Overview of test geometry, material lay-up and test set-up

This document is a further development of the previously sent proposals for the test specimen geometry, material specification and comments on these proposals.

Specimen and material proposal for preliminary program (start-up phase)

Six combinations of two geometries and three lay-ups will be produced by LM for the preliminary tests:

Table 1 Material lay-up

Lay-up	Pure UD	Quasi UD	MD
	$[0_5]$	$[\pm45,0_5,\pm45]$	$[(\pm45,0)_5,\pm45]$
Name in document	UD	MUD	MD
Thickness[1]	4.40 mm	5.62 mm	8.06 mm

[1] based on Material specification as sent out by Torben Jacobsen, 7-5-2002
0° layer = 0.88 mm thick, ±45° layer = 0.61 mm thick.
In the DPA of TG1, MUD and MD are suggested as lay-ups.

The final test programme will concentrate on a single geometry (with supporting ISO/ASTM tests). The lay-ups will consist of the MD lay-up and one selected UD lay-up. In case this is a version with ±45° face layers, so only two combinations will remain for the main body of the testing programme.

Shipments of Test Specimens

Torben said he would send each TL 14 specimens in 3 batches:
May 28th: LM ships to each TL 7 dogbones and 7 straight specimens from lay-up 1.
May 31st: LM ships to each TL receive 7 dogbones and 7 straight specimens from lay-up 2.
June 6th: LM ships to each TL receive 7 dogbones and 7 straight specimens from lay-up 3.

Test Specimen Geometry

Initially, the short Risø dogbone, in combination with an anti buckling guide (ABG), was discussed and tested. However, due to the practical objections against the ABG (for instance in case of NDT) and more complex test set-up necessary, this geometry was discarded.

Instead, a stockier geometry was selected for the preliminary program. It is hoped that the stocky geometry and higher thickness will circumvent the necessity of the ABG.
Because no a-priori agreement could be found regarding straight or dogbone (waisted) specimen, two specimen types will be tested in the preliminary program, of which the most successful will be selected for the tests during the main research programme.
A further discussion on test set-ups used is presented in chapter 0.

- DLR has good experience with straight specimens without ABG.
  Alternatively the specimens according to ISO 527/4 and ISO 14126 are suggested.
- TUD has good experience with dogbone without ABG. They found nice failures in the middle.
- Patras used straight specimens for fatigue testing with an ABG, see also Appendix A.

