# Overview of draft DPA's for phase 1

This document is a combination of the test programmes sent in by the TLs.
Corrected after comments and changes made at TG meetings June 17-19 2002 at Risø.

# 1. Introduction

Based on the information sent out by the TLs, the tables have been filled in.
Because the discussion is still going on, it is not yet possible to come up with final figures, and a lot of comments were added of points to be sorted out.
The task leaders are kindly asked to carefully check the tables and/or add their tests or comments where they have not yet done so or where changes by others cause new comments.

A problem identified at the kick-off meeting, is the possibility of ‘overlap’ of tests between different TGs. Some examples of overlap:

- Most TGs will need static test results to compare them to fatigue strength, residual strength, strength under extreme conditions;
- Residual strength test results will be needed to develop models for variable amplitude;
- Block tests should be done at the same stress levels tested in the residual strength tests;

## 2. Notation

Superscripts denote the task leader, which suggested the test.
So, for instance axial tensile tests on UD lay-up will be carried out 25 times in ambient conditions (Theo asked for 25 tests, Povl for 5), 5 times at +40° C, 5 times at –60° C and 5 times after immersion.

- An empty cell denotes a possible combination that no one seems interested in.
- The TG that is tentatively scheduled to carry out the tests is shown in **bold** type.
- A special bullet is used to highlight discussion topics:➢.

| 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. |
| ABC, CBA | Denotes possible sequence variations in 3 block tests with 3rd block to failure, e.g. 1st block R=0.1, 2nd block R=0.5, 3rd block R=-1 and vice versa. |
| C | Compression static |
| C-C | Compression-Compression fatigue |
| CA | Constant amplitude |
| 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 ±45º 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 +/-45º face layers) |
| UTS | Ultimate Tensile Strength |
| W | WISPER standard loading sequence |
| WX | WISPERX standard loading sequence |

## 3. Static tests on Optimat standard test specimens

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

**Static Tests on Optimat Blades specimens**

| lay-up | Test | Type of test | | UD or MUD | | | | | MD | | | | | ±45º (shear/tubes) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Axial (//) | T | | | 10 | 25 | 5 | | | 10 | | 5 | | | | | | | |
| | C | | | 10 | 25 | 5 | | | 10 | | | | | | | | | |
| Transverse (^) | T | | | | 25 | 5 | | | | | | | | | | | | |
| | C | | | | 25 | 5 | | | | | | | | | | | | |
| 10° | T | | | | 5 | | | | | 5 | | | | | | | | |
| | C | | | | 5 | | | | | 5 | | | | | | | | |
| 60° | T | | | | 5 | | | | | 5 | | | | | | | | |
| | C | | | | 5 | | | | | 5 | | | | | | | | |
| 30° | T | | | | | 5 | | | | | | | | | | | | |
| Axial (//) | T | 40°/-60°/100% | | | | 15 | | | | | 15 | | | | | | | |
| | C | 40°/-60°/100% | | | | 15 | | | | | | | | | | | | |
| 30° | T | 40°/-60°/100% | | | | 15 | | | | | | | | | | | | |
| Transverse (⊥) | T | 40°/-60°/100% | | | | 15 | | | | | | | | | | | | |
| | C | 40°/-60°/100% | | | | 15 | | | | | | | | | | | | |

*[2] Theodore states the straight optimat specimen. It is unclear whether the dogbone shape is also acceptable. For now, they are grouped under the standard Optimat specimens.*
*[3] Tests for task group 3: at +60°C/-40°C/ 100% RV (the latter series being immersed in water for one year, prior to testing)*

In order to have static properties on the same specimen as the fatigue and residual strength properties, it has been proposed to use the standard Optimat Blades Specimen for static tests as well, with fewer tests on ISO standard specimens.

- For now, the static testes under extreme conditions tests are listed under the Standard Optimat Specimen. However, Povl prefers doing all tests on the optimum test geometry (presumably ISO/ASTM), rather than using the Optimat Blades standard test for static tests as well. For extreme conditions, this is quite workable, but for residual strength it probably is not. To be discussed by the TC.
- Theo suggests in OB_TG2_002_UP to get ply properties from ISO/ASTM tests.

