Four-point bending tests on OPTIMAT UD material

OB_TG4_R008 rev. 000
doc. no. 10196

Draft version, August 2004
Confidential

OPTIMAT BLADES

TG 4

Rogier Nijssen
Arno van Wingerde

Change record

Issue/revision	date	pages	Summary of changes

Introduction

This document describes the four point bending tests on 5 GEV206_I0500_#### specimens, carried out on July 14th, 2004.

Test set-up and dimensions

A four point bending test set-up was used (see Figure 1) in the 250 KN homebuilt load frame. In order to have sufficient resolution in the force readings, a 5 kN load cell was placed in the frame.

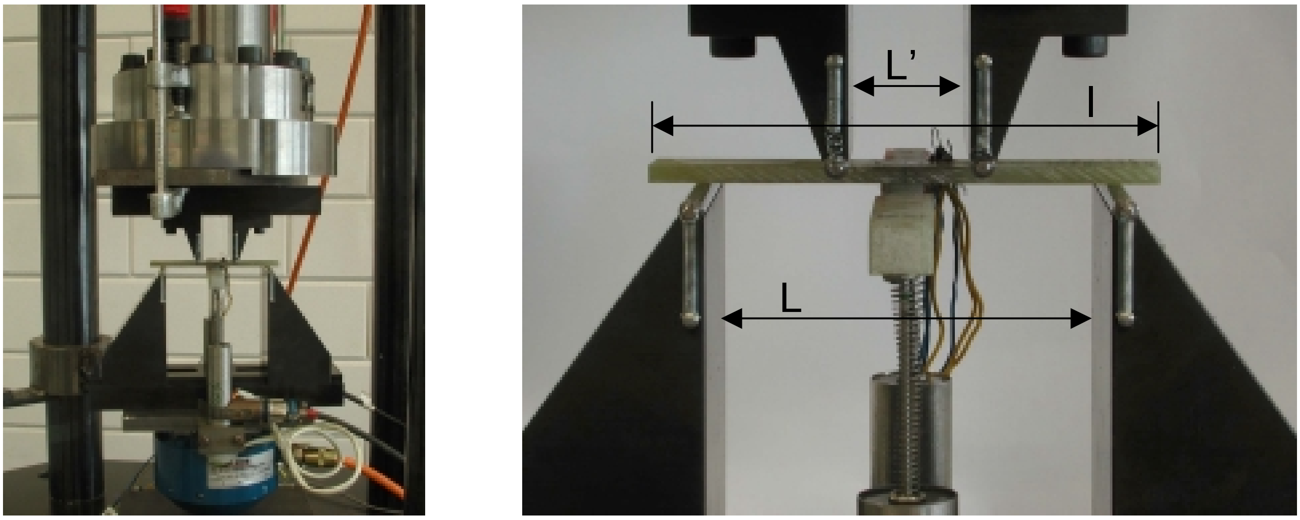

Figure 1: Dimensions of the test set-up

The movement of the lower loading members was displacement controlled. The test speed was selected from table I in [1], to give a strain rate as near as possible to 0.01. The displacement rate v is calculated via [1]:

$$v = \frac{0.01L^2}{4.7h}$$

Using either the nominal or measured values for span L and thickness h gives a displacement rate of around 4 mm/min, the closest value in the abovementioned table is 5 mm/min.
The displacement of the specimen mid-point was measured by two displacement sensors located parallel on either side of the specimen and connected by a stiff beam (see Figure 1). Most of the test specimens were equipped with a HBM 10/120LY11 strain gauge on either side.

Test Specimen, preparation and dimensions

The test specimens were manufactured of standard OB Unidirectional material by LM, with nominal and average dimensions are shown in Figure 2. The specimens have no tabs. In the terminology of [1], this is a Class III material. The standard prescribes the specimen length, width, and the position of the load members as a function of the specimen thickness, according to Table I.

