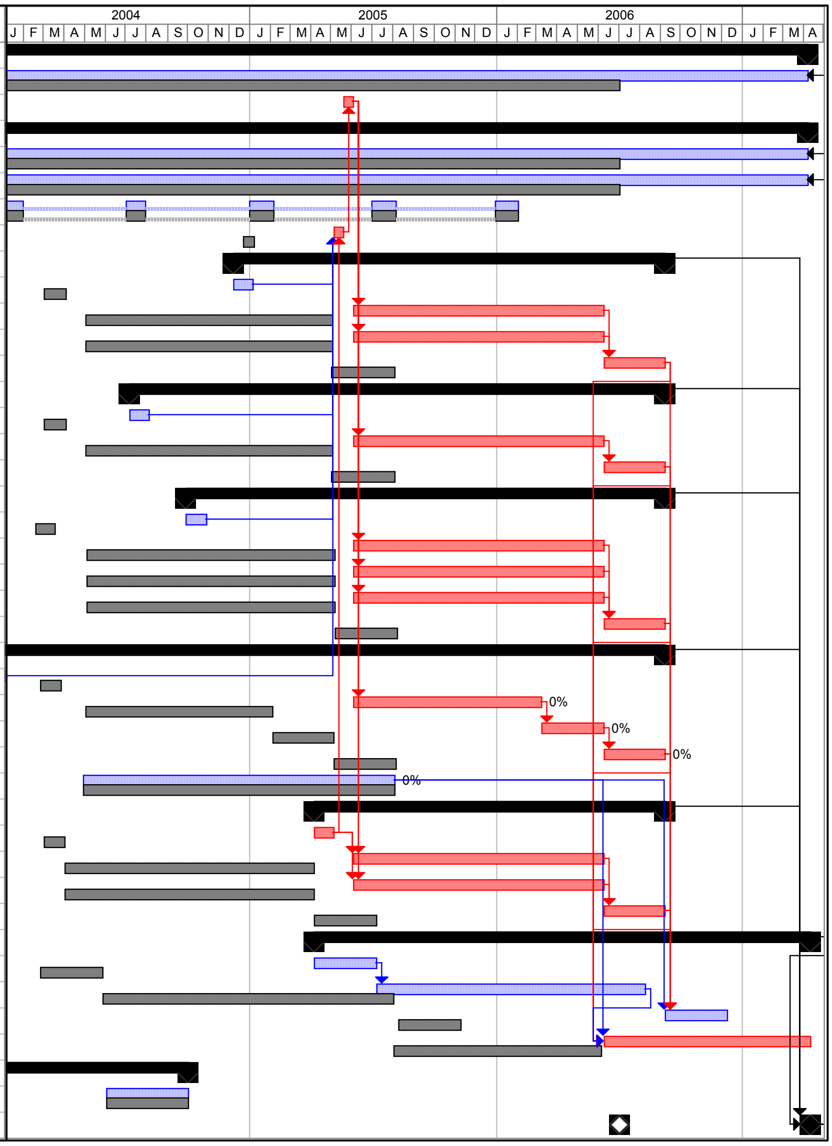


Figure 16 Adapted time schedule Phase 2

9. REFERENCES

1. Material
2. T. P. Philippidis, A. P. Vassilopoulos, T. T. Assimakopoulou, V. A. Passipoularidis, A. Smits, D. van Hemelrijck, OB_TC_R009.pdf
3. A. M. van Wingerde, D. R. V. van Delft, OB_TG2_N000.doc, rev 000
4. D. van Hemelrijck, A. Smits, OB_TG2_R006.doc, rev 000
5. A. Smits, D. van Hemelrijck, OB_TG2_R007.doc, rev 000
6. D. van Hemelrijck, A. Smits, OB_TG2_R008.doc, rev 000
7. A. Smits, D. van Hemelrijck, OB_TG2_R014_VUB.doc, rev 000
8. T. P. Philippidis, A. P. Vassilopoulos, T. T. Assimakopoulou, V. Passipoularidis, OB_TG2_R012rev.000
9. T. P. Philippidis, A. P. Vassilopoulos, T. T. Assimakopoulou, V. A. Passipoularidis, OB_TG2_R013.pdf
10. T. P. Philippidis, A. E. Antoniou, A. Kyrsanidi, OB_TG4_R005
11. A. van Wingerde, P. A. Joosse, D. R. V. van Delft, G. de Winkel, OB_TG4_R004
12. P. A. Joosse, OB_TG4_R003
13. T.P. Philippidis, V.A. Passipoularidis, OB_TG2_003_UP.