# 4. Static tests on ISO/ASTM standard tests specimen

As mentioned in the test specimen proposal, and within discussions within task groups, we also need standard tests to relate the static test results with the Standard Optimat Specimen to standard tests.

We propose to use:

- ISO 527-5 for tension
- Iosipescu for shear (ASTM 5379)
- ASTM D 6641 (the combined Wyoming test equipment) for compression, see Figure 1.
  See also:
  http://wyomingtestfixtures.com/products.htm
  page 18-19.

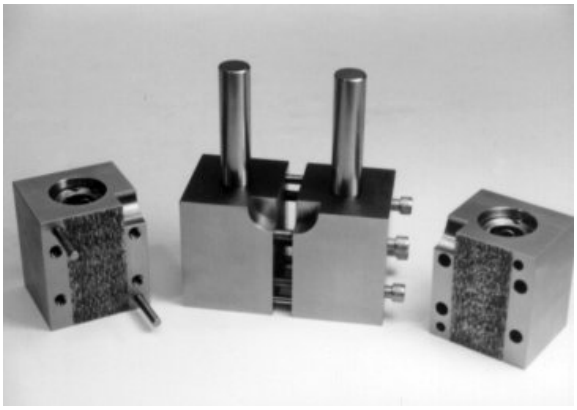

**Figure 1 Wyoming combined loading test set-up**

## Static Tests on ISO/ASTM specimens

| lay-up | Test | Type of test | | UD or MUD | | | | | MD | | | | | ±45º (shear/tubes) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Axial (//) | T | | | | | | | | | | | | | | 25 | | | |
| | C | | | | | | | | | | | | | | | | | |
| Transverse (⊥) | T | | | | | | | | | | | | | | | | | |
| | C | | | | | | | | | | | | | | | | | |
| Thickness | C | | | | | | 5 | | | | | | | | | | | |
| Shear | IPS | | | | | 5 | | | | | | | | | | | | |
| | 13 | | | | | | 5 | | | | | | | | | | | |
| | 23 | | | | | | 5 | | | | | | | | | | | |
| 4 Point Bending | | | | | | | 5 | | | | | 5 | | | | | | |
| Shear | IPS | 40°/-60°/100% | | | | 15 | | | | | | | | | | | | |
| Hygro Thermal | $\alpha_1$ | | | | 25 | | 3 | | | | | 3 | | | | | | |
| | $\alpha_2$ | | | | 25 | | 3 | | | | | 3 | | | | | | |
| | $\beta_1$ | | | | | | 3 | | | | | 3 | | | | | | |
| | $\beta_2$ | | | | | | 3 | | | | | 3 | | | | | | |

*[2] For correct ply results, Theo deems UD necessary for transverse and shear tests, MUD is acceptable for axial tests. For Iosipescu pure UD is required, no MUD*
*[3] Tests for task group 3: at +60°C/-40°C/ 100% RV (the latter series being immersed in water for one year, prior to testing)*
*[4→3] Peter proposes to the TC that the hygrothermal properties (thermal and moisture expansion coefficients) of the thick laminates will be established by TG3. He proposes UD for the ISO/ASTM tests in this table, except for the 4-point bending tests*

- Do we need many static tests for both the Optimat and ASTM/ISO geometries?

## 5. Static tests on special test specimens

A number of tests are carried out on special test specimens, for instance 2D tests for TG2, and test on thick and repaired. Especially for static tests, a lot of additional geometries are considered, so they were split off and put in a separate table.