A 10 mm strain gauge was bonded to either side of the specimen, in the middle and center as

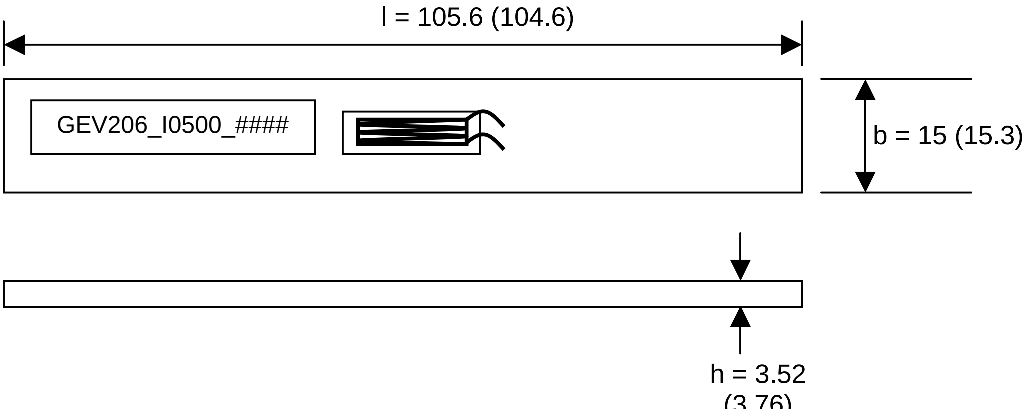

Figure 2: Nominal and (average) dimensions, actual size, see also Table II, III

indicated in Figure 2.

Table I: specimen and test set-up dimensions according to [1], function of specimen thickness h

dimension	ISO	nominal	realized
h	2	3.52	3.76
w	15 (for class III and 3<h<5)	15	15.3
l	30·h	105.6	104.6
L	22.5·h	79.2	84.6
L'	L/3	26.4	28.2

The length of the specimen was defined according to the nominal thickness, but as can be seen from Figure 2, the measured average thickness was slightly higher, which should result in a longer specimen than the 105 mm delivered, and in different set-up dimensions.

In the current tests, the set-up dimensions L, and L', are based on the real thickness, i.e. the values in the column 'realized' in Table I are used. This means, that the ratio l/L is smaller than prescribed by the standard, but since the area of interest is in the centre of the specimen, and the specimen was found to be long enough to span the lay-up points up to failure, this was not deemed detrimental for the results.

Table II gives the measured specimen dimensions for the 10 specimens of this type delivered to WMC (of which 5 were tested to failure and two were tested without strain and/or displacement measurement). The remaining specimens were retained for future reference, according to [2].

Table II: Measured specimen dimensions

OPTIMAT name	w [mm]*	h [m]*	l [mm]
GEV206_I0500_0001	15.30	3.78	104.55
GEV206_I0500_0002	15.43	3.73	104.60
GEV206_I0500_0003	15.29	3.73	104.59
GEV206_I0500_0004	15.33	3.76	104.58
GEV206_I0500_0005	15.32	3.73	104.58
GEV206_I0500_0006	15.28	3.75	104.57
GEV206_I0500_0007	15.41	3.78	104.53
GEV206_I0500_0008	15.33	3.80	104.58
GEV206_I0500_0009	15.33	3.79	104.51
GEV206_I0500_0010	15.37	3.75	104.56
averages	*15.34*	*3.76*	*104.57*
min	*15.28*	*3.73*	*104.51*
max	*15.43*	*3.80*	*104.60*
stdev	*0.05*	*0.03*	*0.03*
count	*10*	*10*	*10*

The tabulated width and thickness are averages of three measurements along the length of the specimen
The grey cells are the specimens that were retained for future reference.

