KTH Aeronautical
and Vehicle Engineering

Handläggare	Datum	Telefon	E-post
Magnus Burman	2012-03-24	070-549 64 50	mburman@kth.se

PROVPROTOKOLL / TEST PROTOCOL

Projekt namn – Objekt namn / Project name – Object name	
FATIGUE TESTING OF SANDWICH CORE MATERIAL, AC80, AC100 AND AC115	
Beställare / Customer	
ARMACELL	
Provmetod – Provstandard / Test method – Test standard	
IN HOUSE PRACTICE, STANDARD METHOD IS NOT AVAILABLE BUT RELATED TO ASTM C393-00 "STANDARD TEST METHOD FOR FLEXURAL PROPERTIES OF SANDWICH CONSTRUCTIONS"	
Provobjekt – Material / Test specimen – Material	
SANDWICH BEAMS	
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KTH Teknikringen 8, – SE–100 44 Stockholm, Tel: 08-790 60 00, Fax: 08-790 65 00, Epost: mburman@kth.se
Pg: 1 56 53-9, Bg: 895-9223, Momsreg.nr/VAT: SE202100305401, www.kth.se

Document Abstract – Notes
Sandwich beams have been tested in four-point bending under fatigue load. The objective was to establish S/N curves for the material.

Material
The core material tested was provided by Armacell as foam core block.
- AC80 batch 297046/29705
- AC100 batch 296791/296809
- AC115 batch 296827/296862

Test specimen
The sandwich panels were manufactured using infusion technique by KTH with four layers of glass reinforced polyester on each side of the panel. Test specimens were cut by KTH to the correct size using a band saw. The specimen dimensions are given in table 1.

Table 1 Specimen geometry and support distances

	AC80	AC100	AC115
Length	540 mm	530 mm	580 mm
Width	50 mm	55 mm	55 mm
Face thickness	3 mm	3 mm	3 mm
Core thickness	49 mm	51 mm	49 mm
Density (nominal)	80 kg/m^3	100 kg/m^3	115 kg/m^3
Inner support span, L_1	82 mm	82 mm	82 mm
Outer support span, L_2	440 mm	440 mm	440 mm

Test set-up
The test set-up is schematically shown in fig. 1 and in fig. 2 a photo of the test is shown, note that it is not the currently tested material shown herein. The rig design allows the supports to rotate around the neutral axis of the beam in order to minimise the stress concentrations near the load introductions. Further the supports are movable in the beam length direction to enable varying settings of L_1 and L_2. The support distances, L_1 and L_2, are given in table 1. The supports are covered with rubber pads in order to smooth out the load transfer. The outer load arms are allowed to move horizontally thus preventing any membrane force to occur.

The four-point bend test method provides an almost pure shear stress in the core, between the inner and outer supports, and is hence suitable for the present purposes. The ASTM test standard C393-00 “Standard Test Method for Flexural Properties of Sandwich Constructions” [1] describes the test setup and requirements but is only designated for static and not fatigue testing.

The testing was performed at 23°C (±1°C) and approximately 50% r.h. The loading ratio R=0.1, i.e the ratio between the minimum and maximum load applied during a loading cycle. The test frequency was adjusted to the load level such that failure would not occur due to local heating in the core, i.e. 2-4 Hz.