10. ANNEXES

10.1. Annex I: Overview of Reports delivered

Report number	Task Group	Title	Subtitle
OB_TG1_R006	TG1	Benchmark Tests Standard OPTIMAT UD Specimen	Static Tension&Compression, S-N at R=-1
OB_TG2_R014	TG2	Assessment Report for 18 month period	Summary progress report for TG2 (01.01.2002 to 30.06.2003)
OB_TG3_R008	TG3	Assessment report	18 month (period 1-1-2002 till 30-6-2003)
OB_TG2_R013	TG2	Static and Fatigue tests on the standard OB UD coupon	Static tensile tests and S-N at R=-1
OB_TG1_R005	TG1	Benchmark on Lifetime Prediction	paper EWEC 2003
OB_TG1_R004	TG1	Static tests of Optimat MD and UD coupons	Benchmark Tests
OB_TC_R012	TC	Introduction to the OPTIMAT BLADES project	paper EWEC 2003
OB_TG5_R005	TG5	Static testing of OPTIMAT MD specimens	benchmark tests by CCLRC-RAL
OB_TG3_R007	TG3	Static tests of UD and MD apecimens using ISO geometries	Test report TG3
OB_TG5_R004	TG5	Static testing of OPTIMAT UD specimens	benchmark tests by CCLRC-RAL
OB_TC_R011	TC	Manufacture and Delivery of Specimens	Test specimens
OB_TG2_R012	TG2	Static and Fatigue Tests of OPTIMAT UD coupons.	Benchmark Tests.
OB_TC_R010	TC	Identification of Specimens	notation
OB_TG5_R003	TG5	Review of residual strength predictive models	Literature review
OB_TG1_R003	TG1	Test plan report	Describing the materials, laminates and tests
OB_PC_R003	PC	Annual progress report 1st year	period 1-1-2002 to 31-12-2002
OB_TG3_R006	TG3	Microstructural model and identification of degradation parameter	Microstructural model and degradation parameter
OB_TG3_R005	TG3	Test plan report	Test report, describing the material, laminates and fatigue tests
OB_TG3_R004	TG3	Extreme conditions	Definition of extreme conditions ad testing procedures
OB_TG1_R002	TG1	Yearly report of TG1	Year 2002
OB_TG3_R003	TG3	Yearly report, 2002	TG3

