

# **Investigation of Blade Material Behaviour under Complex Stress States**

## **DETAILED PLAN OF ACTION WP7: Interaction Effects and Complex Loading of Alternative Material**

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*Confidential*



*TG2*

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## 1. Introduction

In this report, the actions required for Work Package 7 to reach the objectives are defined. The objectives and work description are given in the technical annex (revised Annex I) and repeated in this document for convenience.

The Detailed Plan of Action (DPA), Phase 2, for TG2: "Investigation of Blade Material Behavior under Complex Stress States" consists in essence of tests in 2 materials, i.e. the reference material, investigated in Phase 1, and an alternative material. The alternative material shall be of the same reinforcement but of another resin matrix. The 2 cases are henceforth denoted as DPre and DPal. A comprehensive explanation of the scope, methodology and planning of each test series is presented in the sequel.

An overview of the foreseen tests:

### A. DPre: Verification tests for residual strength and life prediction

DPre1: CA fatigue residual strength tests → 54 coupons GEV208-I1000

DPre2: VA fatigue tests for life prediction → 10 coupons GEV208-I1000

DPre3: VA fatigue residual strength tests → 10 coupons GEV208-I1000

DPre4: Biaxial loading-unloading-reloading static tests → 15 GEV207-S0100 (cruciform)

DPre5: Biaxial CA fatigue tests → 15 GEV207-S0100 (cruciform)

### B. DPal: Tests for UD material characterization and comparison to reference material

DPal1: Static tests → 10 GEV206-R0300 + 10 GEV213-R0390 + 5 GEV208-I1000

DPal1.a: 10 GEV206-R0300

DPal1.b: 10 GEV213-R0390

DPal1.c: 5 GEV208-I1000

DPal2: CA fatigue tests → 15 GEV208-I1000

DPal3: Biaxial loading-unloading-reloading static tests → 15 GEV207-S0100 (cruciform)

DPal4: Biaxial CA fatigue tests → 15 GEV207-S0100 (cruciform)

Involved partners: UP (Task Leader), CRES, VUB, WMC



## **2. DPA for WP 7**

### **Description of Work**

The objectives of this work package are:

- a. To study interaction effects, e.g. variable amplitude loading and complex stress states, on the reference UD material
- b. To generate test results of basic plies and multi-directional laminates for the alternative material
- c. To validate the multi-axial failure theories by comparison of theoretical predictions with test results
- d. To verify complex stress state and interaction effect on reference and alternative material response

### **Task 7.1: DPA – Selection of Alternative Material Combinations**

For the selected alternative material and interaction effects for the reference material, a test plan will be prepared on uni- and multi-axial testing. All partners.

### **Task 7.2: Establishment of Experimental Data**

All basic mechanical properties of UD material will be measured (elasticity and strength) following the methodology of WP 6. For a selected number of load combinations multi-axial static and fatigue tests will be accomplished. Tests on cruciform test specimens will be carried out by VUB. UP, WMC and CRES will carry out the uni-axial tests.

### **Task 7.3: Validation of the Theoretical Prediction**

Using the experimental data from Task 7.2 the theoretical predictions, following from WP 6, will be validated. Both static and fatigue conditions will be examined. Deviations from the theory will be documented and reported. All partners.

### **Modifications to the Annex**

The above description of work complies with updated Annex I of the contract, revised after the MTA meeting, no modifications being made thereafter.

### **Laminate and Specimen Definition**

Tests on the reference material shall be performed on ISO straight-edge GEV208-I1000 coupons, laminate  $[\pm 45]_s$  COMBI 1250 and cruciform GEV207-S0100 coupons, MD laminate  $[(\pm 45/0)_4/\pm 45]$ .

From the alternative material standard OB coupons shall be used, i.e. GEV206-R0300 and GEV213-R0390, along with ISO straight-edge GEV208-I1000 specimens  $[(\pm 45]_s$  COMBI 1250).

Details on number of coupons and specific comments are given in Table 1.



## Test Plan

### Outline of Tests, Instrumentation and Reporting

In WP7, tests on both reference and alternative material are foreseen. Residual strength tests, after CA and VA fatigue, as well as life prediction in VA fatigue shall be performed on the reference material, GEV208-I1000 coupon. To determine the mechanical properties of the alternative material and compare them to the reference, static and constant amplitude fatigue tests are planned. In addition, cruciform specimens of the reference material shall be used in static biaxial tests.

Depending on the test, strain or clip gauges and strain gauge rosettes, Platinum PT100 sensors for temperature measurements<sup>1</sup> and various NDT setups will be used throughout the test series.

All tests will be reported in OptiDAT as soon as tests are accomplished. Test reports, including data, figures and photographs will be prepared after a complete set of tests has been finished.

### Tests on the Reference Material

#### DPre1: Residual Strength Tests after CA Fatigue

Scope: The investigation of strength degradation of the GEV208-I1000 specimen after specified CA tensile loading, R=0.1.

Test specification: CA fatigue tests shall be performed as described in document OB-TG2-R-020 (3 stress levels i.e. 5000, 50000 and 10E6, 18 coupons each). Coupons are to be fatigued at 20, 50 or 80% life fractions (6 coupons per life fraction and stress level) as stated in OB-TG5-R002 and then tested in static tension. NDT procedures to be followed in residual strength tests are described in OB-TG5-R002.