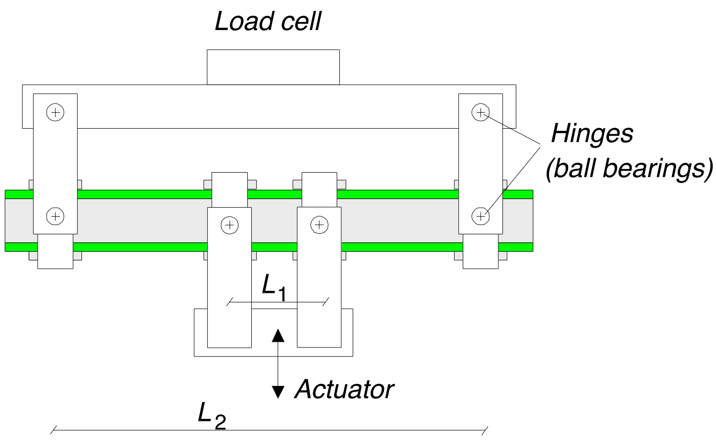


Figure 1. Four-point bending rig

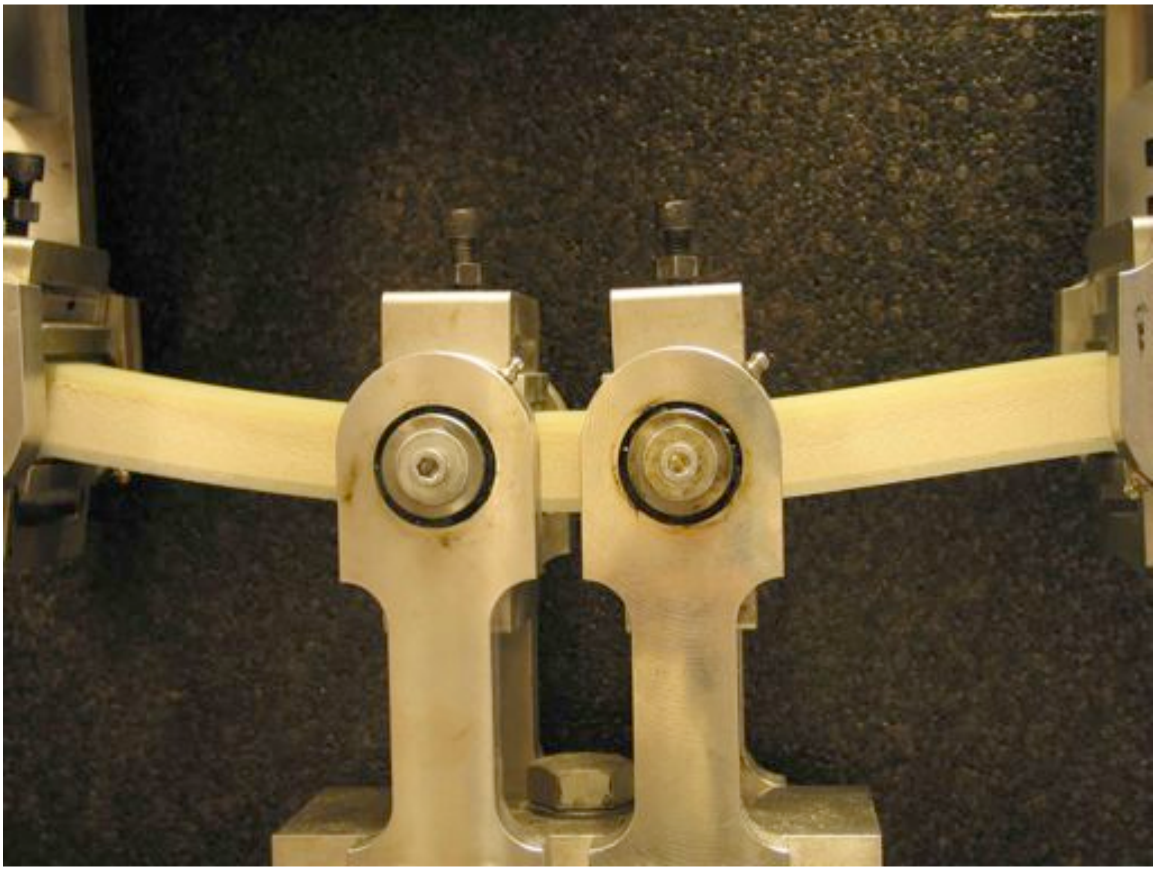


Figure 2. The four point bend test set-up, note that the material in this picture is NOT the material tested herein

Results

Quasi-static (QS) tests were initially performed on five specimen per quality. All specimen had the weld line transverse the beam length direction. The results are presented in table 2 and graphically in figs. 3-5. Typical static failure modes are seen in Appendix A.

The **fatigue** test results are reported as maximum applied core shear stress in MPa taken as shear in the core according to classic sandwich theory,

$$\tau = \frac{P}{2bd} \qquad [1]$$

where P is maximum applied load during the test and b and d is the specimen width and the distance between the neutral axes of the faces respectively. The chosen load ration was $R=0.1$, which is in line with how other core material have been tested.

The results are given in tables 6-8 and shown in figs 6-8. The core shear stress is calculated according to equation 1. The fatigue performance in relation to the static strength of the materials tested is excellent. One can observe that all qualities tested herein can sustain well over millions of cycles at load levels corresponding to 60-70% of the shear strength.

The AC80 material was tested with the weld lines both perpendicular or parallel to the beam length direction. The static tests were all performed with the welds transverse the weld lines. In fig 6 are the fatigue test results shown an here the blue markers correspond to beams with welds transverse to the beam length direction and the purple to beams with the welds parallel.

The common failure mode for cellular foams is with an initiation in the centre part of the beam between the inner and outer supports. Then, in this centre region multiple cells fail individually during the fatigue loading. Eventually the broken cells will start to interact with each other and form the horizontal crack. When this crack has been formed the crack tips are subjected to a Mode II loading (in-plane shear). A crack subjected to a Mode II loading will kink at an angle of 70°. This failure scenario is thoroughly described in [2]. However, the materials tested herein have welded bond lines transverse to the beam longitudinal direction. The fatigue failure will generally initiate in one of these weld lines due to the material discontinuity.

One test sample, AC80-F1, was tested at 0.38MPa (>50% of the shear strength) for 3.6 million load cycles. The test was then stopped and a residual strength test was performed. It is interesting to see that the stiffness is basically the same as the "virgin" material (not tested in fatigue). Furthermore the maximum load sustained in the residual test is higher that the static strength test. This is of course only one sample but still indicate that fatigue loading below a certain threshold level will not effect the stiffness or strength of the material.

Summary

Fatigue test on material AC80, AC100 and AC115 have been performed using four-point bending test set-up. The failure mode was anticipated and the test results show that the material perform well under fatigue shear loading.
One sample, AC100-F10, did not failed under the fatigue load. This test was stoped after 5 million load cycles and then a static fracture test was performed. The shear strength was 0.93 MPa, i.e. well in line with the results from the static test of the specimen not subjected to any fatigue loading.