Results

The test results are given in Table III

Table III: Test results

Specimen	max force	max displacement	flexural stress	flexural strain (calc)	flexural strain (meas.)	flexural modulus
	[kN]	[mm]	[Mpa]	[%]	[%]	[GPa]
GEV206_I0500_0001	-2.34	14.02	-1028	3.2	-	-
GEV206_I0500_0004	-2.24	13.36	-974	3.1	2.8	30.66
GEV206_I0500_0005	-2.27	13.07	-1001	3.0	2.7	30.65
GEV206_I0500_0006	-2.27	12.45	-979	2.9	2.6	31.08
GEV206_I0500_0007	-2.28	12.96	-970	3.0	2.7	29.5
GEV206_I0500_0008	-2.29	12.97	-966	3.0	-	-
GEV206_I0500_0010	-2.25	12.49	-963	2.9	2.6	30.52
min	*-2.34*	*12.45*	*-1028.00*	*2.90*	*2.6*	*29.50*
max	*-2.24*	*14.02*	*-963.00*	*3.20*	*2.8*	*31.08*
average	*-2.28*	*13.05*	*-983.00*	*3.01*	*2.68*	*30.48*
stdev	*0.03*	*0.54*	*23.47*	*0.11*	*0.08*	*0.59*

The flexure stress and –strain were calculated according to [1], taking into account large deflections and friction effects:

$$\sigma_f = \frac{FL}{wh^2}\left\{1+8.78\left(\frac{s}{L}\right)^2 - 7.04\left(\frac{sh}{L^2}\right) - 3.39\mu\left(\frac{s}{L}\right)\right\} \quad (1)$$

$$\varepsilon_f = \frac{h}{L}\left\{4.7\frac{s}{L} - 14.39\left(\frac{s}{L}\right)^3 + 27.7\left(\frac{s}{L}\right)^5\right\} \quad (2)$$

where *F* is the force, and *s* the displacement of the beam mid-point.

In Table III, the values for flexural stress and –strain corresponding to the maximum force are listed. A friction coefficient μ of 0.1 was assumed. A change in friction coefficient most likely influences flexural stress at maximum force most, in the order of 10% for a 0.1 change in friction coefficient. The values in the other columns of Table III are not sensitive to a change in μ.
Figure 3 shows the stress-strain-diagrams. As specimens 1 and 8 were not equipped with displacement sensors, these stress-strain curves are not shown and in Table III the modulus is not listed for these tests.
Figure 4 shows the calculated vs the measured strain. It is not clear why the measured strains are roughly 10% lower than the calculated ones. Friction effects (which are included in (1), but, surprisingly, not in (2)) could account for a lower maximum strain. The gauge factors were double-checked and found to be in order. The *measured* strains were reported in OptiDAT.
Figure 5 shows a test at three stages; approximately half the failure force, close to failure, and after failure. Figures 6 show the failed specimens. Specimens 4, 6 and 10 have the ‘best’ failure modes, where failure was tensile, or a mix of tensile with limited interlaminar shear. The other specimens seem to show some compressive fracture near the load application points, but there is no apparent negative effect on the results.

Acknowledgements

The authors wish to acknowledge Danny Mahieu for his assistance with the tests.

References

1. ISO 14125:1998 (E), *'Fibre-reinforced plastic composites – Determination of flexural properties'*, International standard prepared by TC 61, subcommittee SC13 Composites and reinforcement fibres
2. OB_TC_M006, revision 0, *'Minutes of the 7th Technical Committee Meeting'*, OB document nr. 10193, WMC, July 2004