**Static Tests on special test specimens**

| lay-up | Test | Type of test | | UD or MUD | MD | ±45º (shear/tubes) |
|---|---|---|---|---|---|---|
| 2D test specimens [2] | | | | | | |
| 2D stress state tests | | Cruciform | 3 layer | | 15 | |
| | | Tubes | | | | 15 |
| Long test specimens as reference for repaired specimens [4] | | | | | | |
| Axial (//) | T-T | | | 5 | | |
| Bending | T up | | | 5 | | |
| | C up | | | 5 | | |
| Repaired test specimens [4] | | | | | | |
| Axial (//) | T | | | | | |
| (long spec.) | | | | 90 | | |
| Bending | T up | | | 90 | | |
| (long spec.) | C up | | | 90 | | |
| Thick test specimens [4] | | | | | | |
| Axial (//) | T | | | 5 | 5 | 5 |
| | C | | | 5 | 5 | |
| Transverse (⊥) | T | | | 5 | 5 | |
| | C | | | 5 | 5 | |
| Thickness | C | | | 5 | 5 | |
| | Shear | | | 10 | 10 | |
| Bending | T up | | | 5 | | |
| | C up | | | 5 | | |
| Hygro Thermal | $\alpha_1$ | | | 5 | 5 | |
| | $\alpha_2$ | | | 5 | 5 | |
| | $\beta_1$ | | | 5 | 5 | |
| | $\beta_2$ | | | 5 | 5 | |
| Repaired thick test specimens [4] | | | | | | |
| Axial (//) (long spec.) | T | | | 5 | | |
| Bending (long spec.) | T up | | | 5 | | |
| | C up | | | 5 | | |

*[4] For the repaired test specimens,a number of types are tested, currently, 3 types of repair with 5 specimens per repair type are proposed.*
*[4] For the tests in thickness direction, not only the test in 3-3 direction is proposed, but also tests in 1-3 and 2-3 direction.*

- *[4] Peter refers to tests of TG2 for the thin specimens. He proposes MUD for his tests, except for the hygro thermal tests, where UD is to be used.*

# 6. CA fatigue tests

## CA Tests

| lay-up | Test | Type of test | R | UD or MUD | | | | | MD | | | | | ±45º (shear/tubes) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Standard Optimat Specimens | | | | | | | | | | | | | | | | | | |
| Axial (//) | T-T | shear on long test | 0.1 | 21 | 15 | 15 | 15 | | 21 | | 15 | | | | 15 | | | |
| | | | 0.5 | 21 | | | | | | | | | | | | | | |
| | T-C | | -0.4 | 21 | | | | | | | | | | | | | | |
| | | | -1 | 42 | 15 | 15 | x | | 21 | | 15 | | | | | | | |
| | | | -2.5 | 21 | | | | | | | | | | | | | | |
| | C-C | | 10 | 21 | 15 | 15 | x | | 21 | | 15 | | | | | | | |
| | | | 2 | 21 | | | | | | | | | | | | | | |
| Transverse (⊥) | T-T | | 0.1 | | 15 | | | | | | | | | | | | | |
| | T-C | | -1 | | 15 | | | | | | | | | | | | | |
| | C-C | | 10 | | 15 | | | | | | | | | | | | | |
| 10° | T-C | | 0.1 | | 10 | | | | | | | | | | | | | |
| 60° | T-C | | 0.1 | | 10 | | | | | | | | | | | | | |
| 10° | T-C | | -1 | | | | | | | 10 | | | | | | | | |
| 60° | T-C | | -1 | | | | | | | 10 | | | | | | | | |
| Axial (//) | T-T | 40°/-60°/100% | 0.1 | | | 15 | | | | | 15 | | | | | | | |
| | T-T | submersed | 0.1 | | | **5** | | | | | **5** | | | | | | | |
| | T-C | 40°/-60°/100% | -1 | | | 15 | | | | | 15 | | | | | | | |
| | C-C | 40°/-60°/100% | 10 | | | 15 | | | | | 15 | | | | | | | |
| 2D test specimens [2] | | | | | | | | | | | | | | | | | | |
| 2D Stress state tests | T-T | Cruciform thin laminate | 0.1 | | | | | | | 30 | | | | | | | | |
| | T-C | Tube | -1 | | | | | | | | | | | | 45 | | | |
| Long test specimens as reference for repaired specimens [4] | | | | | | | | | | | | | | | | | | |
| Axial (//) | T-T | | 0.1 | | | | | | | | | 15 | | | | | | |
| Repaired test specimens [4] | | | | | | | | | | | | | | | | | | |
| Axial (//) | T-T | | 0.1 | | | | | | | | | 15 | | | | | | |
| Thick test specimens [4] | | | | | | | | | | | | | | | | | | |
| Axial (//) | T-T | | 0.1 | | | | | | | | | 15 | | | | | 15 | |
| | T-C | | -1 | | | | | | | | | 15 | | | | | 15 | |
| | C-C | | 10 | | | | | | | | | 15 | | | | | 15 | |
| Repaired thick test specimens [4] | | | | | | | | | | | | | | | | | | |
| Axial (//) | T-T | | 0.1 | | | | | | | | | 15 | | | | | | |