Note: Identical tests have been performed during Phase 1, resulting in interesting findings. The aim of further testing is to enrich the database with more test points.

#### DPre2: VA Fatigue Tests for Life Prediction

Scope: The investigation of the behavior of the GEV208-I1000 coupon in VA loading.

Test specification: Details on test procedure shall be available soon. Tests at 2 stress levels are foreseen, 5 coupons each.

#### DPre3: Residual Strength Tests after VA Fatigue

Scope: The investigation of strength degradation of the GEV208-I1000 specimen after VA loading.

Test specification: Details on VA fatigue procedure shall be available soon. Tests at 2 stress levels, 5 coupons each, are foreseen. Coupons are to be fatigued at a number of spectrum flights corresponding to 50% of VA fatigue life and

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<sup>1</sup> Temperature on the surface of the specimen should not exceed 35 °C



then tested in static tension. NDT procedures to be followed in residual strength tests are described in OB-TG5-R002.

**DPre4: Biaxial loading-unloading-reloading static tests of MD Cruciform Specimens**

Scope: Investigation of damage progression due to incremental static loading and study of the effect of biaxial loading. 15 cruciform specimens (5 biaxiality ratios, 3 specimens each)

Test specification: Document OB-TG2-R016.

**DPre5: Biaxial CA fatigue tests of MD Cruciform Specimens**

Scope: Investigation of fatigue behaviour, MD material, under biaxial loading. 15 cruciform specimens (5 biaxiality ratios, 3 specimens each)

Test specification: Details on CA fatigue procedure for cruciform specimens shall be available soon.

**Tests on the Alternative Material**

**DPal1: Static Tests for Material Characterization**

Scope: Measurement of mechanical properties of the alternative material.

Test specification: Tests are to be performed as described in documents OB-TG2-R018 (parallel and transverse to the fiber direction) and OB-TG2-R020 (in-plane shear properties).

**DPal2: CA Fatigue Tests for Material Characterization**

Scope: Investigation of tensile CA fatigue behavior of the GEV208-I1000 coupon at R=0.1 and comparison to the corresponding data from the reference material.

Test specification: As described in OB-TG2-R020. All test frequencies will be 5 Hz.

**DPal3: Biaxial loading-unloading-reloading static tests of MD Cruciform Specimens**

Scope: Investigation of damage progression due to incremental static loading and study of the effect of biaxial loading. 15 cruciform specimens, MD alternative material (5 biaxiality ratios, 3 specimens each)

Test specification: Document OB-TG2-R016.

**DPal4: Biaxial CA fatigue tests of MD Cruciform Specimens**

Scope: Investigation of fatigue behaviour, MD alternative material, under biaxial loading. 15 cruciform specimens (5 biaxiality ratios, 3 specimens each)



Test specification: Details on CA fatigue procedure for cruciform specimens shall be available soon.

### **Evaluation**

Based on the test data generated in this work package, concerning complex stress states, and Tasks 3.3 and 3.4, the comparison of the performance of 2 different resins (reference and alternative) will be achieved. The database of the reference material (coupon GEV208-I1000) will be enhanced with more CA residual strength tests as well as RS tests after VA loading. Interaction effects will thus be investigated. Life prediction and residual strength of a specific coupon (GEV208-I1000) in VA loading will be attempted.



### 3. Test specimen specifications according to TG2 DPA Phase 2

Notes: Thickness of COMBI 1250: 0.88 mm, thickness of biaxial fabric: 0.61 mm

|    | Test code name | Description of Test                                  | Coupon OB Definition | Laminate Stacking Sequence         | Number of Specimens | Comments             |
|----|----------------|--|----------------------|------------------------------------|---------------------|----------------------|
| 1  | DPre1          | CA Residual Strength Tests, R=0.1                    | GEV208-I1000         | [45/-45] <sub>s</sub> , COMBI 1250 | 54                  | Reference Material   |
| 2  | DPre2          | VA Fatigue Tests                                     |                      |                                    | 10                  |                      |
| 3  | DPre3          | VA Fatigue Residual Strength Tests                   |                      |                                    | 10                  |                      |
| 4  | DPre4          | Static (L-U-R) biaxial tension of cruciform specimen | GEV207-S0100         | [(±45/0) <sub>4</sub> /±45]        | 15                  | Reference Material   |
| 5  | DPre5          | CA fatigue of cruciform specimen                     |                      |                                    | 15                  |                      |
| 6  | DPal1.a        | Static tension, compression (?)                      | GEV206-R0300         | [0 <sub>4</sub> ], COMBI 1250      | 10                  | Alternative Material |
| 7  | DPal1.b        | Static tension, compression (⊥)                      | GEV213-R0390         | [0 <sub>7</sub> ], COMBI 1250      | 10                  |                      |
| 8  | DPal1.c        | Static tension, in-plane shear                       | GEV208-I1000         | [45/-45] <sub>s</sub> , COMBI 1250 | 5                   |                      |
| 9  | DPal2          | CA Fatigue, in-plane shear, R=0.1                    |                      |                                    | 15                  |                      |
| 10 | DPal3          | Static (L-U-R) biaxial tension of cruciform specimen | GEV207-S0100         | [(±45/0) <sub>4</sub> /±45]        | 15                  |                      |
| 11 | DPal4          | CA fatigue of cruciform specimen                     |                      |                                    | 15                  |                      |