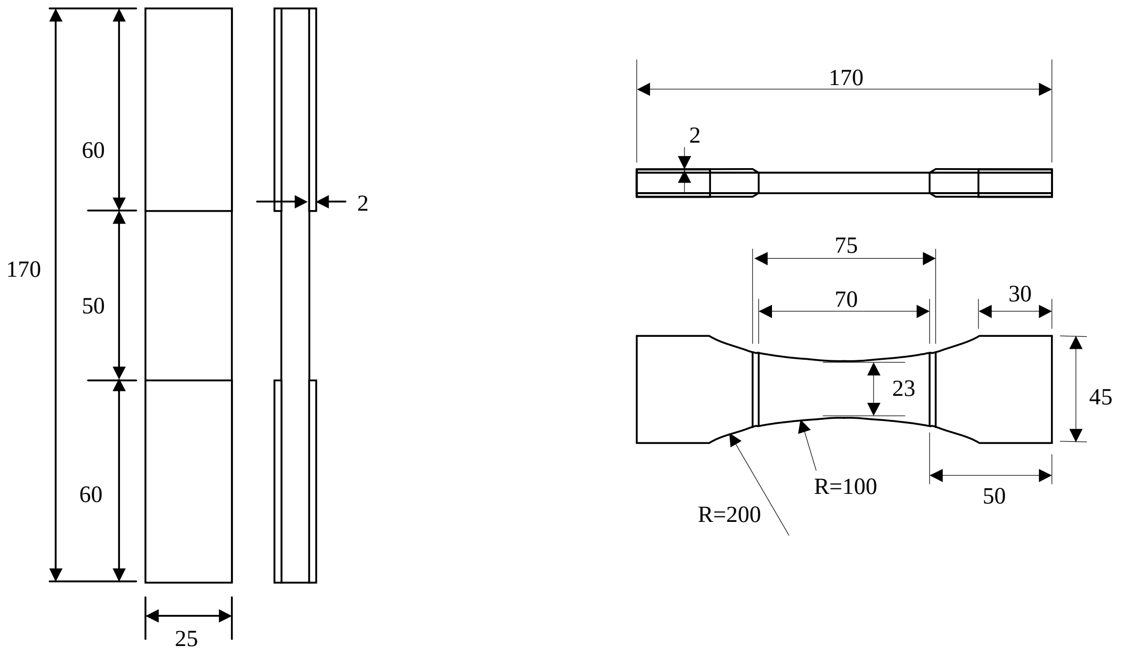

Figure 1 Straight and dogbone geometry for preliminary test programme

Appendix A: Test Set-up at Risø

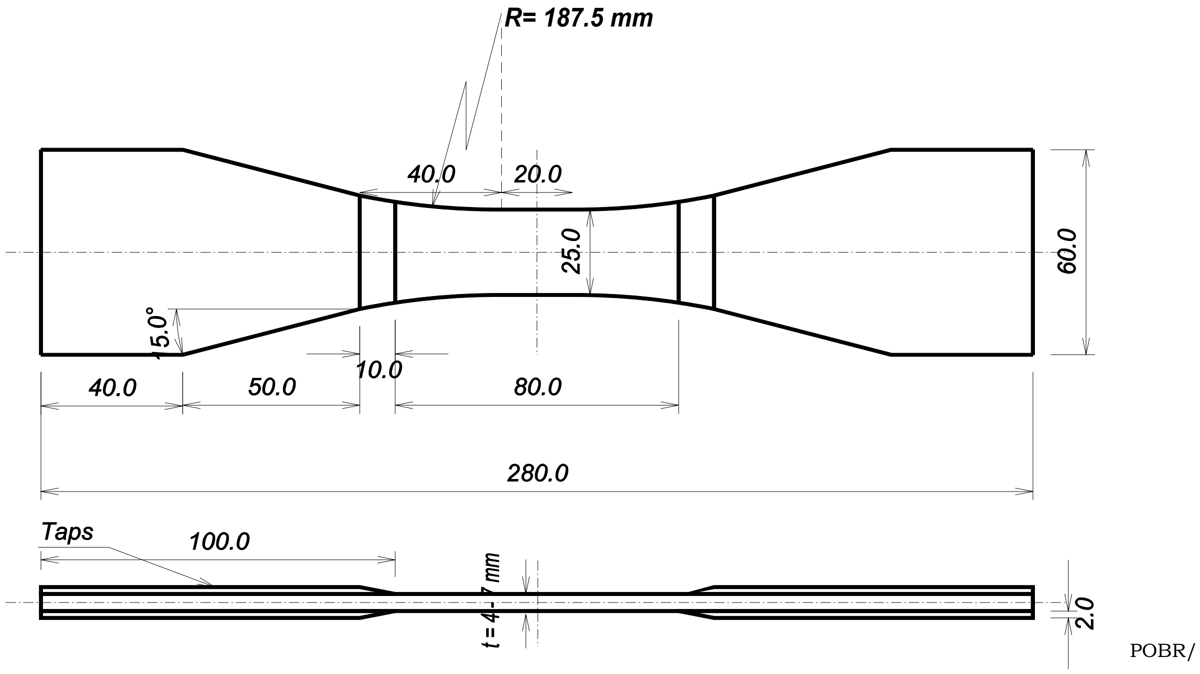

Figure 2 Fatigue test specimen used at Risø

The test specimen used at Risø equipment used is shown in Figure 2.
similar to the simple anti-buckling guide set-up used at Risø as indicated by Povl Brondsted, see Figure 4.

Two suggested differences for use in OPTIMAT BLADES were:

1) Perhaps the OPTIMAT jig ought to have adjustable grips, to eliminate movement in the loading direction during load reversal. This movement may occur if the specimen does not fit neatly into the set-up, or if clamping force is lost due to wear during the test.