Tables – Figures

Table 2 Static test data AC80

Specimen	Width	Max load kN	τ_{max} Mpa
S1 (2)	49.17	3.40	0.66
S2 (5)	51.78	3.61	0.67
S3 (6)	50.52	3.49	0.66
S4 (7)	49.98	3.54	0.68
S5 (8)	50.30	3.45	0.66
	50.35	**3.50**	**0.67**

Table 3 Static test data AC100

Specimen	Width	Max load kN	τ_{max} Mpa
S1 (2)	55.24	5.18	0.87
S2 (6)	54.62	5.06	0.86
S3 (10)	54.77	5.02	0.85
S4 (15)	54.09	5.00	0.85
S5 (20)	54.34	5.14	0.87
	54.61	**5.08**	**0.86**

Table 4 Static test data AC115

Specimen	Width	Max load kN	τ_{max} Mpa
S1 (2)	55.28	6.03	1.05
S2 (5)	55.32	6.04	1.05
S3 (6)	55.15	6.26	1.09
S4 (7)	54.95	6.04	1.05
S5 (8)	55.25	6.13	1.06
	55.19	**6.10**	**1.06**

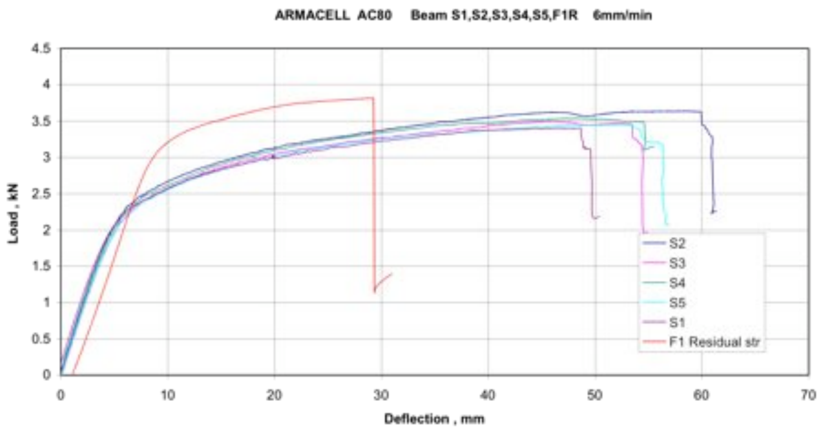


Figure 3 Load - deflection curves for static tests AC80, including residual strength test

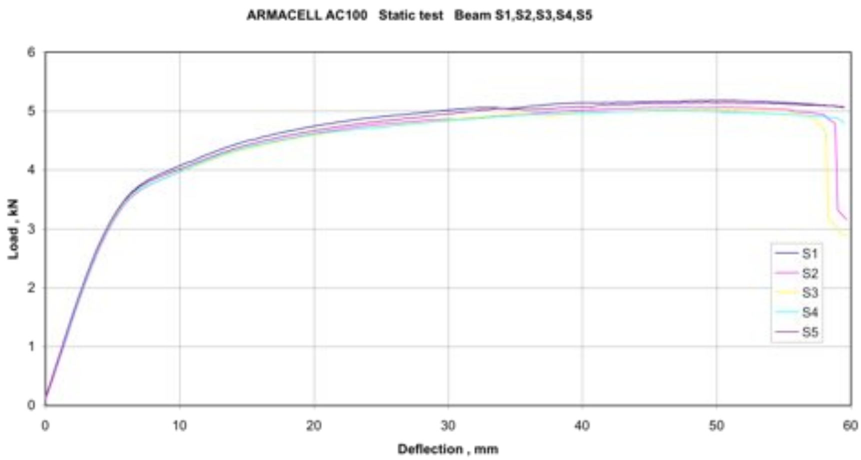


Figure 4 Load - deflection curves for static tests AC100

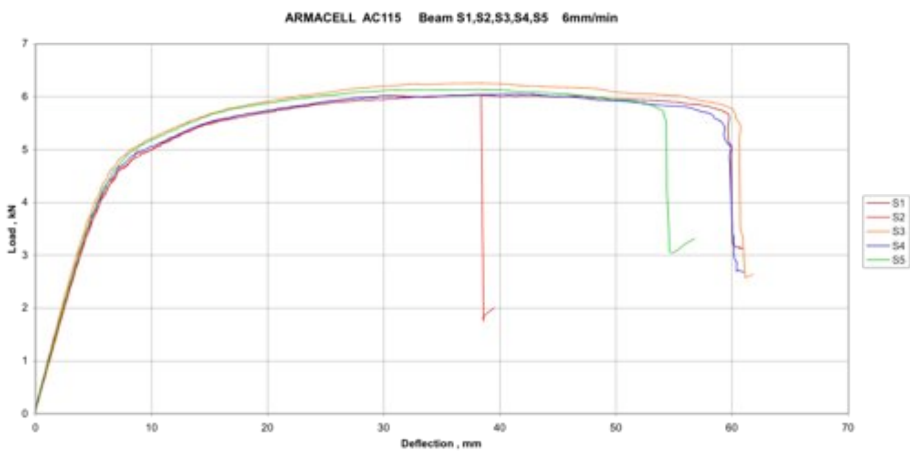


Figure 5 Load - deflection curves for static tests AC115

Table 5 Fatigue test data, AC80

Specimen	Width [mm]	Pmax [kN]	τ_{max} [Mpa]	R	No of cycles	Freq ency	Fracture
F1	50.06	2.000	0.383	0.1	> 3638200	2.5	Test stopped
F2	50.10	2.440	0.467	0.1	2145700	2.0	in core
F3	48.93	2.800	0.549	0.1	192709	2.0	in bondline close to laminat
F4	51.06	2.600	0.489	0.1	1505120	2.0	in core
F5	49.27	2.950	0.575	0.1	440608	1.5	in core
F6	49.88	2.700	0.519	0.1	1406311	2.0	in core

