TG3 – WP 8

Investigation of blade material behaviour under external (extreme) conditions.

WP8: Mechanical properties at extreme conditions

Participants

- Risø – Task leader
- WMC
- VUB
- UP
- VTT
- LM
- Vestas

Conditions

Extreme Conditions		
#	Environmental conditions	Remarks
1	Ambient room conditions	Reference
2	Temperature T=+60C	Extreme
3	Temperature T=-40C	Extreme
4	Humidity*	Extreme

* - Humidity – Test samples will be immersed in water and kept for 6 month and 12 month at ambient room temperature. The actual water take up will be measured by weight. The chemical composition of water and experimental procedure are according to standard ASTM D 1141-98, “Standard Practice for Substitute Ocean Water”.

Description of work packages (cont.)

Work package No : **WP8**	Start month: **1**		End month: **26**					
Work package title:	**MECHANICAL PROPERTIES AT EXTREME CONDITIONS**							
	Work package leader:	RISØ						
Participant:	TUDT	RISØ	VUB	VTT	LM	Vestas		
Person-months per participant:	4	18	3	9	1	1		

Objectives:

To determine the degradation mechanisms of fibre reinforced polymer materials under extreme climatic conditions and to determine the effect on the mechanical properties and design data for the reference material.

Description of work:

Task 8.1: DPA - Identification of degradation parameters and material

Major degradation mechanisms are defined and a literature research is carried out to identify the beneficial microstructural parameters. The degradation mechanisms are seen in the light of influence on component degradation and will be related to the basic damage mechanisms in the materials. By all partners.

Completed.

Task 8.2: Identification of extreme conditions relevant for wind turbines

Together with manufacturers and users the extreme conditions are identified. Especially the erection of wind turbines in hot regions (deserts), in arctic regions and in offshore positions necessitates a deeper understanding of the influences from environments. Temperature fluctuations, influences from humidity, chemical attacks, erosion and the combined effects are expected to be the main degradation factors. By all partners, LM and Vestas contributing from practical experience, RISØ and VTT from a research point of view.

Completed.

Task 8.3: Phenomenological modelling and experimental determination

Localised damage in form of delaminations, weakening in fibre-matrix interfaces and matrix embrittlement make changes to global properties such as damping, fatigue and fracture. This behaviour will be subject to constitutive modelling and materials parameter analysis and the material response can be predicted in phenomenlogical non-linear models based on damage mechanics. Environmental effects will influence the evolution of the local damage and the more critical parameters will be identified by means of sensitivity analysis. Experimental techniques to measure these parameters are already established and static as well as dynamic (damping and fatigue) mechanical tests are carried out. The extent of these test will depend on the number of critical parameters, and 5 static test and 15 dynamic tests are planned under various conditions in order to define the testing in task 8.4.

All partners will contribute to the identification of the parameters. Tests will be carried out by RISØ and VTT.

Completed. Models established for fibre breakage.

Task 8.4: Mechanical testing of reference material

An extensive mechanical testing programme is planned in order to investigate the influences from the degradation mechanisms on the mechanical properties and the sensitivity. 50 Static tests, 100 fatigue and damping tests and possibly 25 long-term creep tests will be accomplished at constant values of the above-identified extreme conditions (at least 4 levels). Test will be carried out mainly by RISØ and VTT, but also by TUDT and VUB.

Test programme completed with the exception of a C-C and C-T tests at 60° C and C-C tests at –40°.

Creep tests were not conducted based on an early decision.

Task 8.5: Mechanical testing for cycling climate conditions

Fluctuations of climate conditions are expected to influence the overall degradation. The effect of variation of climate conditions on the mechanical properties will be predicted by setting up models verified by mechanical tests. Definition of "trend lines" for ageing parameters for relatively short periods of accelerated ageing will be one of the routes to go. Another way is to use accelerated ageing of test coupons which will be achieved by immersion in water, temperature cycling for varying periods of time and in varying conditions of humidity, and by exposure to ultraviolet radiation. It will be considered if the test coupons should be loaded during ageing similar to creep tests. Also the number of tests must depend on the parameters, but 50 tests are planned. Test will be carried out mainly by RISØ and VTT.