*[1]Christoph uses 6 tests 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.*
*[2]Theo wanted 20 per cell, so the reliability can be established as well.*
*R ratio is not given by Theo for off axis tests and 2D stress state tests*
*Off-axis and 2D tests: 2 stress levels, 5 tests per stress level (=10 per cell)*
*[3] Tests for task group 3: at +60°C/-40°C/ 100% RV (the latter series being immersed in water for one year, prior to testing)*
*x[4] Peter takes the results from TG1*

# 7. VA fatigue tests and block tests on Optimat standard tests specimen

## VA and Block Tests

| lay-up | Test | Type of test | R | UD or MUD | | | | | MD | | | | | ±45º (shear/tubes) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Standard Optimat Specimens | | | | | | | | | | | | | | | | | | |
| W | | | - | 15 | | | | | 15 | | | | | | | | | |
| WX | | | - | 15 | | | | | 15 | | | | | | | | | |
| RW | | | - | 15 | | | | | | | | | | | | | | |
| RWX | | | - | 15 | | | | | | | | | | | | | | |
| NW | | | - | 15 | | | | | 15 | | | | | | | | | |
| NWX | | | - | 15 | | | | | | | | | | | | | | |
| T-T | | AB* | | 15 | | | | | | | | | | | | | | |
| T-C | | AB* | | 15 | | | | | | | | | | | | | | |
| C-C | | AB* | | 15 | | | | | | | | | | | | | | |
| T-T | | HL | 0.1 | 15 | | | | | | | | | | | | | | |
| T-C | | HL | -1 | 15 | | | | | | | | | | | | | | |
| C-C | | HL | 10 | 15 | | | | | | | | | | | | | | |
| T-T | | AB* | | 15 | | | | | | | | | | | | | | |
| T-C | | AB* | | 15 | | | | | | | | | | | | | | |
| C-C | | AB* | | 15 | | | | | | | | | | | | | | |
| T-T | | HL | 0.1 | 15 | | | | | | | | | | | | | | |
| T-C | | HL | -1 | 15 | | | | | | | | | | | | | | |
| C-C | | HL | 10 | 15 | | | | | | | | | | | | | | |

## 8. Residual strength tests on Optimat standard tests specimen

| Residual Strength tests | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| lay-up | Test | Type of test | R | UD or MUD | | | | | MD | | | | | ±45º (shear/tubes) | | | | |
| Standard Optimat Specimens | | | | | | | | | | | | | | | | | | |
| Axial (//) | T-T | 20/50/80% | 0.1 | | | | | 72 | | | | | 72 | | | | | 36 |
| | T-C | 20/50/80% | -1 | | | | | 72 | | | | | 72 | | | | | |
| | C-C | 20/50/80% | 10 | | | | | 72 | | | | | 72 | | | | | |
| Transverse (⊥) | T-T | 20/50/80% | 0.1 | | | | | 72 | | | | | | | | | | |
| | T-C | 20/50/80% | -1 | | | | | 72 | | | | | | | | | | |
| | C-C | 20/50/80% | 10 | | | | | 72 | | | | | | | | | | |

*[5]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 the number of tests per cell =36 tests.*

# 9. Fatigue test programme

The general idea is that after the static tests have been carried out, a number of tests will establish the general position of the main S-N line for R=-1.
Based on this line, **three stress levels** can be established for the CA fatigue tests, aiming for a fatigue life of for instance $10^3$, $10^5$ and $10^7$ cycles.
For other R-values, a first estimate can be made based on the Goodman diagram, plus a few preliminary tests to establish three stress levels.

Although it requires some extra test for fitting 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 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 and thick laminates, we can just test at specific stress levels, where a wealth of comparison data concerning (for instance scatter) at that stress level is available, without any necessary conversion steps.
- Another advantage is that relatively much data is available at the extremes of the S-N line, so that the slope can be determined more accurately.