Table 6 Fatigue test data, AC100

Specimen	Width	Pmax, [kN]	τ_{max}, [Mpa]	R	Load cycles	f [hz]	Fracture
F1	54.65	4.260	0.720	0.1	85.900	1.5	Fracture in core
F2	54.86	4.038	0.680	0.1	363.700	1.5	Fracture in core
F3	54.72	3.790	0.640	0.1	808.900	2.0	Fracture in core
F4	54.64	3.900	0.660	0.1	993.285	2.0	Fracture in core
F5	54.37	3.705	0.630	0.1	800.139	2.0	Fracture in core
F6	54.43	3.535	0.600	0.1	2.078.919	2.0	Fracture in core
F7	54.24	3.405	0.580	0.1	2.439.000	2.5	Fracture in core
F8	54.48	3.210	0.545	0.1	2.586.500	2.5	Fracture in vertical bond
F10	54.43	3.000	0.509	0.1	> 5.000.000	3.0	No fail, residual strength 5.50kN = 0.93 MPa
F11	54.35	3.100	0.527	0.1	3.608.000	3.0	Fracture in core

Table 7 Fatigue test data, AC115

Specimen	Width [mm]	Pmax [kN]	τ_{max} [Mpa]	R	Load cycles	f [hz]	Fracture
F1	55.54	4.468	0.780	0.1	> 2107476	2.0	in bondline close to laminat
F2	55.42	4.782	0.820	0.1	653859	2.0	in core
F3	55.44	4.922	0.860	0.1	424417	2.0	in bondline close to laminat
F4	55.45	5.365	0.920	0.1	232513	1.5	in bondline close to laminat
F5	55.18	5.574	0.960	0.1	3273	1.5	in core
F6	55.05	4.980	0.860	0.1	635430	2.0	in core
F7	55.18	5.372	0.925	0.1	212926	1.5	in core

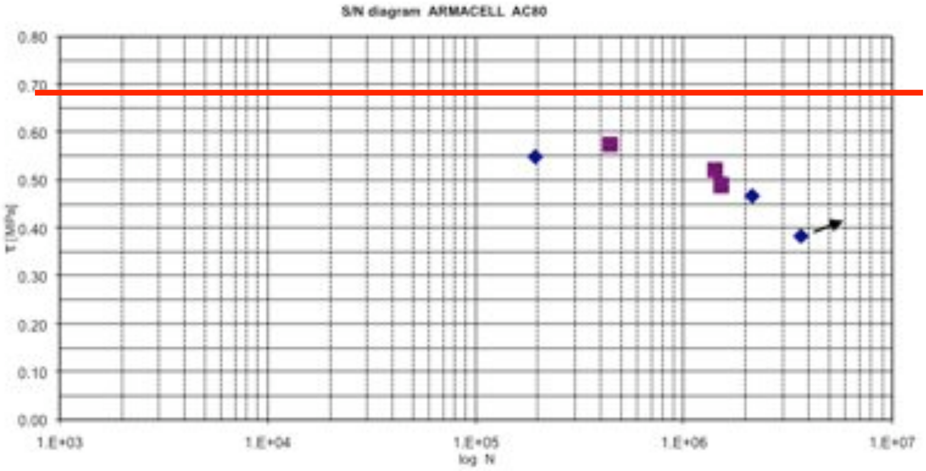


Figure 6. S/N diagram AC80, the red line indicate approximately the shear strength.

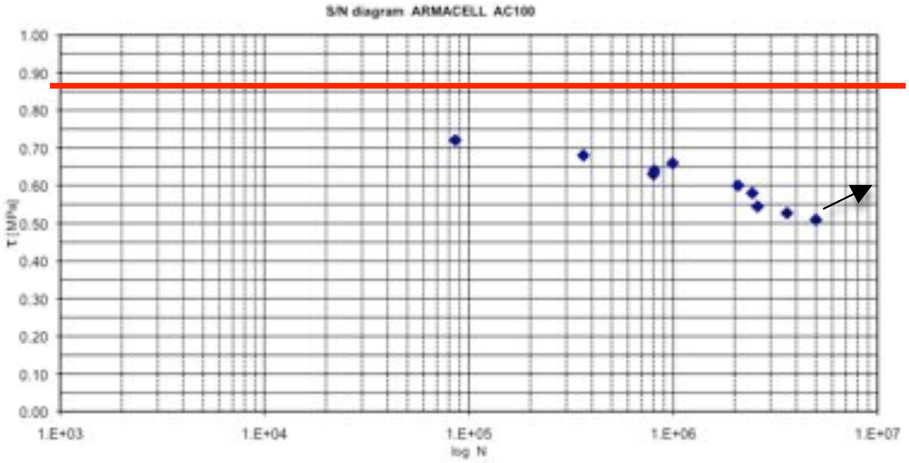


Figure 7. S/N diagram AC100, the red line indicate approximately the shear strength.