Was not initiated due to a decision in Task 5.1

Deliverables:
2 Microstructural model and identification of degradation parameters.
3 Definition of extreme conditions and procedures for testing under extreme conditions.
12 Phenomenological micromechanics models for sensitivity analyses.
21 Effects of extreme conditions on properties of the reference material.
20 Effect of environmental ageing on reference material (report)
21
Milestones and expected results:
M5 Identification extreme conditions and action plan
M13 Evaluated extreme conditions effect

The Mid-Term Assessment is to be made against the satisfactory completion of the program items and includes the following achievements.

- **Determination of the static and fatigue behaviour under extreme condition**

Status Deliverables WP8

Table 2. List of Deliverables						
No	Deliverable title	Form	Month Due	Document	Month delivered	% Done
1	Test report describing the material, laminates and fatigue tests	Report	5	OB_TG3_R005	13	100
2	Microstructural model and identification of degradation parameters.	Report	5	OB_TG3_R006	13	100
3	Definition of extreme conditions and procedures for testing under extreme conditions.	Report	5	OB_TG3_R004	13	100
7	DPA for phase 1	Report	6	OB_TG3_O003	3	100
9	Approved DPA for phase 1	Report	6	OB_TG3_O004	12	100
12	Phenomenological micromechanics models for sensitivity analyses.	Report	18	OB_TG3_R014	26	100
21	Effects of extreme conditions on properties of the reference material	Report	26	OB_TG3_R015	34	80
22	Effect of environmental ageing on reference material (report)	Report	26	OB_TG3_R016	36	85
28	Approved DPA for phase 2, incl. alternative materials	Report	38			0
35	Report on variations in extreme conditions predictions due to material choice	Report	48			0
36	Database containing degradation behaviour of tested material combinations	Optidat				0
xx	Classification of failure modes	Report	46			0
xx	Verification of modelling using results from alternative tests	Report	48			0

Assessment of WP 8

- Mechanical tests carried out according to the following table
- Modelling of the damage mechanisms in Glass fibre reinforced Epoxy composites has been suggested and demonstrated.

Test matrix WP8

Environmental conditions	No of specimens to be tested											No of specimens to be tested						
Laboratory	Static										Total static	Fatigue						Total fatigue
Test method	T	T	T	T(‖)	T(⊥)	I	C	C	C(‖)	C(⊥)		T-T	T-T	T-C	T-C	C-C	C-C	
Laminate	UD 0	UD 90	UD 30	MD 0/+x	MD 0/+x	UD 90	UD 0	UD 90	MD 0/+x	MD 0/+x		UD 0	MD 0/+x	UD 0	MD 0/+x	UD 0	MD 0/+x	
Reference	10	10	10	10	10	10	10	10	10	10	100	30	15	30	15	30	15	135
Riso	5	5	5	5	5	5	5	5	5	5	50	15	15	5		5	15	55
VTT				5	5						10	5		5		15		25
WMC						5	5	5	5	5	25	5		15		5		25
VUB	5	5	5								15	5		5	15	5		30
T 60 C	5	5	5	5		5	5	5	0	0	35	5	5	5	5	5	5	30
Riso											0	5	5	5	5	5	5	30
VTT											0							0
WMC	5	5	5	5		5	5	5			35							0
VUB											0							0
T -40 C	5	5	5	5		5	5	5	0	0	35	5	5	5	5	5	5	30
Riso											0							0
VTT	5	5	5	5			5	5			30	5	5	5	5	5	5	30
WMC						5					5							0
VUB											0							0
RH 100%	0	0	0	0		0	0	0	0	0	0	15	15	5	5	5	5	50
Riso											0							0
VTT											0							0
WMC											0	5	5	5				15
VUB											0	10	10		5	5	5	35
Submersed	10	10	10	10	10	10	10	10	10	10	100	10	10	0	0	0	0	20
Riso	10	10	10	10	10	10	10	10	10	10	100	10	10					20
VTT	xx	xx	xx		xx		xx	xx	xx	xx		xx	xx					
WMC																		
VUB																		
total in colums	30	30	30	30	20	30	30	30	20	20	270	55	40	45	30	45	30	265
Riso	5	5	5	5	5	5	5	5	5	5	150	20	20	10	5	10	20	105
VTT	5	5	5	10	5	0	5	5	0	0	40	10	5	10	5	20	5	55
WMC	5	5	5	5	0	15	10	10	5	5	65	10	5	20	0	5	0	40
VUB	5	5	5	0	0	0	0	0	0	0	15	15	10	5	20	10	5	65

pending

To be reported

pending

Report sent to Risø

Results achieved from the first period

- The effects of extreme conditions on the reference material are found on basis of the testing.
- It has been found that that elevated temperature and humidity influence on the basic mechanical properties. This is mainly reflected in reduced shear properties and in elastic degradation. These failure modes will be studied more intensively in WP 9.