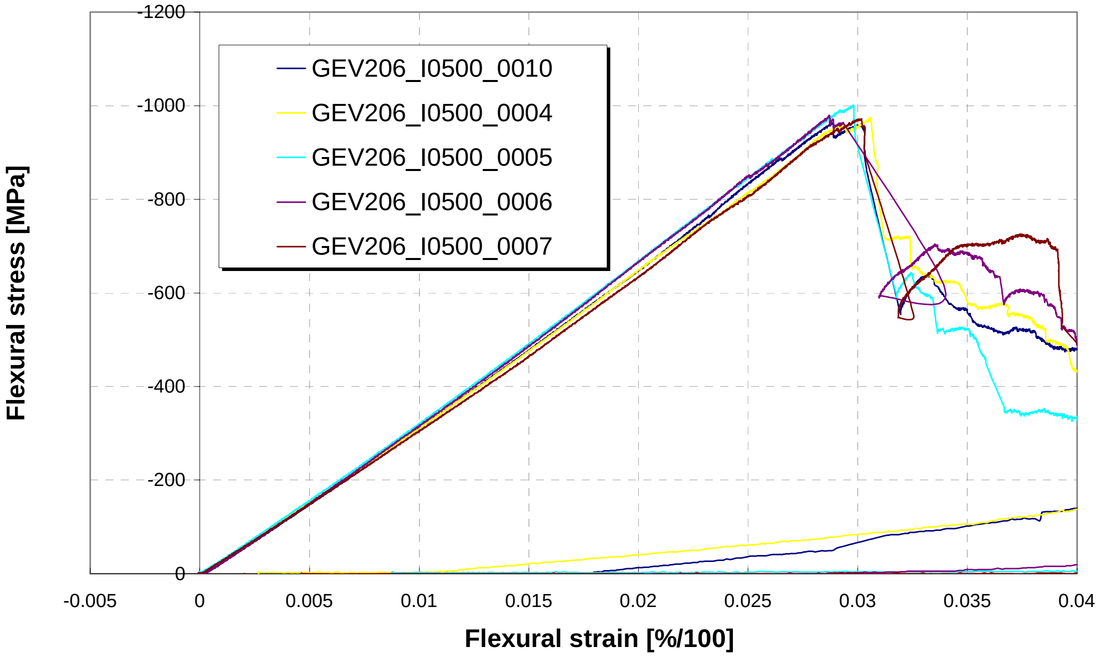

Figure 3: Stress-strain diagrams

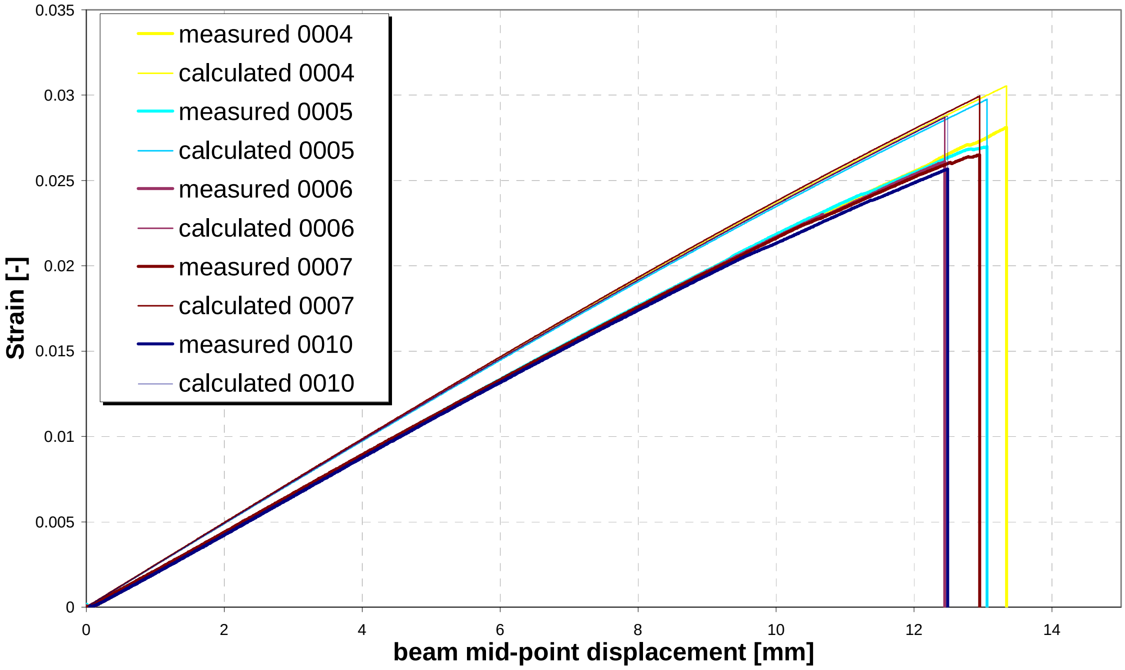

Figure 4: measured vs calculated strains