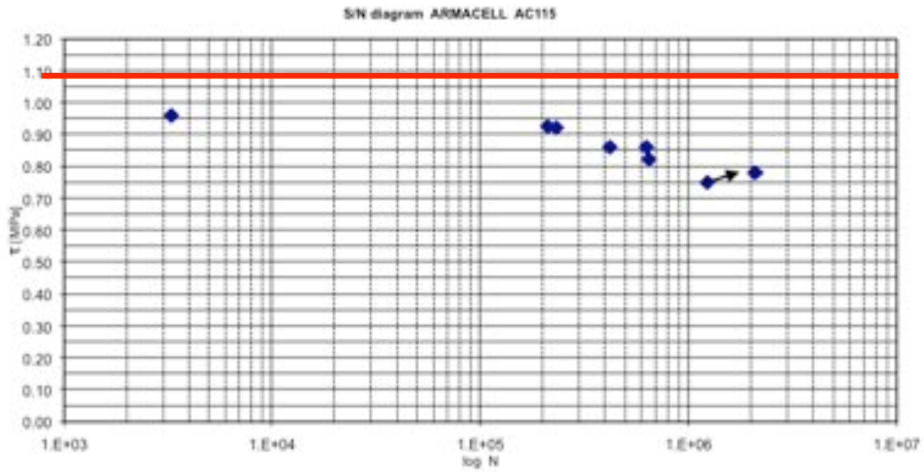
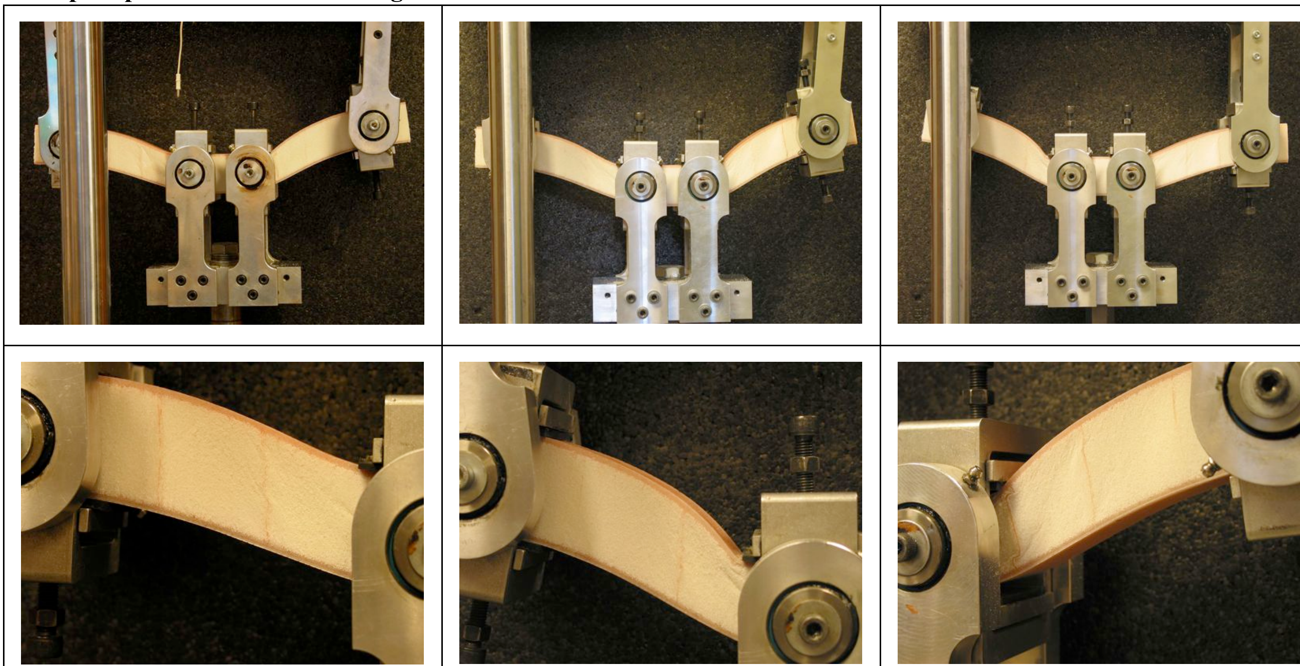
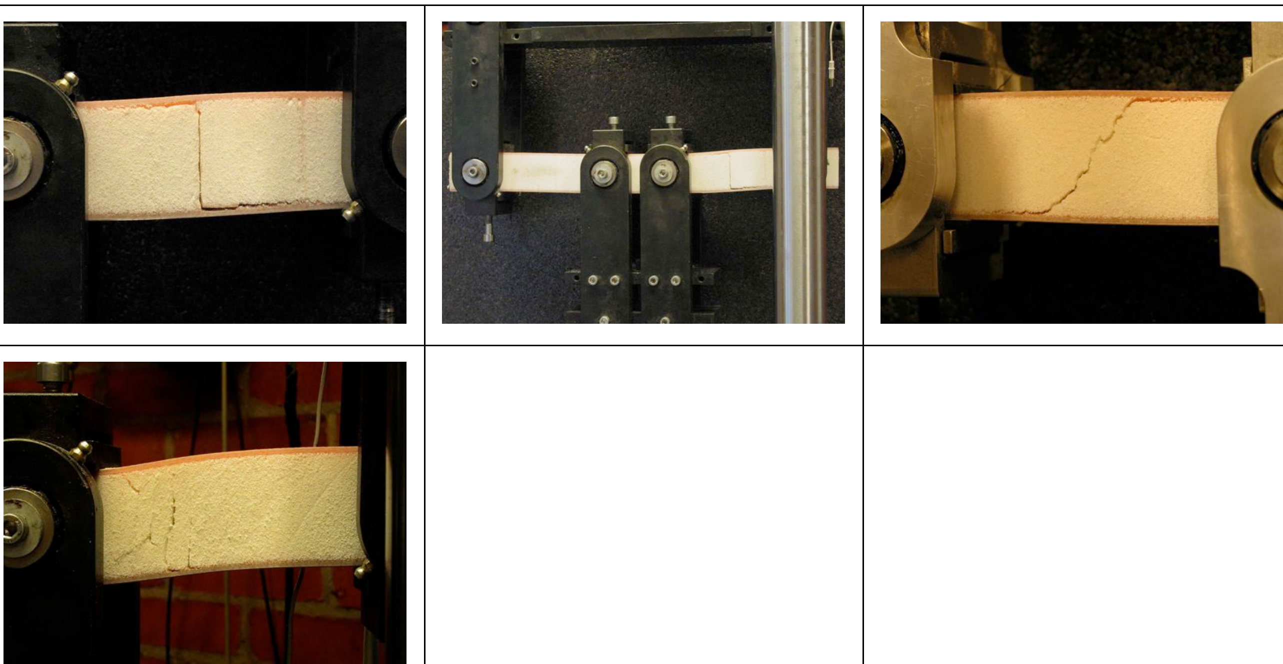