- Povl prefers varying stress levels, to cover the whole length of S-N line better.
- Theo currently has proposed four stress levels, rather than three.
- We think the stress levels should be aimed to correspond to $10^3$, $10^5$ and $10^7$ cycles.

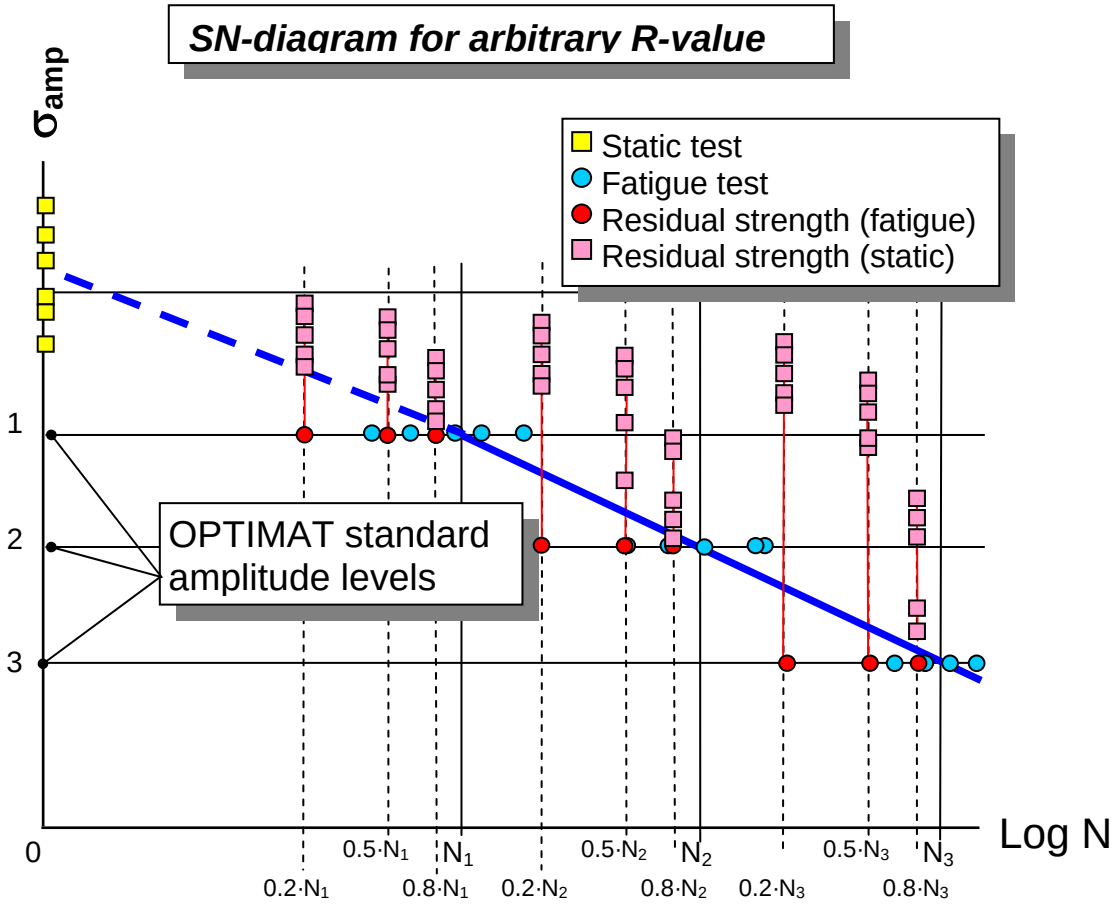


**Figure 2 Static, fatigue and residual strength tests**

# 10. Questions for the next TC meeting (June 20th)

**Test specimen**

- *Do we opt for the straight specimen or the dogbone?*
  Or if the test results of the preliminary programme are unsatisfactory, do we need another geometry.
- *How many tests do we need with standard ISO/ASTM geometry for verification with accepted practise and for material properties?*
  - We do need static data for the S-N line and residual strength evaluation.
    It is necessary to have that data on the standard specimen, otherwise it will be hard to compare with residual strength test results.
  - If we opt for the straight specimen, is it still worthwhile to do ISO/ASTM tests as well? Given the importance of the issue at hand and the relative ease of testing, we could probably afford do a number of static tests for both ISO/ASTM and OPTIMAT geometries.
  - Should the static properties under extreme conditions be determined on ISO or OPTIMAT test specimens?
    For comparison with fatigue tests under extreme conditions it is probably preferable to do the static tests under extreme conditions on the OPTIMAT specimen, but for the "optimal" material specs, ISO/ASTM may be preferable.
- *Which ISO/ASTM specimens do we select?*
  - For an EC project ISO might be preferable over ASTM.
  - We propose ISO 527-5 for tension, Iosipescu for shear, and ASTM D 6641 (the combined Wyoming test equipment) for compression.