Comparison to original planning

- **Work tasks 8.1 to 8.3 has been fulfilled.**
- **Work task is close to be completed. Last static tests at –40° are ongoing and 4x5 tests at 60° and 2x5 tests at –40° are pending (Risø,VTT) (70 % completed)**
- **Work task 8.5 (Mechanical testing for cycling climate conditions) was not possible within the frame of the project.** *(Decision in WT 8.1 – DPA)*
- **Milestones M 15 and M 13 are reached satisfactory.**
- **WP 8 will be finished at the end of March (month 39)**

TG3 – WP 9

Investigation of blade material behaviour under external (extreme) conditions.

WP9: Extreme conditions for alternative materials

Description of work packages (cont.)

Work package No : **WP9**	Start month: **27**		End month: **43**					
Work package title:	**EXTREME CONDITIONS FOR ALTERNATIVE MATERIALS**							
	Work package leader:		RISØ					
Participant:	TUDT	RISØ	VTT	LM				
Person-months per participant:	6	9	14	1.5				

Objectives:

To characterise the variability of extreme conditions for alternative materials by additional experiments.

Description of work:

Task 9.1: DPA - Alternative materials testing at extreme conditions
Based on the experience, primarily from WP 8, a limited test plan will be prepared to establish the behaviour of the alternative materials under extreme conditions. Alternative materials can be more or less sensitive to some of the extreme environmental conditions and the most sensitive models will be selected to map this behaviour. By all partners.

Task 9.1: DPA - Alternative materials testing at extreme conditions
Based on the findings in phase 1, primarily from WP 8, a test plan will be prepared to establish a deeper understanding of the effects of the most detrimental environmental effects. These have been found to be elevated temperatures either by heating the test specimen up to 60°C or by running the tests at higher frequencies. A supplementary number of additional tests on the reference material and an investigation of the behaviour of an alternative material (glass fibers in a alternative resin is suggested) under the selected conditions are foreseen. Alternative materials can be more or less sensitive to some of the extreme environmental conditions and the most sensitive models will be selected to map this behaviour.

Task 9.2: Mechanical testing of alternative material combinations

A limited testing programme is initiated and carried out in order to investigate the influences and the sensitivity for alternative material combinations. The aim of this programme is to find differences of behaviour due to the different material combinations (e.g. the resin system). In order to define the most sensitive combinations, short term tests will be used in this part of the investigation. Because of limited resources, only a brief scan is expected, but in case serious differences from the reference material are found, limited long term tests may be necessary. 4 alternative material combinations are planned. 5 static and 25 dynamic test are expected on each material combination. Tests are carried out by VTT, RISØ and TUDT.

Task 9.2: Mechanical testing of reference and alternative material at elevated temperatures

A testing programme is carried out in order to investigate the mechanisms that are limiting the mechanical properties at elevated temperatures. The elastic properties, strength and fatigue lifetime will be analysed and the degradation effects compared to reference properties will be quantified. Test will conducted both at constant temperatures and under varying temperature sequences where effects of temperature variations and temperature gradients will be investigated.

In order to define the most sensitive combinations of mechanical loads and environmental effects, short term tests will be used in this part of the investigation. A brief scan is expected, but in case serious differences from the expected effects are found, limited long term tests may be necessary. The results wil have strong links to WP5.

Task 9.3: Interaction tests of extreme conditions with variable amplitude loading

This task synthesises the knowledge gained in WP 3, 4, and 8.
Stochastic loading can influence the effect of extreme conditions. Based on the results from the sensitivity tests in WP 8, the most influential conditions combined with the most critical stochastic loading defined in WP 3 and 4 will be chosen as test parameters. The interaction tests for extreme conditions will be carried out on flat specimens of the reference material with the same geometry as applied for the constant amplitude. Stochastic loading histories as WISPER and NEW WISPER tests of the other work packages are used to test the material, which at the same time is exposed to extreme conditions. 30 tests are foreseen. Tests are carried out by VTT, RISØ and TUDT.

Task 9.3: Identification and classification of damage modes

Basicly damage initiates from matrix cracking, interfacial failure and fibre breakage. The damage modes of the failed specimens will be studied and a classification of failure modes will be suggested. The aim of this task is to identify and study the mechanisms causing the degradation due to elevated temperatures and and hopefully this knowledge can lead to understand the frequency effects observed in phase 1.