2) The OPTIMAT Anti-Buckling Guide (ABG) is essentially a Risø simple ABG with a slightly larger hole to allow space for condition monitoring equipment. The movement in the transverse direction is constrained. See discussion in 0.

Povl Brondsted has expressed a willingness from Risø to provide test set-ups for the OPTIMAT BLADES partners and give drawings etc. This will enable all partners to carry out their fatigue tests in a more standardized way, thereby improving the quality and uniformity of the programme.

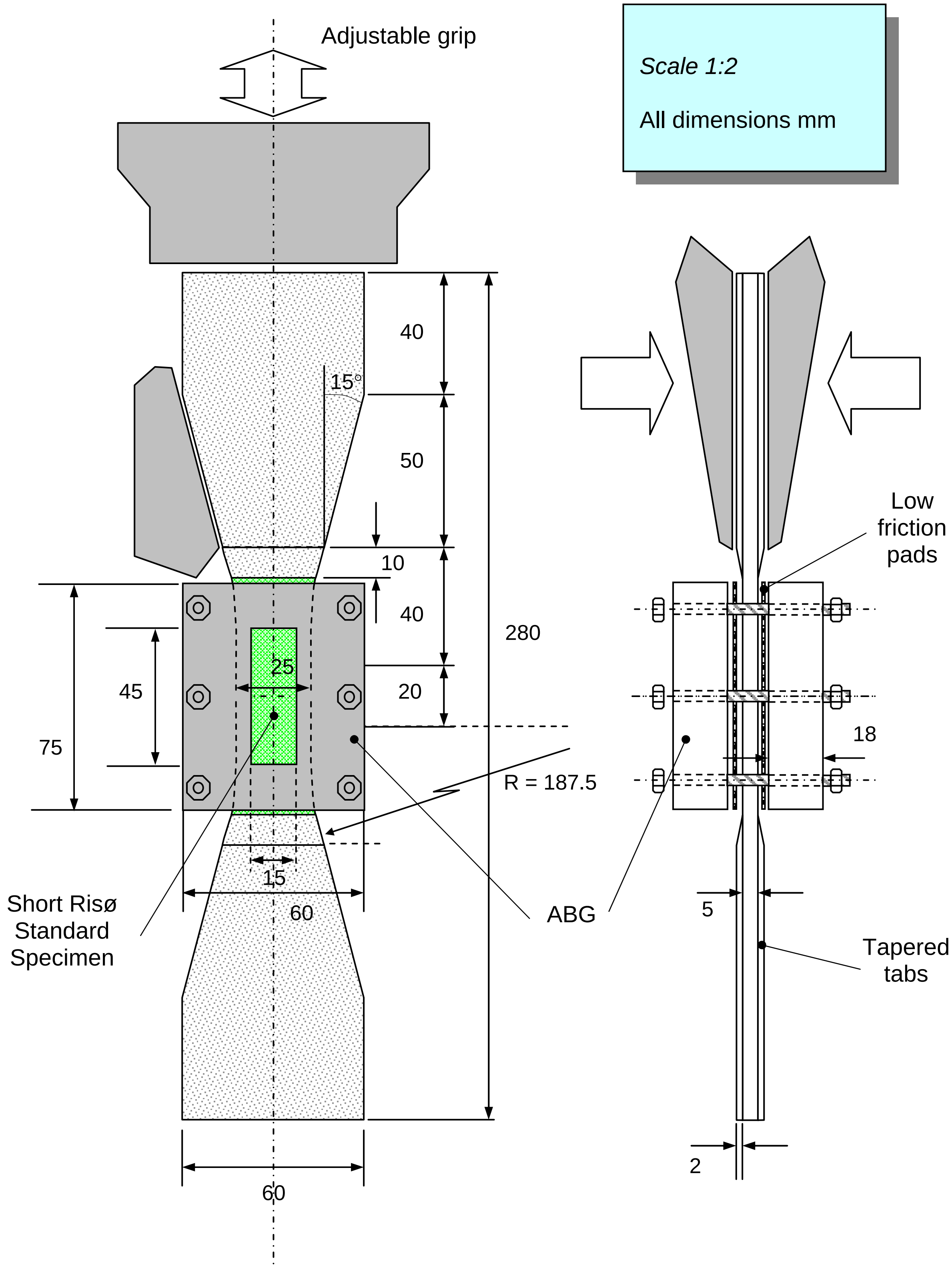

Figure 3 Standard OPTIMAT Test Specimen Proposal

Modified Risø Anti-buckling guide (ABG)