  *We should also establish the precise specimen dimensions, tabs etc., since the guidelines typically allow various test specimens.*
  - Theo proposed various thickness (1,2,3 and 5 mm) and test specimens in the appendix of OB_TG2_R002_UP. The large number of plate thicknesses alone requires additional effort from LM.

**(M)UD Material lay-up**

- *Do we opt for ±45° face layers (MUD) or 0° only," pure" UD (UD)?*
  - The first option may lead to better test results.
  - However, should this option be selected, we still need to make extra plates of pure UD as well, for instance for the determination of properties and off-axis properties, where the ±45° layers could have a severe impact on the results.
  - A fatigue model based on UD (ply) properties may yield overoptimistic results, since the stress concentring effect of layers in various directions is absent in pure UD tests.

**Fatigue test programme**

- *Do we test at specific stress levels or test all along the S-N line?*
  Testing at specific levels requires a few preliminary tests to establish the S-n line and hence the test loads. See discussion in 9.

- *Should we maintain a constant strain rate or the fatigue tests, instead of a fixed frequency?*
  - Should we carry out static tests at the same (high) strain rate as well?

- *If we opt for fixed stress levels, how many?*
  Assuming a straight S-N line, which is fairly typical but not guaranteed, 2 stress levels

at the extremes would suffice.
A third level would be useful as well:

- Check whether the S-N line can be assumed to be straight
- For use when only a few fatigue tests are planned for specific purposes (for instance 2D fatigue tests)
- As a starting point for tests where the difference from the established S-N line might be large to either side (for instance extreme conditions which may be beneficiary or detrimental for the fatigue behaviour.

  We propose three levels aimed at $10^3$, $10^5$ and $10^7$ cycles and to use the same levels for thick laminates, extreme conditions, 2D tests etc. in order to have good, 1:1 comparable test data where also the reliability can be determined without interpolation along the S-N lines.

- *Opt for ±45° face layers (MUD) or 0° only," pure" UD (UD)?*
  The first option may lead to better test results. However, should this option be selected, we still need to make extra plates of pure UD as well, for instance for the determination of properties and off-axis properties, where the ±45° layers could have a severe impact on the results.

**Check with the project proposal; questions for TLs**

- *To all: do you agree with the resulting test programme, especially for your TL. I didn't make any changes without consulting the TL involved, but errors do happen……*
- *Calibrate instruments necessary?*
- *Isolate thermocouples.*

- *Christoph:* The repeated block test with each block about a damage of 1% are meant to check Miner's rule, whereas the block test with second block to failure (and first block to 50% $N_f$) are useful to check on sequence effects. Christoph, in view of the difference between stress and strain based results and the seemingly large influence of the strain rate, you may want to consider those points as well.
- *Emphasis on UD or MD?*

- *Theodore:we have updated this document based on OB_TG2_005_UP*. Delft is also keen on carrying out 2D tests, but we have some questions regarding the 2D stress field. For 2D testing: TUD preferred cruciform, since tubes hard to produce and only ±45º. Will be hard to set up on time!

- *Povl: For TG3, we miss creep tests.*
  How about salt water? How are the 100% RV fatigue tests done (presumably in 100% RV conditions)? Extra tests in submersed added, models on water take-up etc. from another Risø research programme. Creep out of programme for TG3.

- *Peter: For TG4, I changed the number of tests was changed from OB_TG_R001(TUDT.*
  The out-of plane shear tests were confined to UD etc. You mentioned MUD explicitly in your DPA, what if we go for UD?

- *Geoff: for TG5, the number of laminates is not specified,. Furthermore, a number of reductions in testing time are to be discussed in TG5.*