Task 9.4: Testing of larger components

Larger components such as bolted and adhesively bonded root ends and wing parts are tested under extreme conditions. Joints are highly stressed parts in the wind turbine blades. An average blade is fastened by over 50 bolts and the reliability of these joints are one of the most critical factors in the wind turbine with respect to safety. Hence it is necessary to qualify these joints under the extreme climate conditions. 10 component tests are planned, to be carried out by RISØ and VTT.

Task 9.4: Modelling of damage behaviour

The damage progress is followed by observing the stiffness degradation during the tests. Analysis of experimental data from WP8 and WP9 wil be performed and the damage tensor will be implemented in the continuum damage models. The models will be put into action and used by another partner (VTT) and it will be considered to what extent a generalisation of the approach is possible (milestone and decision point)
If the generalisation is successful an internal state variable evolution law based on temperature effects associated with damage in fiber direction is formulated in terms of used theory, and determined experimentally. The experimentally determined evolution law of internal state variable is used in damage dependent constitutive relationships for laminate in order to predict the static strain - stress behavior of arbitrary laminates.
If the generalisation of the continuum damage model appears not to be possible, the modelling will change focus to a mechanistic phenomenological description of the generals damage degradation.

Task 9.5: Creation of a degradation database

All mechanical property data are collected in a database forming the background for design allowances. By all partners.

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Deliverables:

35 Report on variations in extreme conditions predictions due to material choice
36 Database containing degradation behaviour of tested material combinations

Milestones and expected results:

M18 Test plan alternative materials under extreme conditions
M27 Finalisation database properties on extreme conditions

Deliverables:

28 Approved DPA for phase 2, incl. alternative materials M 39

35 Report on variations in extreme conditions predictions due to material choice M 48
35a Classification of failure modes M 48
35b Verification of modelling using results from alternative tests M 48
36 Database containing degradation behaviour of tested material combinations M 52

Milestones and expected results:

M18 Test plan alternative materials under extreme conditions M39
M18a Implementation of damage evolution models for a general approach. (Decision point), M 44
M27 Finalisation database properties on extreme conditions M50

Proposal for detailed plan of action WP 9

- The elastic properties, strength and fatigue lifetime will be analysed at elevated temperature conditions, and the effects will be quantified. The effects on alternative materials will be studied
- Failure modes will be studies by visual inspection and microscopy.
- Analysis of damage mechanisms and evolution will be studied.
- The continuum mechanics model will be generalized for general use – *if possible*
- Verification of the modelling by testing alternative material
- The quantified values will form the basis for necessary safety factors or partial coefficients and give input to WG6.

Assessment of WP 9

The work in WP 9 will make it possible to suggest established procedures for measuring and analysing the effects of extreme conditions (especially temperature) on the mechanical properties based on a limited number of test.

Comparison to original planning

- It will not be possible to test larger components and neither the idea of testing interactions between different conditions and e.g. loading will be possible to address in this project. These limitations are primarily due to the difficulties encountered in the initial phases with the definition of appropriate test specimen geometries and the apparently large scatter in the basic results.
- Originally defined deliverables and milestones for the workpackage are expected to be fulfilled. Extra delivarables are foreseen.

Test matrix for WP9

Environmental conditions	No of specimens to be tested										
Laboratory							Total static	Fatigue			Total fatigue
Test method	T	T	T	I	C	C		T-T	T-C	C-C	
Laminate	MD 0	MD 90	MD 30	MD 90	MD 0	MD 90		MD 0	MD 0	MD 0	
RT	5	5	5	5	5	5	30	10	10	10	30
Riso	5	5	5	5	5	5	30	10			10
VTT							0		10		10
WMC							0			10	10
T 60 C	5	5	5	5	5	5	30	10	10	10	30
Riso							0	10			10
VTT	5	5	5	5	5	5	30		10		10
WMC							0			10	10
T combined	0	0	0	0	0	0	0	20	20	20	60
Riso							0	20			20
VTT							0		20		20
WMC							0			20	20
total in colums	10	10	10	10	10	10	60	40	40	40	120
Riso	5	5	5	5	5	5	30	40	0	0	40
VTT	5	5	5	5	5	5	30	0	40	0	40
WMC	0	0	0	0	0	0	0	0	0	40	40