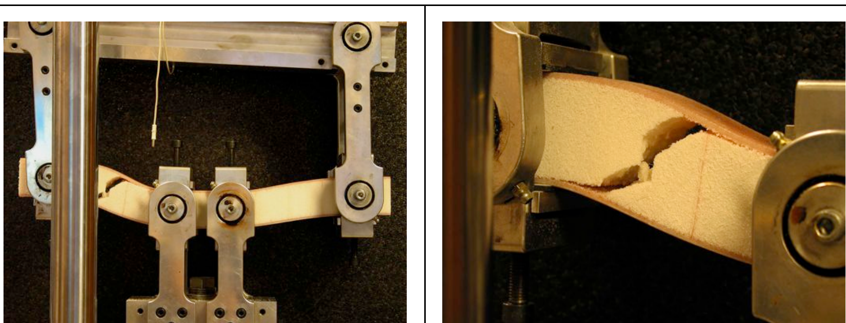
Figure 8. S/N diagram AC115, the red line indicate approximately the shear strength.

Sampled pictures from the testing - AC80



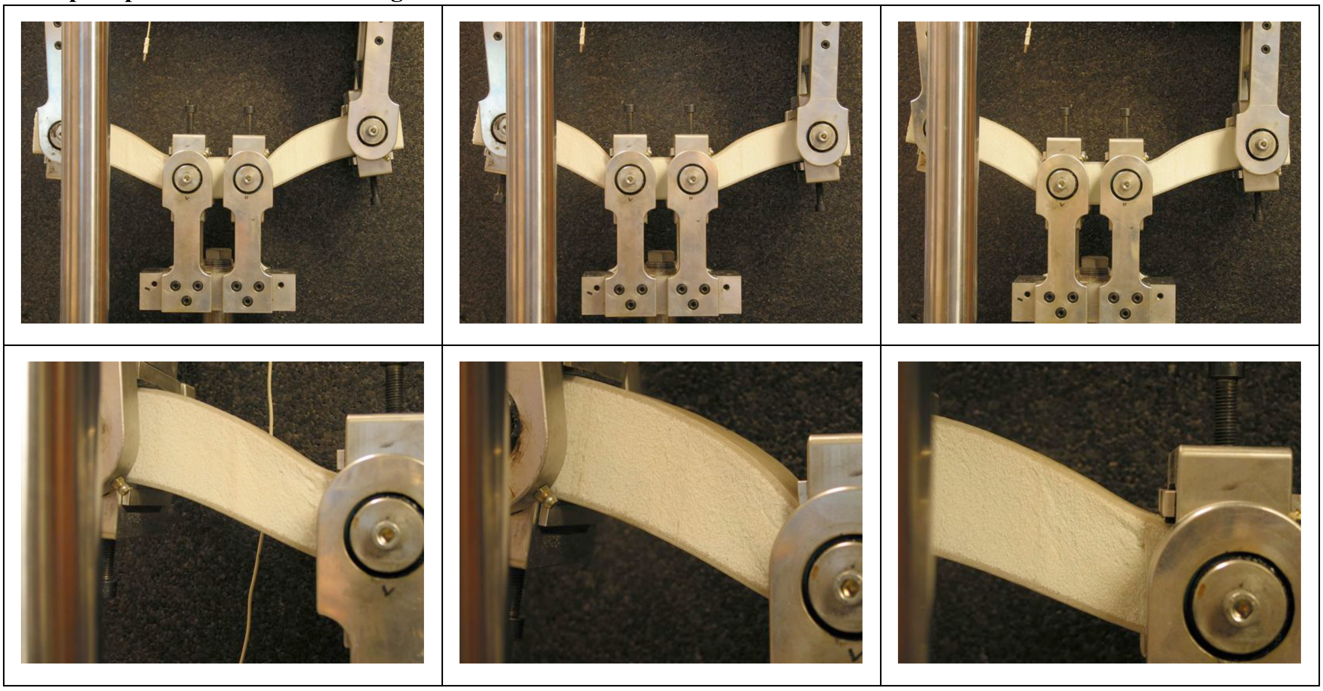
Failure mode for AC80 static test



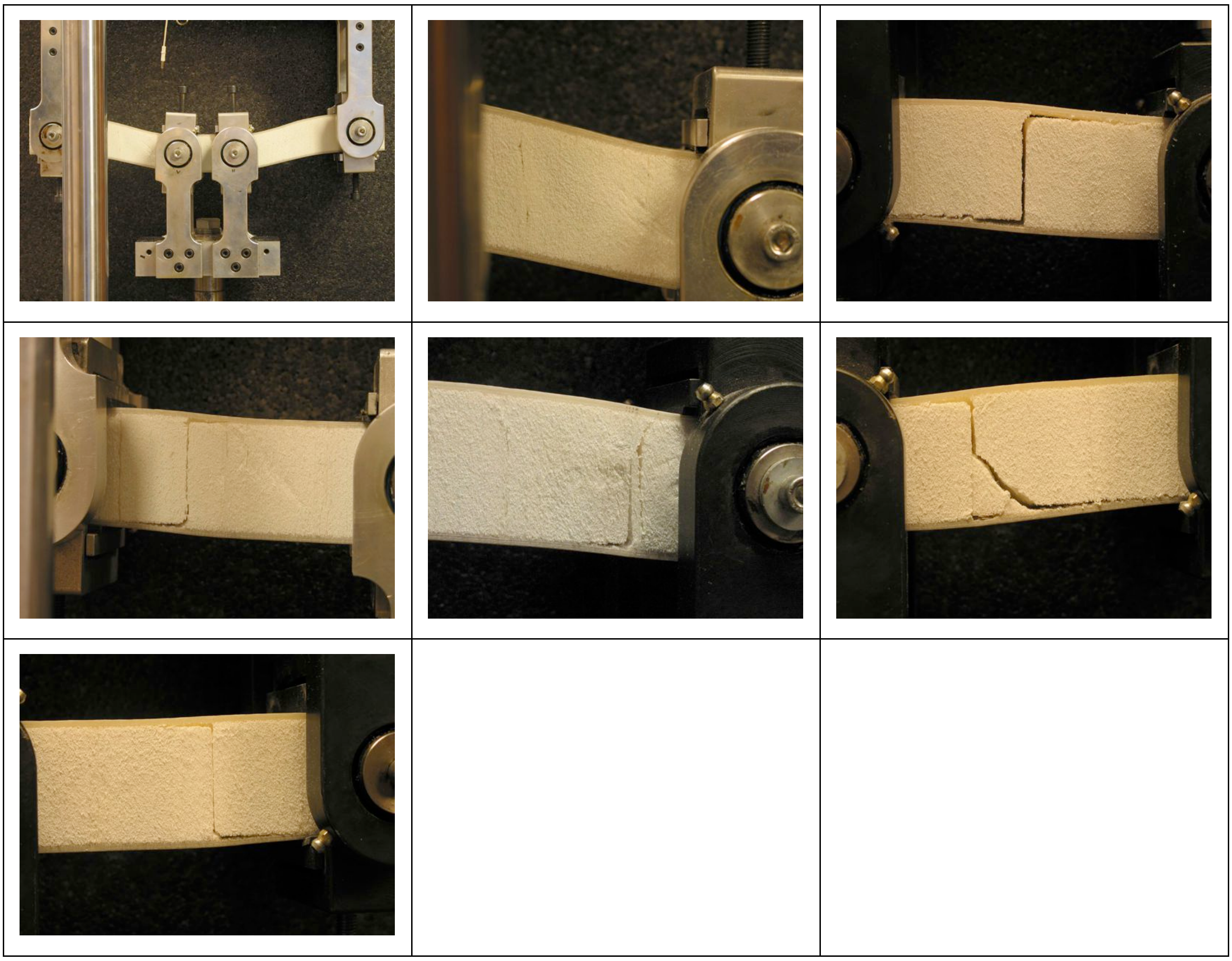


Failure mode for AC 80 fatigue test and residual strength test