Obviously, an anti-buckling guide (ABG) is necessary given the slenderness of the test specimen. Risø currently uses a simple ABG, shown in Figure 4, essentially consisting of two parts of steel clamping the plate together without holes or an advanced ABG, shown in Figure 5, which is attached to the lower end of the test bench and can move in longitudinal direction.

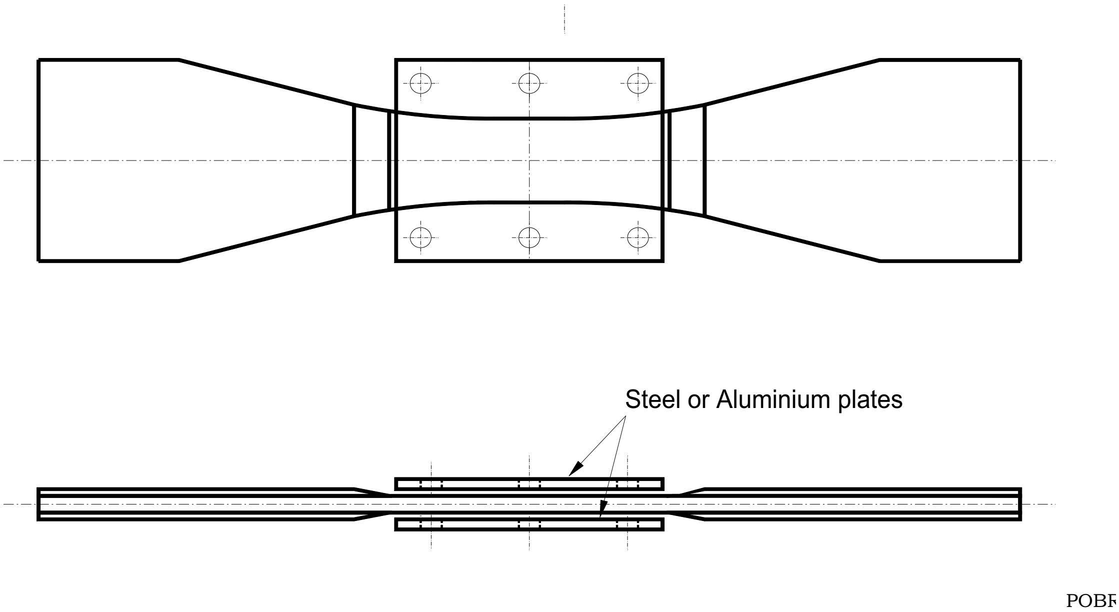

Figure 4 RISØ simple ABG

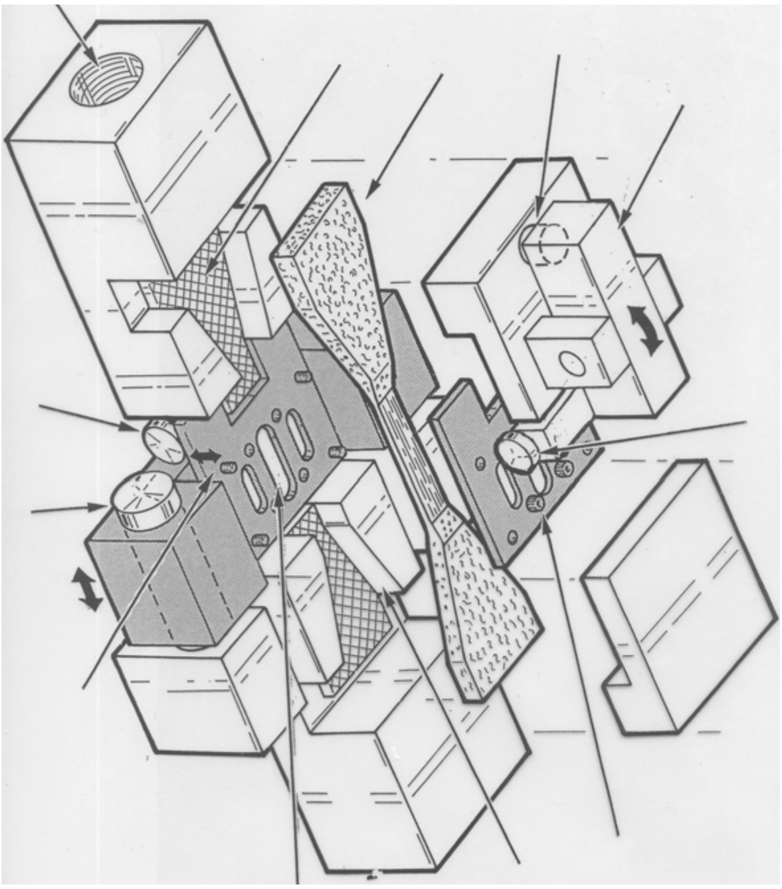

Figure 5 RISØ advanced ABG

Risø claims good results with both ABG, so for simplicity we might opt for the simple ABG shown in Figure 4. Unfortunately, clamping two massive steel plates on the test specimen inhibits both visual inspection and photos and many types of measurement.
Therefore, holes must be available through which to measure. In case this set-up would have been used, it was proposed, that the ABG are used even in case of tensile loading, in order to have a consistent set-up across all load ratios.

Two choices exist:

1. The edges of the specimen are free at the measurement location. In this case, it is expected that, during a fatigue test, delamination will initiate first at the specimen edges. With this ABG, an area of 25x45 mm is available on the specimen for monitoring. 45 mm is the minimum space required to apply clip gauges. The specimen is to a certain extent accessible from the side.

   Leaving the edges unsupported and a hole of a certain length may result in insufficient protection against buckling.

2. Supporting the edges would allow for a longer (but narrower hole available for measurements. See for instance Figure 5, which could be adapted for use with a simple ABG as in Figure 4. An area of 15x45 mm could be left open, see Figure 3, resulting in 5 mm wide support along the edges. For this type of ABG, the ABG must be designed in order to prevent lateral displacement, which could result in uneven support of the edges. An ABG which supports the specimen edges is expected to constrain the delamination of the edges of the test specimen.

Appendix B: Test set-up used at Patras and remarks concerning present tests.