Report number	Task Group	Title	Subtitle
OB_TG5_R002	TG5	Recommended procedure for conducting OPTIMAT Blades residual strength test	Test procedure
OB_TG2_R011	TG2	Yearly report (2002)	TG2
OB_TC_R009	TC	Preliminary tests.	Static axial & biaxial tests of UD and MD specimens
OB_TG2_R010	TG2	FE analyses of new geometries of cruciform specimens	see also OB_TG2_R008
OB_TG2_R009	TG2	Proposals for new geometries of cruciform specimens	Biaxial loading
OB_TG2_R008	TG2	Proposals for new geometries of cruciform specimens	Biaxial loading
OB_TG2_R007	TG2	Preliminary test results of cruciform test specimens	Report 1: Basis geometry
OB_TG2_R006	TG2	Biaxial testing of fibre reinforced composites	Report 1: introduction
OB_TC_R008	TC	Preliminary tests Part 1	Static and fatigue tests of UD and MD laminates
OB_TG4_R005	TG4	Numerical Prediction of simple specimen mechanical response	CLT and FE-Shell formulations
OB_TG4_R004	TG4	FE analysis of Standard optimat UD specimen	
OB_TG4_R003	TG4	Preliminary prediction of specimen properties	CLT and 1st order FEM analyses
OB_TG4_R002	TG4	Repair techniques for Composite parts of Wind Turbine Blades	-
OB_TC_R007	TC	Preliminary test results on MD reference material (2nd)	Influence of gauge length
OB_TC_R006	TC	Preliminary test results on UD reference material (2nd round)	TASK GROUP 2: Investigation of blade material behaviour under complex stress states
OB_TG3_R002	TG3	Prelimenary tests 2	Compression tests
OB_PC_R002	PC	Semi-annual progress report	period 1-1-2002 to 30-6-2002
OB_TC_R005	TC	Detailed Plan of Action WP10 and WP11	Format example for the TL's
OB_TG5_R001	TG5	DPA TG5	WP 13,14
OB_PC_R001	PC	-	-
OB_TG4_R001	TG4	DPA TG4	WP 10, 11
OB_TG3_R001	TG3	TG3: Detailed Plan of Actions	-
OB_TG2_R005	TG2	TG2: Detailed plan of action, Phase 1	-
OB_TG2_R004	TG2	Verification test program. UD off-axis and MD specimens	-

Report number	Task Group	Title	Subtitle
OB_TG2_R003	TG2	Residual strength characterization of orthotropic ply material	-
OB_TG2_R002	TG2	Proposal for UD coupon tests	-
OB_TG2_R001	TG2	Test program for basic material (UD plate) characterization	-
OB_TG1_R001	TG1	TG1: Detailed Plan of Action Variable Amplitude, Phase 1, WP 3	-
OB_TC_R004	TC	Overview of draft DPA's for Phase 1	-
OB_TC_R003	TC	Overview of test geometry, material lay-up and test set-up	-
OB_TC_R002	TC	Consistent Test Program Procedure Proposal	-
OB_TC_R001	TC	Standard OPTIMAT Test Specimen Proposal	-
OB_SC_R001	SC	Reference material (OPTIMAT) Glass-epoxy material	-

10.2. 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.

Currently, over 2500 tests are foreseen in Phase 1 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																		
			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
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 17.*

Figure 17 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

lay-up	Test	Type of test	UD					MD					±45º (shear/tubes)					Remarks
			TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	
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																		
			TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	TG1	TG2	TG3	TG4	TG5	
lay-up	Test	Type of test	UD					MD					±45° (shear/tubes)					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

lay-up	R	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
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

lay-up	R	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
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, $4\cdot10^5$ 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.*

