Yearly report of TG3 (2003)

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Draft version

OPTIMAT BLADES

TG3

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Change record

Issue/revision	date	Pages	Summary of changes
draft	12-02-04	Na	na
V01	23-2-2004	4-6	More comments, plots and data tables are added

DETAILED REPORT FOR TASK 3

In the following, detailed information can be found regarding the activities for Task 3: 'Extreme conditions' (WP8 and WP9).

Main objectives for this period

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

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

Overview of technical achievements

DPA of WP8 and WP9
After a considerable amount of discussion, the DPA has been drafted in accordance with the choices made regarding the specimen geometries for the whole project. The DPA has been approved by the Scientific Committee in their Stuttgart meeting of December 16.

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

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

Phenomenological modeling and experimental determination
The statistical methods, such as linear regression, maximum likelihood using pooled or censored data, statistics for conditioned random variables, Weibull statistics, or combination of mentioned are available to describe fatigue life diagrams and its tolerance bounds. All the methods have been analyzed theoretically and compared in order to formulate methods that satisfy the considered tests and its objectives. The linear regression in log-log domain with 95%95% confidence limits is selected. It gives the most conservative design curve for fatigue life. The extreme conditions has no apparent effect on the fatigue life of reference UD material (R=0.1), see Figure 1.

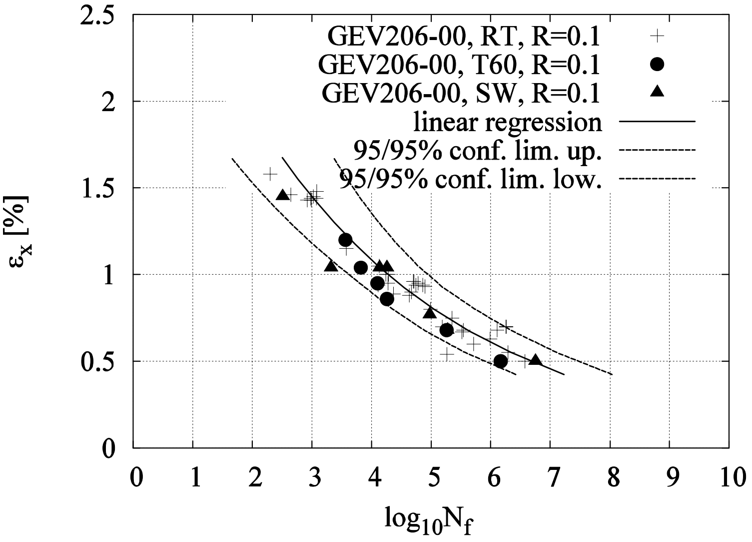


Figure 1.

However, Considerable degradation of mechanical properties has been observed for UD basic material as a result of exposure to salt water for 6 month, see Table 1, Table 2. The additional tests are selected and mentioned theoretical tolls are selected that will be used in order to reveal the mechanisms.

Table 1 Elastic properties of GEV206

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

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

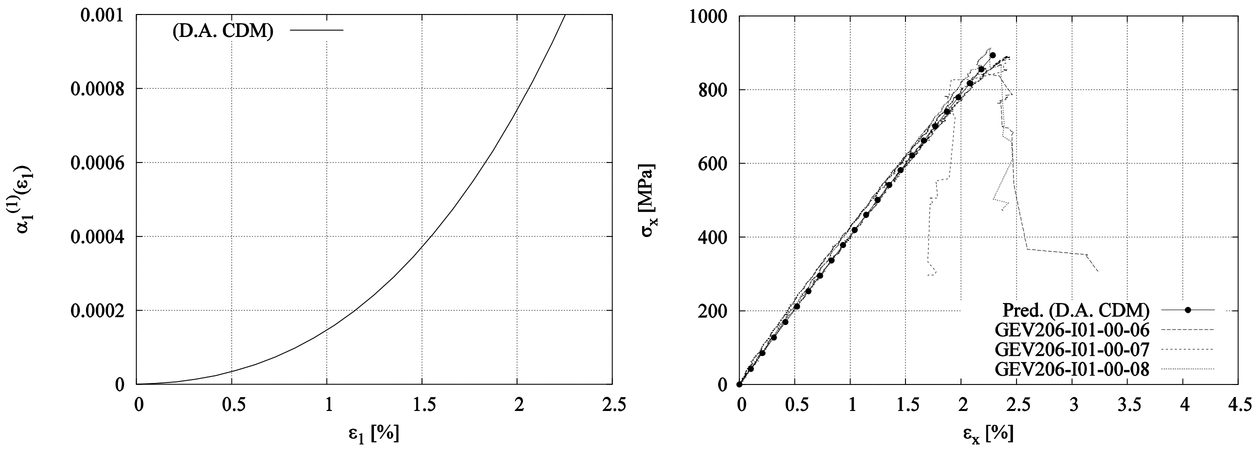
Table 2 Strength properties of GEV206

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

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

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

Corresponding test program is compiled that renders all the necessary data for characterization of considered mechanical properties at selected extreme conditions. The experiments have been carried out, and the damage evolution law for corresponding damage mode can be characterized experimentally at different environmental conditions. The fiber fracture in the UD material at static tensile loading conditions is described with corresponding damage tensor, and it's values are measured experimentally, see Figure 2a. Further the quantified damage tensor is used into damage dependent constitutive law of the laminate, and the strain stress behavior is described, see Figure 2b. That way, the validity of the general formulation of the approach is conformed, and will be used for other damage modes for different extreme conditions.



a) b)

Figure 2

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

Comparison of planned activities to accomplished work

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

Planned activities for the next period

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

Deliverables

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

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

Pre-draft version of Design Recommendations

In the following a sketch is given of what the Design Recommendations could look like for the part addressed by TG3. No exact figures can be given at this moment.

The elastic properties, strength and fatigue lifetime will be analyzed at different extreme conditions, and expected differences will be quantified. Where the quantified values can be transformed into safety factors if necessary.
Analysis of damage mechanisms and evolution will be studied that results in knowledge of what damage mechanisms are the most sensitive and to be considered at design stage of the blade in order to ensure more predictable lifetime of the blade. Also gives basic understanding of what would happen if the lay-up of the laminate would be changed.