There are several contradicting issues in UD coupon geometry (this is also the case for the multidirectional laminated specimens also), especially with concern to TG2 & TG5 aims:

1. Residual strength tests are in essence CA fatigue tests followed after a predetermined number of cycles by static tests, either tension or compression, to failure. However, as it can be seen in the table of the appendix, fatigue coupon tests have different geometry from those used in static tests, especially in combinations such as e.g. CA fatigue @ R=10 and then residual strength test in tension, or CA fatigue @ R=0.1 and then residual strength test in compression. The fact that residual strength test results must be compared and eventually correlated with static test results complicates even more the situation.
2. In TG5, residual strength test coupons loaded in CA fatigue containing compression must be of reduced gauge length, to avoid buckling, while they should leave enough space for NDT sensor mounting (which is hampered by the use of anti buckling jigs).

The above hold also true for the case of laminated coupons with different fibre orientation in each ply, i.e. multidirectional lay-up. Again, static and fatigue test coupons are usually of different geometry and it is exactly the residual strength tests series that creates the contradiction, in parallel with the need for NDT sensor placement.

In the past 5-6 years, our group was involved in a research study for fatigue life evaluation of multidirectional laminates, e.g. $[_02/\pm45]S$, loaded under complex stress by using on- and off-axis coupons cut from the plate. Straight edge coupon nominal dimensions were 250 x 25 x 2.7 mm with aluminium tabs, 2 mm thick and 45 mm in length, leaving a gauge length of 160 mm. In cases where the load program was containing compressive cycles, the anti buckling jig shown below was used. However, although the performance of this arrangement was deemed satisfactory for fatigue testing, it cannot be used for static compressive tests, or neither residual strength tests, nor it can accommodate NDT sensors due to the anti buckling jig.