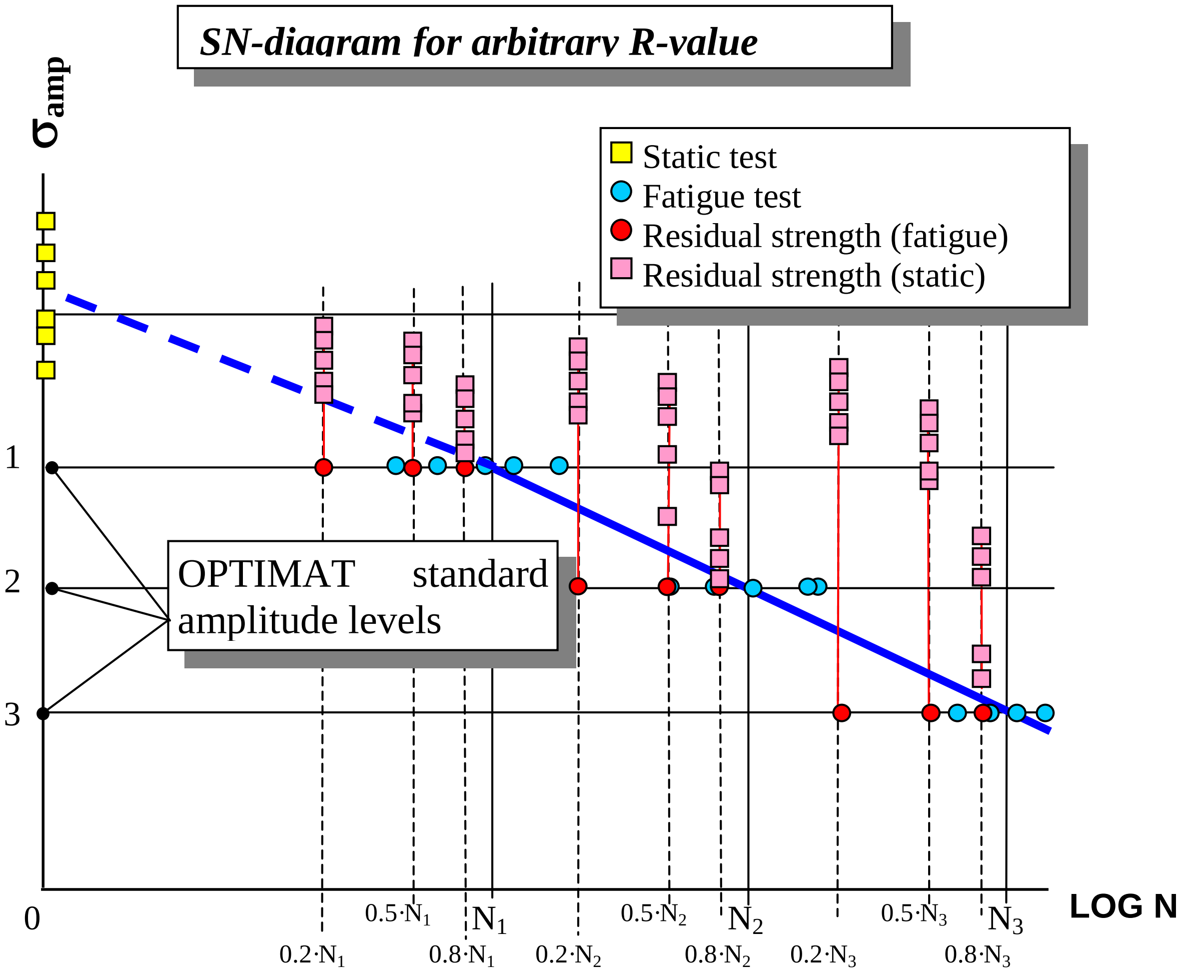


Figure 18 Static, fatigue and residual strength tests

10.3. Annex III: Cost Summary in Euro

Participant No (23)	Assistant to Contractor No (24)	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)	Requested Contribution from the Community (29)	Adjusted Contribution from the Community (33)
1	(25)	ECN	26.4	246,422	0	0	22,500	0	0	0	0	150,588	419,510	FC	50.00	209,755	209,755
1	(26)	Co-ordination	0.0	0	0	0	0	0	0	0	0	0	0	FC	0.00	0	0
1	(27)	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	209,755
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	448,407
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	200,590
4		DEWI	4.0	20,844	0	0	3,496	0	0	0	0	24,840	49,180	FC	47.30	23,262	23,262
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	206,695
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	203,812
7		CRES	32.0	128,869	0	0	14,500	30,096	0	0	0	115,993	289,458	FC	50.00	144,729	144,729
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	160,056
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	297,704
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	98,166
11		GL-Wind	6.0	34,732	0	0	10,000	0	0	0	0	41,680	86,412	FC	50.00	43,206	43,206
12		DNV	6.0	44,191	0	0	10,000	0	0	0	0	55,240	109,431	FC	50.00	54,715	54,715
13		LM	17.2	83,303	0	0	16,500	30,500	0	0	0	83,303	213,606	FC	50.00	85,763	85,763
14		Polymarin	14.0	80,350	0	0	14,999	12,001	0	0	0	28,070	135,420	FC	47.50	84,312	84,312
15		NORDEX	4.1	56,016	0	0	5,499	2,000	0	0	0	0	63,515	FC	38.25	24,292	24,292
16		Gamesa	10.1	66,484	0	0	15,000	12,000	0	0	0	53,187	146,671	FF	47.30	69,375	69,375