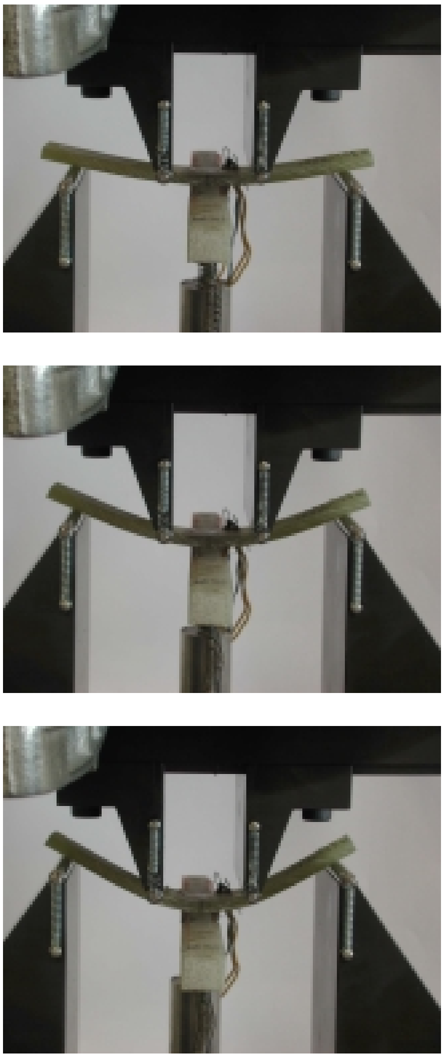

Figure 5: Top-to-bottom:Specimen GEV206_I0500_004 at 1 kN, 2 kN and after maximum force.

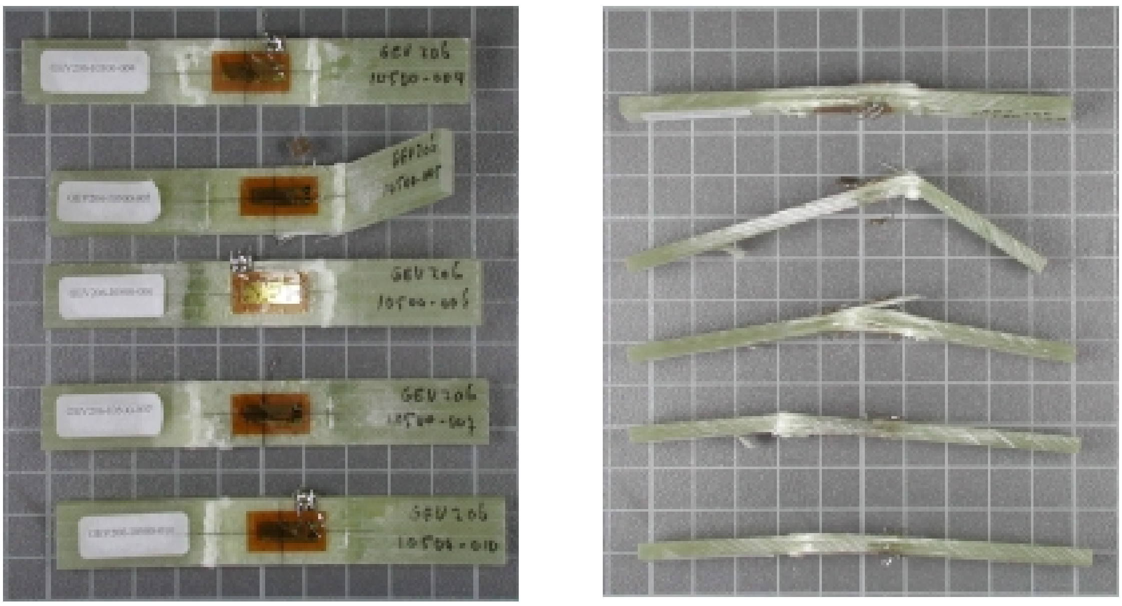

Figure 6: failed specimens