Sampled pictures from the testing – AC100

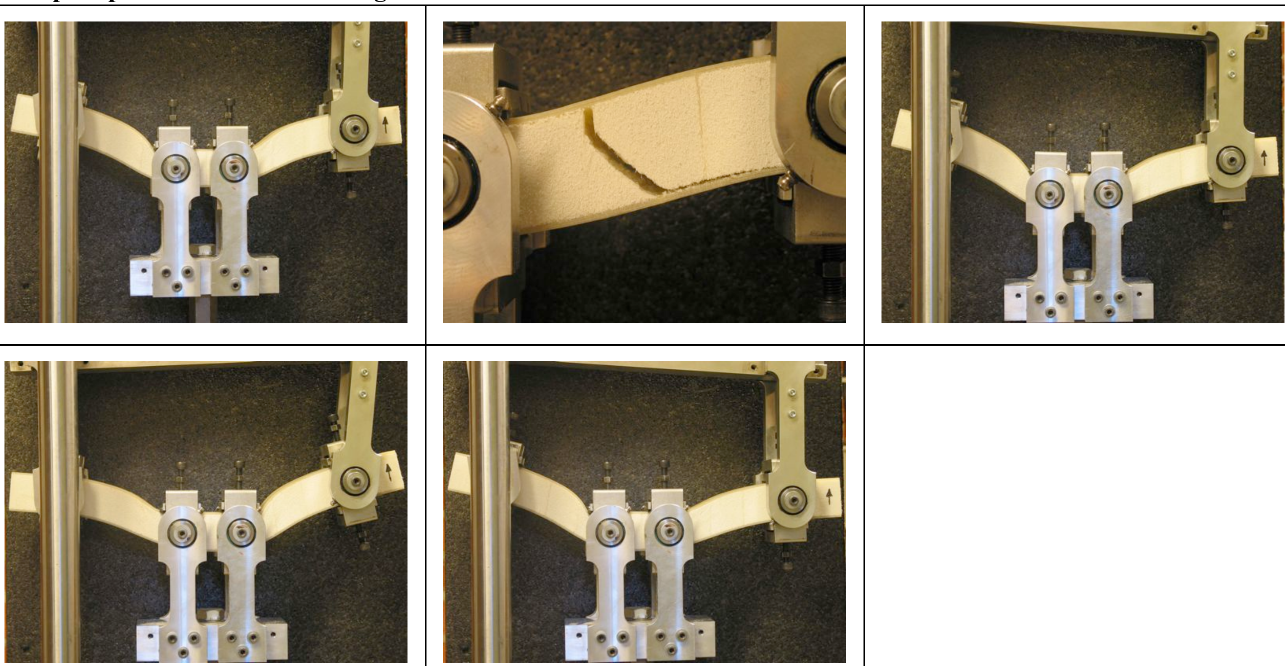


Failure mode for AC100 static test

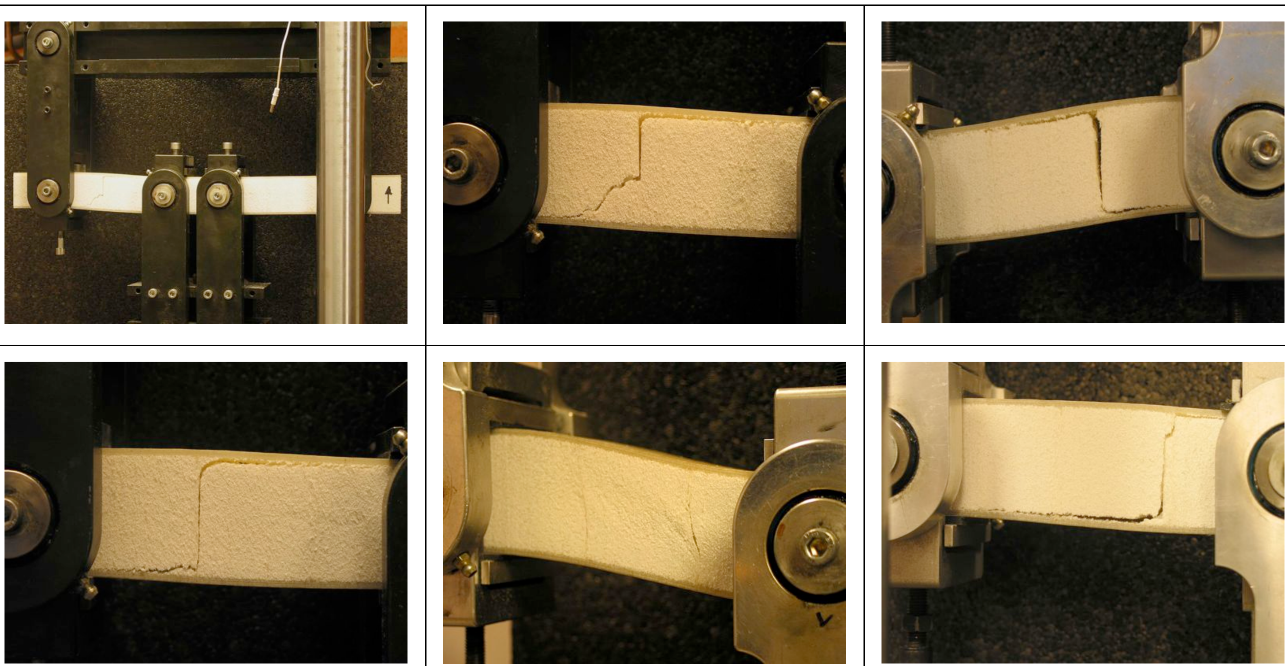


Failure mode for AC 100 fatigue test. Picture (b) and (c) is the same sample, F2, just before failure and after failure.

Sampled pictures from the testing – AC115



Failure mode for AC115 static test



sFailure mode for AC115 fatigue test and residual strength test

Reference

[1] *Annual Book of the ASTM Standards,* American Society for Testing and Materials, Philadelphia, PA.

[2] Burman M. and Zenkert D., "Fatigue of Foam Core Sandwich Beams - Part 1: Undamaged Specimens", *Department of Aeronautics*, Kungliga Tekniska Högskolan, Report 96-12, 1996